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Neighbor Discovery and Resource Allocation for Device-to-Device Communication

By

Faustin Ahishakiye

Supervisor: Frank Y. Li

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Department of Information and Communication Technology
Faculty of Engineering and Science
University of Agder

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Abstract

Device-to-Device (D2D) communication has attracted lots of attention as one of the most advanced wireless communication technologies which allows access to services offered by nearby devices bypassing the Base Station (BS). The potential advantages of this direct communication paradigm include high data rate, network offloading and range extension, as well as commercial proximity services and social networking. From the User Equipments (UEs) and BS perspective, additional protocol overhead and discovery resource are required for D2D links. In such a context, neighbor discovery and resource allocation approaches need to be studied. For an efficient D2D communication, the main problem is how the UEs in proximity detect each other and establish a D2D link in a timely and efficient manner. In this thesis we investigate D2D-enabled cellular network and we study neighbor discovery and resource allocation in such network. We split the cell into two parts: the inner part in which UEs communicate via BS and the outer part where UEs use D2D links as a means of communication. The blocking probability for these two parts is calculated based on Poisson and Engset distributions. We propose two protocols for neighbor discovery, namely, reactive (on-demand) discovery and proactive (multicast) discovery and both of them are infrastructure-coordinated protocols. The control overhead is calculated and numerical results are provided based on three cases of D2D pair requests in different timeslots in order to compare these two protocols. The performance evaluation and results show that the reactive protocol performs better when the D2D communication traffic load is low whereas proactive protocol is preferable if D2D communication demand is high. If the overflowed UEs in proximity are allowed to discover each other using our protocols together with dedicated resource from the BS and communicate via D2D links; results show that the cellular network blocking probability is reduced.

Keywords: Device-to-Device communication, ProSe discovery, protocol design, control overhead, performance comparison.

Preface

This thesis is the result of the IKT590 Master's thesis Project, which is corresponding to 30 ECTS points, at the Department of Information Communication Technology (ICT), Faculty of Engineering and Science, University of Agder (UiA) in Grimstad, Norway. The work has started from 2 January 2014 and ended on 2 June 2014.

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Faustin Ahishakiye

Abbreviations

3GPP	Third Generation Partnership Project
ACK	Acknowledgement
BS	Base Station
CRC	Cyclic Redundancy Check
CRS	Control Reference Signal
CSI	Channel State Information
D2D	Device-to-Device
DA	Discovery Announce
DCI	Downlink Control Information
DREQ	Discovery Request
D-RNTI	Discovery Radio Network Identifier
DRSP	Discovery Response
DSN	Distributed Schedule Numbers
FDD	Frequency Division Duplex
GoS	Grade-of-Service
HSS	Home Subscriber Server
ID	Identification
IMSI	International Mobile Subscriber Identity
LTE	Long Term Evolution
MINLP	Mixed Integer Nonlinear Programming
MNO	Mobile Network Operator
MSI	Mobile Subscriber Identity
MTU	Maximum Transmission Unit
OH	Overhead
OLSR	Optimized Link State Routing
PID	Peer Identity
PMSI	Permanent Mobile Subscriber Identity
PPP	Poisson Point Process
PRACH	Physical Random Access Channel
ProSe	Proximity Service
RAPC	Resource Allocation and Power Control
RB	Resource Block
RB_ID	Resource Block Identity
RF	Radio Frequency
SIV	Service Information Version
TDD	Time Division Duplex
TMSI	Temporary Mobile Subscriber Identity
TR	Technical Report
TTI	Time Transmission Interval
TTL	Time to Live
UE	User Equipment
WAN	Wide Area Network
WLAN	Wireless Local Area Network

List of Symbols

S	Total number of traffic sources/user equipments
S_c	Total number of traffic sources/user equipments for cellular communication
S_{D2D}	Total number of traffic sources/user equipments for D2D communication
C	Number of channels/number of resources blocks
C_c	Number of channels/number of resource blocks for cellular communication
C_{D2D}	Number of channels/number of resource blocks for D2D communication
φ	Service rate, inverse mean service time
λ	Arrival rate
λ_k	Total call arrival rate/ total call generation rate
φ_k	Total service rate/ total call completion rate
H	Holding time
A	Offered traffic
β	Offered traffic per idle source
a	Offered traffic per source
γ	Call intensity per idle source
ϑ	Carried traffic per source
Y	Total carried traffic
i	Number of iterations
B_C	Call congestion/blocking probability
B_{D2D}	Device-to-Device blocking probability
$B_C(A)$	Erlang distribution blocking probability for cellular UEs
$B_C(\beta)$	Engset distribution blocking probability for cellular UEs
$B_{D2D}(\beta)$	Engset distribution blocking probability for D2D UEs
E_C	Time congestion
C_C	Traffic congestion
Δ	Number of call attempts per unit time
τ	User density/Poisson intensity
n	Number of nodes/UEs selected randomly
l	Length/larger
$\mathit{\Lambda}$	Area
r	Small cell radius/minimum radius
R	Big cell radius/ target radius
$P(r \leq R)$	Probability of nearest node
Ṝ	Region considered
d	Distance
$P(X = k)$	Poisson probability density function for finding k nodes
X	Random variable
k	Number of nodes in progress/ number of nodes out of n nodes selected
α	Dedication Coefficient (between 0 and 1)
D	Target distance
j	Number of D2D users in small cell/ number of current observed D2D users
W	Total bandwidth
BW	Bandwidth for communication
Q	Reuse factor
M	Number of D2D pairs
L	Number of timeslot
T	Period/Total number of timeslot
t	Time instant
$V(i)$	Random number of D2D pairs
$P(d \leq D)$	Probability of nearest neighbor
μ	Mean

σ^2	Variance
$P(k)$	Target probability of finding k D2D nodes out of n nodes selected
$P(n\|V)$	Gaussian/Normal distribution probability density function for V D2D pairs requests
OH^{re}	Control overhead for reactive protocol
OH^{pr}	Control overhead for proactive protocol
$E[X]$	Expectation value
$P(\rho)$	Exponential distribution probability density function
ρ	Holding parameter of Exponential distribution
$P(t)$	Lognormal distribution probability density function
$P_D(x)$	Rayleigh distribution probability density function
$P(x)$	Erlang-k distribution probability density function
m	Shape parameter for Erlang-k distribution
A_{re}	Offered traffic for reactive protocol
A_{pr}	Offered traffic for proactive protocol
P_b	Binomial blocking probability
P_c	Binomial blocking probability for cellular UEs in inner part
P_{re}	Binomial blocking probability for D2D UEs in outer part based on reactive protocol discovery
P_{pr}	Binomial blocking probability for D2D UEs in outer part based proactive protocol discovery
N_c	Served users in inner part
A_{tot}	Total offered traffic
A_{voice}	Offered traffic for voice traffic
A_{data}	Offered traffic for data traffic
A_{inner}	Offered traffic in inner part
A_{outer}	Offered traffic in outer part
β_{inner}	Offered traffic per idle source in inner part
β_{outer}	Offered traffic per idle source in outer part

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1 Introduction

Mobile communication systems have been largely explored in order to implement technologies that allow people to exchange information in a meaningful way. Among these technologies, the Third and Fourth Generation (3G/4G) together with Long Term Evolution (LTE) were the main solution for cellular networks in terms of high speed and high capacity wireless communication. Not until recently that these technological wonders seem to require other innovations that expand the possibilities of what mobile cellular networks can do and what services they can offer. This is promised by the next generation in which Device-to-Device (D2D) is a part of. This Chapter presents an overview of D2D communication as one of Five Generation (5G) mobile communication system. It provides a background on neighbor discovery and resource allocation together with other related studies by researchers in the field. The problem statement, purpose and proposed solution based on the research approaches are discussed herein.

1.1 Background and Motivation

Very recently, D2D communication has been one of the significant hot topics in wireless communication systems focusing on the next generation cellular networks. D2D enables tremendous advances with respect to communication technologies that provide higher transmission data rates, better spectrum efficiency and emerging networking applications. The Third Generation Partnership Project (3GPP) has introduced D2D communication as a striking solution for many scenarios that require direct access, both with and without infrastructure. In the infrastructure mode, the initiation of a D2D conversation is coordinated by a Base Station (BS). That is, the BS assists users to discover their D2D peers and then let them communicate with each other directly. On the other hand, without the assistance from infrastructure, User Equipment (UE) searches and transmits to its neighbor in the proximity in a self-organized manner.

The Proximity criteria need to be fulfilled for the two users forming a D2D pair to communicate. Among the required criteria, the geographical distance between them is highlighted. That is a UE must be nearby another UE in order to communicate through a direct link. The Proximity Service (ProSe) is studied in this context and it is an essential feature of D2D communication. ProSe discovery is defined as a procedure of how the UEs in proximity find each other. In [1], ProSe discovery and D2D functionalities are the main focus in case of lack of network coverage. That is the possibility of UEs to search other surrounding neighbors and detect their presence. Once this step is done, UEs might try also the possibility of direct communication. When UEs are inside the network coverage, it is possible that the BS helps them to discover each other, by informing them about their proximity and coordinates the discovery process. Thus, ProSe feature needs to be integrated in the overall wireless access network and UEs might have an overview on whether the communication is through direct mode or via infrastructure mode.

However, UEs demand for higher data rate transmission and higher spectral efficiency increases the traffic load to BS and this pushes to not only use infrastructure mode but promote as well direct mode. Therefore, D2D communication allows the network offloading in case of network flooding. Since the D2D communication is operating with the existing cellular network, resource allocation techniques need to be investigated as well so that the available resource is efficiently shared between cellular UEs and D2D UEs. The available resource can be either in terms of number of channels or number of resource blocks (RBs). From LTE perspective, one RB consists of 180 kHz for the duration of one slot and each RB contains 12 sub-carriers. In infrastructure mode when the whole resource is used, the remaining UEs which are not served are blocked until another channel is idle. This is a motivation of studying D2D communication in cellular network because things look different when D2D links are introduced. There is a possibility that the blocked UEs can use the D2D communication as long as the proximity criterion is fulfilled and ProSe discovery is enabled. The approximation of the distance between candidates UEs for D2D needs to be studied together with how much discovery resource is required for these UEs in proximity, so that we can mitigate the problem of exhausted resources of cellular networks.

Various use cases and scenarios of ProSe discovery have been identified by 3GPP in [2], with an overview on how discovery can be performed given the requirements, preconditions, service flow and post-conditions. More approaches have been proposed in [3] on how to support proximity-based services. These solutions cover proposals from protocol design for ProSe discovery to ProSe communication. All necessary functionalities to be supported by the BS in order to enable UEs perform ProSe discovery are highlighted therein. In [4], Qualcomm proposes techniques and design principles for performing D2D discovery. They propose a common discovery design for both Public Safety (PS) and non PS applications. Furthermore, they propose a common design across in network coverage, partial network coverage and out of network coverage scenarios for PS applications. They suggest that BS reserve periodic resource in the uplink sub-frames for discovery. In [5] and [6], different strategies are studied for service and neighbor discovery in D2D communication, proposing network-assisted algorithms for neighbor discovery and interference management. The exchange of signaling messages is described with respect to the information for identifying a new D2D pair and the path gain between them. They propose three options for interference management to reduce the interference caused by D2D links. In Option 2, BSs use the same dedicated frequency resources for discovery. In Option 2 a hopping pattern is allocated to UE discovery sequence and Option 3 is based on splitting of discovery resource units among UEs at the cell centre and UEs at the cell edge. A centralized resource allocation technique was used here and it yields significant gains for their study [6].

However, no numerical analyses for D2D discovery are given by [2]–[4] and no protocol overhead is calculated in [5] and [6]. In [7], D2D Terminal Discovery mechanism and initial synchronization are studied with limited interference impact on the primary cellular UEs based on pseudo Physical Random Access Channel (PRACH). They aimed on the compatibility with existing LTE system and only focus on the reduction of interference impact on the primary cellular UEs. And at the same time, related researches have been carried out into these topics [8]–[15]. Most of them focus on power control, node connectivity and interference management for D2D communication. They propose algorithms for node connectivity and resource allocation schemes for avoiding the interference. Power optimization techniques are discussed therein for D2D underlaying cellular network.

The BS needs to assign resources to UEs interested in D2D neighbor discovery for control and discovery information. The available resources are shared between the cellular users and the D2D pairs based on the Channel State Information (CSI). D2D pairs can use dedicated resource or may reuse the spectrum resources of the cellular system, thus improves the spectrum efficiency. Since the D2D pair will communicate directly without any need of BS after the initiation of D2D communication, this gives an advantage that the licensed spectrum is allocated to local communication. Nevertheless when D2D shares the same resource with cellular system, this will on the other hand cause the interference to the cellular users using the same spectrum. Here, techniques for interference management are necessary. Different resource allocation methods for D2D links have been proposed as well. For instance, in [16], they formulate the problem of radio resource allocation to the D2D communications as a Mixed Integer Nonlinear Programming (MINLP) for the purpose of minimizing the interference. A resource allocation and transmitter power control scheme, called Resource Allocation and Power Control (RAPC) is proposed in [17]. All the proposed schemes are not taking to consideration UEs distributions throughout the cell, mainly at cell edge and their blocking probability when the network is congested.

Our focus is on investigating the use cases and scenarios suggested for neighbor discovery and propose new protocols for neighbor discovery. The comparison of proposed protocols design in terms of control overhead is also a main issue in this thesis. We aim at enabling the blocked UEs to use D2D communication. This work examines the number of incoming D2D UEs requests for neighbor discovery in the vicinity following different distributions and takes to consideration the offered traffic of D2D links. Although D2D communication is a hot topic and lots of studies are in progress, mechanisms for UEs in proximity to detect each other and discovery resource assignment from BS to D2D links, need to be explored. This is a strong motivation on both UEs and operators perspective. We want to contribute new knowledge on neighbor discovery and resource allocation mechanisms in D2D communication systems.

1.2 Problem Statement, Purpose and Scope

Although D2D communication is very interesting, adding D2D features to existing LTE cellular networks poses many challenges. The operators and BS itself may resist to new technologies that takes away its BS-UE control and at the same time causes interference to existing UEs. On the other hand, when all traffic are to pass through the BS, network congestion increases due to limited resource in cellular network and higher data transmission rate and efficiency spectrum requirements. For D2D communication itself, discovering each other for UEs in proximity is a serious problem. Resource allocation to D2D pairs is also another challenge to D2D communication. Therefore a study on neighbor discovery and resource allocation in D2D-enabled cellular network needs to be done. Our fundamental design questions are:

1) How UEs can discover potential D2D candidates in proximity and establish a direct connection, with the assistance from the BS which coordinates the discovery process?

2) How the BS assigns the available resource to both D2D UEs for neighbor discovery and ProSe communication together with existing traditional cellular UEs?

3) What are the benefits of using D2D links in cellular networks? How D2D UEs are distributed, how much traffic they generate and how to reduce the blocking probability in D2D-enabled cellular network?

4) In addition we need to calculate how much the control overhead required for D2D neighbor discovery is; considering different D2D UEs distributions.

With regards to these challenges, only 3GPP specifies the use cases and identifies the potential requirements for both UE and BS controlled discovery and communication between neighboring devices. It is suggested that ProSe works under continuous Mobile Network Operator (MNO) control and 3GPP network coverage including when roaming [2]. When the UEs are in roaming network, proximity location reporting has to be transferred between networks. UEs participating in D2D communication may also belong to different operators.

According to 3GPP in [3], the BS should keep monitoring the location of the UE, compare the location of a UE with the one it wants to discover and notify them when they are in proximity of each other so that they can setup a D2D communication. The UE itself needs to subscribe to an alerting service for the purpose of locating other UEs in proximity. On the other hand, to establish a D2D communication, some configuration parameters have to be exchanged beforehand, so that there is no explicit user interaction needed.

The main goal of this work is to investigate D2D communication schemes for neighbor discovery and resource allocation based on infrastructure mode. The purpose of our work is fourfold:

- ✧ Since the UEs at the cell edges have connection problems with the BS, we indicate the benefits of using D2D links in a cellular network mainly in outer part of the cell. That is at the cell edges for UEs in proximity, and the remaining UEs in inner part of the cell, communicate via the BS. We assume that D2D links use dedicated resources and the blocking probability is calculated for each part. Network congestion is reduced when D2D links are enabled in case of network flooding.

- ✧ The next purpose of this thesis is to investigate the existing schemes for neighbor discovery and resource allocation for D2D communication and propose new protocols for ProSe discovery and ProSe communication. Here the protocol design that takes to consideration all the ProSe functionalities is necessary. There is a need to match the use cases and scenarios in [2] with a protocol design for service discovery. In fact the main problem is that you cannot have protocol design strategies that meet all the suggested use cases and scenarios. Therefore, our task is to select two use cases and propose protocol designs for them.

- ✧ Moreover, this work studies the performance analysis of the proposed protocols and compares them in terms of control overhead and transmission range, assuming that the incoming D2D requests for ProSe discovery follow different random distributions.

- ✧ Finally the performance analysis is done in terms of the overflowed traffic. We consider offered traffic per idle source for cellular alone mode. Then, the available resource is shared between the cellular mode in inner part of the cell and the D2D mode in outer part of the cell. In this case we calculate the blocking probability assuming a new offered traffic for cellular UEs and D2D offered traffic based on Binomial distribution. In addition, we propose how resources can be allocated in case of heterogeneous traffic. That is a certain percentage of the available resource is assigned for data traffic and the remaining for voice traffic and vice versa.

This study is limited to mathematical and visualisation analysis using MATLAB simulation environment. We consider BS coordinated discovery. That is the D2D neighbor discovery and ProSe communication with infrastructure mode. The study of the interference caused by the introduction of D2D links in cellular network is out of scope of this work.

1.3 Problem Solution

This study is based on D2D-enabled cellular network in which the D2D UEs coexists with the traditional UEs communicating via the BS. The goal is to study the neighbor discovery and how available resource is allocated to D2D links and cellular UEs in a meaningful manner. As long as the communication is through the BS with limited resource; some of the UEs are blocked. We aim at reducing the BS traffic load and improving network spectral efficiency by allowing the D2D links in the outer part of the cell, for the UEs which have at least a neighbor in certain meters away from each selected node. The cell is split into inner part and outer part for cellular and D2D communication respectively. Resource allocation is achieved by allowing each part to use dedicated resource. We propose to use D2D links in small cell around the cell edges. Each UE with at least one neighbor within the targeted distance will need only resource for ProSe discovery and once the discovery is successful, then UEs communicate using D2D. The performance analysis is done by calculating and comparing the blocking probability for both UEs in cellular mode and UEs in D2D mode. Two scenarios are considered, the first one with an infinite number of sources modeled using the Poisson distribution. Secondly, a finite number of sources are considered following the Engset distribution.

The next problem to solve is to find out which protocols can be used for service discovery for D2D communication using less control overhead. In this study, we identify two scenarios for D2D service discovery. The first one is referred to as *Network ProSe* in which the network provides discovery assistance for ProSe-enabled UEs requesting a service. The second use case is referred to as *Open ProSe* and it is a ProSe discovery procedure in which UEs discover each other without any prerequisite knowledge on the reachability of other UEs. In both cases, the BS is assisting the neighbor discovery of UEs.

More specifically, we propose two protocols for service discovery in D2D communication where the exchange of discovery messages is either UE-initiated or BS-initiated. The UE-initiated protocol follows the principle of reactive (pull) mechanism where the UE starts the first contact to the BS, requesting for ProSe discovery in an on-demand manner. The BS-initiated protocol instead follows the idea of proactive (push) mechanism, multicasting an advertisement periodically to all D2D subscribers no matter there is a ProSe request or not. The frame structure for the two protocols is proposed as well. The comparison of these two protocols is performed with respect to control overhead under three different cases of D2D UE requests. The performance of the proposed protocols is evaluated through numerical analysis using MATLAB simulation environment.

In addition we suggest how the available resources can be shared between cellular mode and D2D mode for the overflowed traffic. The performance analysis in terms of traffic offered is evaluated to assess which protocol can be used to maximize the benefits of using D2D links to the blocked UEs. So far heterogeneous traffic are assumed and we assess how D2D links can be used if a high (low) traffic load is required for voice compared to data traffic and vice versa.

1.4 Thesis Outline

The rest of the thesis is organized in seven chapters as follow:

Chapter 2 presents the background technologies. The teletraffic theory in general and the theory related to service discovery for D2D communication that we are going to use are discussed.

Chapter 3 describes teletraffic analysis when D2D links are enabled in cellular networks. Both infinite and finite numbers of sources scenarios are discussed with respect to Poisson and Engset distributions.

Chapter 4 gives details of our system model, the protocol design and frame structure format for reactive and proactive protocols. .

Chapter 5 provides the analysis of the protocols. The neighborhood and control overhead are calculated with respect to three cases. In addition different distributions of D2D requests are studied.

Chapter 6 presents the analysis of the overthrow traffic and heterogeneous traffic.

Chapter 7 concludes this thesis by giving the summary, contributions and future work.

2 Background Technologies

D2D neighbor discovery and communication is a rich area for research and development as long as direct communication is concerned. Different research studies have been done, giving insight into the use of D2D communication in cellular mobile systems. In this chapter, we provide previous studies relevant to our work and related D2D communication in general. We first discuss the concepts of teletraffic in cellular networks. Secondly we introduce more about D2D discovery and resource allocation in D2D- enabled cellular network. In addition, we provide literature review in some theories which are going to be used in this thesis research work.

2.1 Traffic Characteristics and Erlang's Loss System

The teletraffic system model describes three main elements. The first one is *structure* which refers to a system with C identical channels in parallel. The second element is *strategy*; where an arriving call needs only one channel and can be accepted if and only if there is at least one *idle channel*. When all channels are occupied, the system is congested and all incoming calls are blocked. The last element is *traffic*. It is assumed that the arrival process is a Poisson process with rate λ**,** and the service times are exponentially distributed with intensity φ which corresponds to a mean value of $H = 1/\varphi$**.** These two parameters allow us to define the offered traffic (A) in cellular networks. It is defined as the traffic carried when the infinite number of channels is assumed. According to Erlang's loss model with Poisson arrival process, the offered traffic is equivalent to the average number of call attempts per mean holding time as shown in Eq. (2.1) [18, Eq. (4.1)].

$$A = \lambda * H \tag{2.1}$$

As far as the number of channels is concerned, we can consider:

An infinite number of channels $C = \infty,$ with Poisson distribution are envisaged. In this case we never experience blocking (no congestion). Since Poisson distribution is valid both in time and in space, the number of channels at random point is Poisson distributed with mean and variance equal to the offered traffic. The time congestion (E_C) and call congestion (B_C) are both equal to zero.

When the number of channels is limited; this means that C is finite ($C < \infty$). The truncated Poisson distribution is considered in this case. To experience the congestion it will depend on whether the number of sources is less or greater than the number of available channels.

The probability that all C channels are occupied at a given random point is given by Eq. (2.2) [18, Eq. (4.10)] which is referred to *Elrang's B* formula. It is the blocking probability.

$$B_C\,(A) = \frac{\frac{A^C}{C!}}{\sum_{i=0}^{C} \frac{A^i}{i!}}\ , \tag{2.2}$$

where C is the number of channels and A is the offered traffic load with parameter λ and H. Also i describes the number of iterations corresponding to the current number of channels and is varying from $i = 0$ up to $i = C$. In this case, the call congestion which is the probability that a random call attempt is lost will be equal to the time congestion. This means all call attempts are proportionally blocked. Now, $B_c(A) = E_c(A) = C_c(A) = \frac{A-Y}{A}$, where $E_c(A)$ and $C_c(A)$ denote the time congestion and traffic congestion respectively. Time congestion is by definition equal to the proportion of time a system is blocking new call attempts, whereas the traffic congestion is the probability that a call is delayed. From the relation above Y represents the carried traffic and normally is calculated as $Y_C(A) = A \times \{1 - E_C(A)\}$. Fig.2.1 shows the trend in curves of the blocking probability as a function of offered traffic at various values of the number of channels. The figure illustrates that the less the number of channels the higher is the blocking probability.

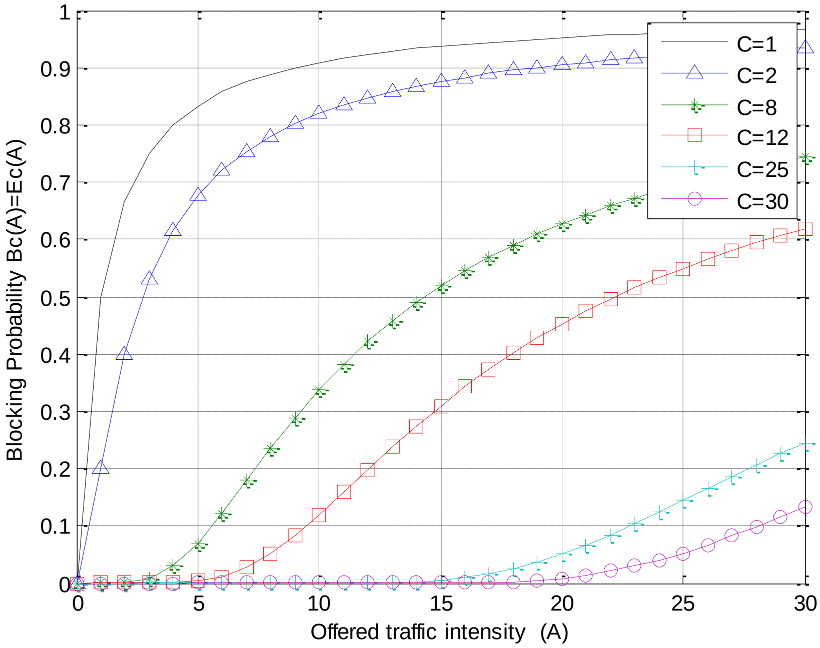


Fig.2.1 Blocking probability for different number of channels.

Despite the analysis of the number of channels based on Erlang's model, we can also analyse the number of sources. Note that two traffic models are interesting in this case: Erlang model which describes the random traffic and Engset model which describes the more specific traffic than random traffic. Here still we analyse the traffic congestion as the performance metric parameter.

First we consider an infinite number of sources where the number of sources is greater than the number of channels ($S \leq C$). That is the number of channels is sufficient and the system is treated as Poisson case and expressed as the Binomial distribution with parameter β which denotes the *offered traffic per idle source*. A call attempt from an idle source in this case is never blocked, and the carried traffic per source α is equal to the offered traffic per source a, which is the proportion of time in which the source is busy and it depends to the congestion.

The following parameters are interesting for the Binomial traffic case[18, pp.135]:

- γ is the call intensity per idle source
- $H = 1/\varphi$= Holding time,
- $\beta = \gamma/\varphi$= offered traffic per idle sources
- $a = \frac{\beta}{1+\beta}$ = offered traffic per source
- $A = S.a = S.\frac{\beta}{1+\beta}$ = total offered traffic
- $Y = S.\vartheta$ = total carried traffic where ϑ represents carried traffic per source
- $E_c = 0$ = Time congestion and $B_c = 0$ =Call congestion
- $\Delta = S(1-\vartheta).\gamma$ = Number of call attempts per time unit and $S(1-\vartheta)$ is the average number of the idle source.

Secondly we consider a finite number of sources where the number of sources is limited but is restricted to become greater than or equal to number of channels ($S \geq C$). It is possible to experience call blocking and in this case we deal with the Engset distribution [18, pp.141]. With limited number of sources all performance metric parameters differ. Engset system is characterized mainly by free parameters: the *offered traffic per idle* *source* (β), the *number of sources* (S) and the *number of channels* (C). Using these parameters, time congestion and call congestion are calculated in Eqs.(2.4) and (2.5) respectively. The total carried traffic for Engset distribution is given by Eq. (2.6).

$$E_C(\beta) = \frac{\binom{S}{C}\beta^C}{\sum_{i=0}^{C}\binom{S}{i}\beta^i} \tag{2.4}$$

$$B_C(\beta) = \frac{\binom{S-1}{C}\beta^C}{\sum_{i=0}^{C}\binom{S-1}{i}\beta^i} \tag{2.5}$$

$$Y = \frac{\beta}{1+\beta} * \{S - (S - C) * E_C(\beta) \tag{2.6}$$

The relationship between time congestion, call congestion and traffic congestion is shown in Eq. (2.7), (2.8) and (2.9).

$$E_C(\beta) \ = \frac{S}{S-C} * \frac{B_C(\beta)}{1+\beta(1-B_C(\beta))} \tag{2.7}$$

$$B_C(\beta) = \frac{(1+\beta)*C_C(\beta)}{1+\beta*(C_C(\beta))} \tag{2.8}$$

$$C_C(\beta) \ = \frac{A-Y}{A} = \frac{S-n}{S} * E_C(\beta) \ . \tag{2.9}$$

For the Engset distribution we can conclude that the following relation holds $E_C(\beta) > B_C(\beta) > C_C(\beta)$ [18, pp.142-150]

2.2 Proximity Discovery and ProSe Communication

Proximity discovery is a term used for a direct detection of neighbor's devices and services offered by those devices on a communication network. This can be achieved by a process which identifies that a UE is in proximity of another and this process is called *ProSe discovery*. After UEs find each other they can establish a direct link between them. In these circumstances their conversation is called *ProSe communication.*

Normally neighboring UEs may establish a communication path either directly between themselves or through local BS. Being nearby each other only does not mean that two UEs will be involved in D2D communication. It will depend to whether UEs themselves select D2D mode as their means of communication. They may select a default path mode as shown in Fig. 2.2 which refers to a local routed mode. In this case the communication goes via the BS. This is a traditional communication where UEs use uplink and downlink for transmission. When they choose to use a direct path, the communication is known as direct path which is shown in Fig. 2.3. This is a D2D communication without infrastructure where a UE transmits to its neighbor in proximity without any assistance of the BS.

However, D2D communication can also be with infrastructure mode. Here the BS coordinates the discovery process by assisting UEs to discover each other. Once the discovery is successful, the BS let them communicate using D2D link. Discovery resource has to be assigned a D2D pair in this case. In addition, UEs have to register for ProSe service to their mobile network operator (MNO) in order to access ProSe. The BS needs to check the permission to use this service. According to [2], there are three sets of use cases for ProSe. The first set is the general use cases which are cellular-based. The second set of use cases is WLAN-based. The last set is the public safety use cases. In this thesis, the focus is on cellular-based D2D communication. More specifically, we focus on D2D communication with infrastructure mode or simply BS coordinated D2D mode.

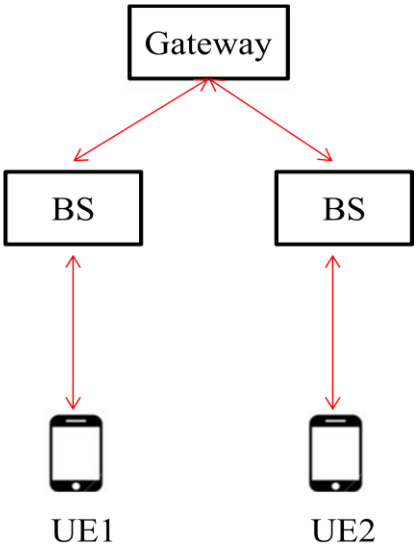


Fig.2.2 Data path for legacy networks.

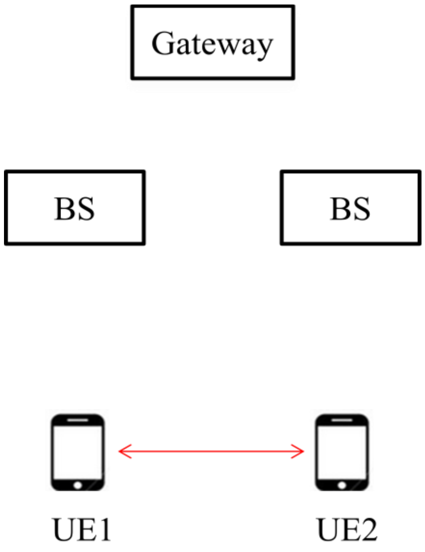


Fig.2.3 Direct mode data path.

For instance, when two UEs are close enough to each other and are still communicating via BS as shown in Fig.2.2; this is known as a data path for legacy networks [2]. However, it is possible that the BS releases the data path to D2D communication for the two UEs in proximity as shown in Fig.2.3; and this is called direct mode data path.

2.3 D2D Neighbor Discovery Use Cases and Techniques

D2D neighbor discovery is a process that identifies a UE which is nearby another UE so that the two UEs can form D2D candidates. On the other hand, service discovery is based to ProSe which refers to the detection of the presence of nearby services by a UE. Thus, a UE can try to find his neighbor in proximity or trigger a nearby service. ProSe discovery can be either enabled by a network or can be a standalone service enabled that could use information from the discovered UE. This can be done for certain applications in the UE device that are permitted to use this information. For example when UE wants to find a nearby taxi or just find a nearby restaurant. In this case, UE can open the application in its device and start triggering to find the nearby taxi.

In 3GPP TR 22.803, there are many types of ProSe discovery as described in [2]. Several use cases and scenarios are identified explaining how the proximity service should be done. Open and restricted ProSe use cases can be defined depending on whether permission to discover or to be discovered is required or not. Open ProSe is the case where there is no explicit permission that is needed from the UE being discovered. Whereas alternatively restricted ProSe discovery only takes place with explicit permission from the UE that is being discovered. For Network ProSe, the BS assists UEs interested in neighbor discovery to detect their neighbors. When subscribers are from different cells, the discovery can be achieved by notifying that two UEs are in proximity, even though they are staying in different cells. In case of discovery with roaming subscribers, discovery between UEs in different cells are done under roaming conditions. In case of public safety a user can be notified about nearby services when it is subscribed to the ProSe service of that restaurant or store. Note that, this can be done when UEs are in coverage of the network or not; can discover but not be discovered.

Additionally depending on the information obtained, ProSe discovery can be used for subsequent actions for example to initiate direct communication [3]. 3GPP highlighted two roles for the UE in ProSe discovery:

- ✧ *Announcing UE*: The UE announces certain information that could be used from UEs in proximity that has permission to discover.
- ✧ *Monitoring UE*: The UE that receives certain information that is interested in from other UEs in proximity [3].

Based on the BS authorization the UE can act as “*announcing UE*” only in the band designated by the registered BS but act as a “*monitoring UE*” in the resources authorized by the BS as shown in Fig.2.4 [3].

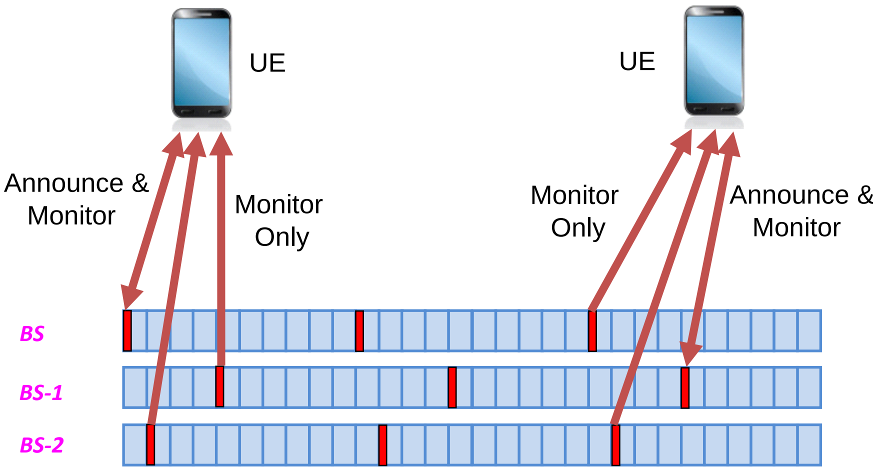


Fig.2.4 Announcing and monitoring UEs roles in different BS [3].

Different discovery techniques should be applied for the establishment of a direct link communication. When D2D communication is network assisted based; the BS and/or UEs detect first the presence of their neighbors and identify them as D2D candidates. Previous technologies such as Bluetooth, ZigBee, and FlashLink as well as others have used similar processes known as peer discovery and device pairing. In this case an *inquiry process* and *paging process* allow a master node to identify devices in range and to establish links towards the desired slave nodes [19]. In LTE, *cell search* functionality is similar also to peer discover where a UE determines the network parameters such as time and frequency for the purpose of downlink demodulation and cell ID determination. In other words the UE discovers the cell. For both cellular and ad-hoc networks one party need to transmit a known synchronization or reference signal called beacon to initiate the discovery. So far the two neighbors will have to meet in time, in space and in frequency. One of the neighbors needs to take the responsibility of transmitting the beacons if the process is carried out randomly without any coordination. Therefore the process of searching/transmitting beacons is both time and energy consuming.

When the BS coordinates this discovery process in D2D with infrastructure assisted network, scanning and sending beacons is less time consuming and more energy efficient. Peer discovery techniques consist of two methods; *a-priori* and *a-posteriori* [19]. In a priori method, the BS (or UEs itself) identifies D2D candidates without requiring that the devices have started a communication session prior to proximity [20, pp.5]. In fact, the BS can assign a beacon resource which is broadcasted in its coverage area so that D2D UEs (server and client) candidates may readily find one another. In this case the BS does not take an active role in the discovery process. On the other hand, the BS is more involved in discovery process where it instructs the server to register first to the BS and generates the beacon. The client willing to use D2D communication also sends a request to the BS.

In a-posteriori method, the BS realizes that the two communicating UEs are closer enough to use D2D link and identifies them as D2D candidates while they are already engaged in an ongoing cellular communication. The UEs in ongoing communication can then agree on the token and once it is established they may register it to the BS which easily recognizes them as D2D candidates. This is a UE assisted posteriori discovery. There is also a radio access network based on a-posteriori discovery where a BS analyzes the Internet protocol (IP) packets (IP addresses for both the source and the destination) to detect the communicating D2D pairs within the same cell [19]. In our case we are more interested in a priori discovery where the identified D2D candidates aren’t yet involved in a prior communication.

Qualcomm has proposed techniques for D2D discovery in [4]. The proposed design principles suggest that UEs willing to participate in discovery be synchronized to each other and have a common notion of discovery resources. In Frequency Division Duplex (FDD) deployment D2D discovery is supposed to happen on uplink band whereas in case of a Time Division Duplex (TDD) deployment, discovery can occur over both downlink and uplink sub-frames. However for simplicity and to have a common design across FDD and TDD, uplink is preferred. It is suggested also that due to network dynamics, discovery protocol runs periodically and hence uplink discovery resources are allocated periodically. Here once the resources for discovery are allocated to D2D pair during uplink sub-frame, the remaining resources will be beneficial to cellular users. Lastly Qualcomm proposes that discovery should use a small amount of resources. Our designed protocols are based on these interesting design principles and we compare them taking into account which one uses small control overhead resources. Reserving resource for discovery, discovery resource selection, timing of discovery sub-frames, hopping of discovery resources and discovery with coexistence with WAN communication are also highlighted in [4].

2.4 ProSe UE Registration

For a UE to be designated to an application identifier, a UE must register with an application server for services such as ProSe. 3GPP specification does not specify this procedure. Then to activate ProSe features for a specific application, the UE registers the application with the ProSe function [3]. This procedure is shown in Fig.2.5.

The registration is achieved in the following steps:

- ✧ Step1: The UE registers an application by first sending a ProSe registration message to ProSe function. The message contains the ProSe ID (ProSe A), the application ID identifying the App Server, the application specific identifier (App A) and the link layer identifier (Link A).

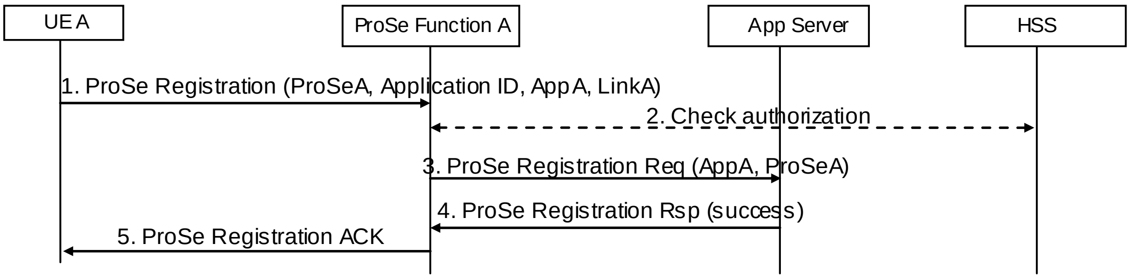


Fig.2.5 UE registration for ProSe discovery [3].

- ✧ Step 2: In this step the ProSe function interact with the home subscriber server (HSS) for authentication purpose, to check whether UE is authorized for ProSe. It is also possible that authentication and authorization be configured locally at ProSe Function.
- ✧ Step 3: ProSe Function A sends a ProSe Registration Request to the App Server indicating that a user of this application (identified as App A) has requested to register to use ProSe for that application. If the App Server accepts the request, it stores the user's application-specific ID A (App A) and ProSe ID (ProSe A) together.
- ✧ Step 4: The response is sent to ProSe Function from the App Server indicating that the registration was successful or not.
- ✧ Step 5: If the registration was successful (or not) then the UE needs to receive an Acknowledgement (ACK) from the ProSe Function A.

Our protocol design in this thesis does not show the registration procedure, it is assumed to be done before, it is a precondition.

2.5 Resource Allocation Methods for D2D Communication

In order to meet the requirement of the higher data rate transmission in mobile communication, the spectrum which is allocated to mobile communication systems must be used efficiently. Resource sharing can be done by either assigning a separate resource to D2D pairs or by reusing the same resource of the cellular users and use some strategies to avoid the interference. Here the frequency reuse factor can be taken into consideration so that two adjacent frequencies are not used in neighboring cells. D2D system can share the resource of LTE uplink or downlink and different modes can be used for sharing.

There are two kinds of resource allocation schemes in general: the first one is BS assisted and the second one is BS controlled. BS assisted means the resource allocation is determined by the D2D UE itself by using some strategies. It provides less signalling between D2D UE and BS. Since D2D is introduced in cellular networks, then we need to make sure D2D communication links won’t cause much performance loss to cellular system. The interference from the D2D system to cellular system must be under control. Therefore, it is good to let BS control the D2D resource allocation under the sacrifice of more signal exchange between BS and D2D UEs. With this resource allocation scheme we need to make sure that D2D communication shares the resources that won’t cause severe interference to cellular communication and if severe interference occurs, BS can terminate the D2D communication or allocate other resource to D2D communication.

When the BS is responsible for the resource allocation, it can allocate the resource either dynamically (i.e. based on current D2D transmission demand) or statically (i.e. certain resources are periodically reserved for D2D transmission) [21]. The dynamic allocation utilizes the radio resources more flexibly at the cost of heavy control overhead while the converse is true for static allocation. For D2D discovery, static allocation seems appropriate. If radio resources are allocated dynamically, UEs need to be continuously active, which leads to high energy consumption. In contrast, static allocation may minimize the impact of discovery on UE battery.

According to [22], the available resources in cellular networks with D2D links can be allocated in the following modes:

- Cellular mode: All UEs are communicating using cellular network. That is they use the traditional communication via the BS. Even D2D pairs use this path, there are no direct links.
- Dedicated resource mode: The available resource is shared between cellular UEs and D2D pairs. This means D2D UEs communicate using dedicated resources.
- Reusing the resource of only one cellular user: Here D2D link uses the resource of one cellular UE making sure that it doesn’t cause severe interference.
- Reusing the resources of more than one cellular user: In this case D2D UEs share the same resources with more than one cellular user, then the technique for interference management is required.

In this work we assume D2D pairs use dedicated resource. However we suggest a new method: “Orthogonal sharing method” where the D2D UEs share the same resource with the cellular UEs but for D2D, we will introduce spatial reuse of resource in small cell at the edges.

2.6 Spatial Node Distribution

Assume a spatial Poisson pattern with intensity τ $(\tau = n/ \Lambda)$ over a two dimensional, with n nodes distributed in the area Λ of a two dimensional space $[0, l]^2$. The nearest neighbor nodes in two dimensional spaces can be shown in Fig.2.6.

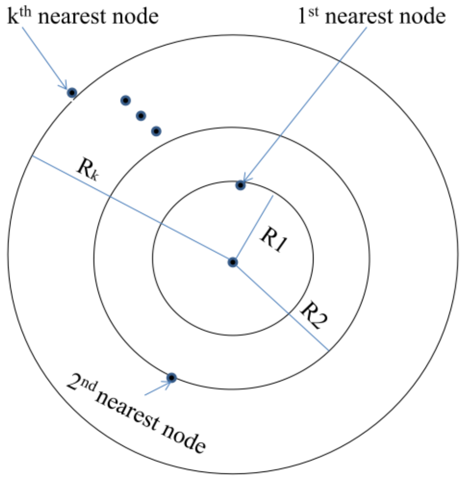


Fig.2.6 Nearest neighbor node.

The locations of the nodes are usually treated as random. The Poisson point process is the simplest and most important model for random point pattern. Nodes are uniformly distributed. It is possible to determine the (random) distance R between a particle and its nearest neighbor node. According to [8], the first nearest neighbor node is calculated taking the transmission range as R into consideration as shown in Fig.2.6. The probability function of the nearest node distance is given in Eq. (2.10).

$$P(r \leq R) = 1 - e^{-\tau * \pi * R^2} \tag{2.10}$$

The second and the kth nearest neighbor nodes are determined in [8], for this work we are interested in the first nearest neighbor in order to calculate the proximity probability. For D2D communication to be successful, the transmission range within two UEs should satisfy the condition of being less or equal to the targeted distance which is in this case equal to the considered cell radius R.

3 D2D-Enabled Cellular Networks

The analysis of D2D communication system needs to take to consideration the network traffic issue. This is due to the fact that D2D communication is working under cellular networks and much traffic will be generated, both traffic via the BS and D2D links. Therefore, the calculation for blocking probability and call congestion is necessary. In this chapter, we introduce first the traffic arrival; secondly we discuss the node distribution and resource allocation in our system model. Finally we calculate the blocking probability for two scenarios, both infinite and finite number of sources with respect to the number of available channels for traffic.

3.1 Introduction on Traffic Arrival

Wireless communication systems have many challenging aspects and one of them is the need to seek for innovative solutions for engineering that provide a large increase in spectrum efficiency and radio channel capacity. This is in accordance with the definition given to traffic (or just Teletraffic) theory in [18, pp.(1-2)]. It is defined as the application of probability theory to solve different problems concerning planning, performance evaluation, operation and maintenance of communication systems. Despite of handling the new traffic generated in wireless network applications, teletraffic should also determine important numerous parameter dependencies such as network density, time, calling rate, call holding time, location area and geometry so that they can be represented in a meaningful model.

However, the D2D communication demand includes many aspects requiring the study of the above mentioned parameters. As discussed in the introduction chapter, when the D2D communication is used with normal traditional communication, many problems arise especially in case of multiple D2D requests for ProSe discovery and ProSe communication. For sure some of the UEs requesting or trying to access the service will be blocked, others will be delayed. Therefore, we need to analyse the call congestion of the network comparing the traditional system alone without and the one with D2D links. First we study how the presented UEs are distributed to gain insights into how much traffic they can generate.

The system model considered contains the inner part and the outer part. The inner part consists of the traditional UEs which communicate via BS whereas the outer part consists of the D2D UEs which have at least one neighbor within a targeted distance D. So far we assume a large number of sources in inner part which is taken as infinite and Poisson point distribution is considered in this case for cellular UEs. We also assume a finite number of sources in outer part of the cell for D2D UEs and the corresponding model in this case is the Engset distribution. Finally, for simplicity, the number of sources in the inner part is distributed into small cell with a reuse factor of seven so that the number of sources is reduced and we consider Engset distribution for both parts. Here we apply the method of sharing available resource where each part uses dedicated resource.

3.2 Node Distribution

In this section, we are interested in nodes distribution within the cell and two assumptions are suggested. First we assume that all nodes within the cell are uniformly distributed and we later consider point Poisson distribution of all UEs.

In the first case, all UEs are uniformly distributed in the cell and for two neighbors UEs to form a D2D pair; they have to be separated by a distance d which is kept the same between all UEs. We need to know how many of them can form D2D pairs. The distance d between D2D pair follows the uniform distribution. This means that if we assess the node density in the region considered, all the nodes are equally concentrated.

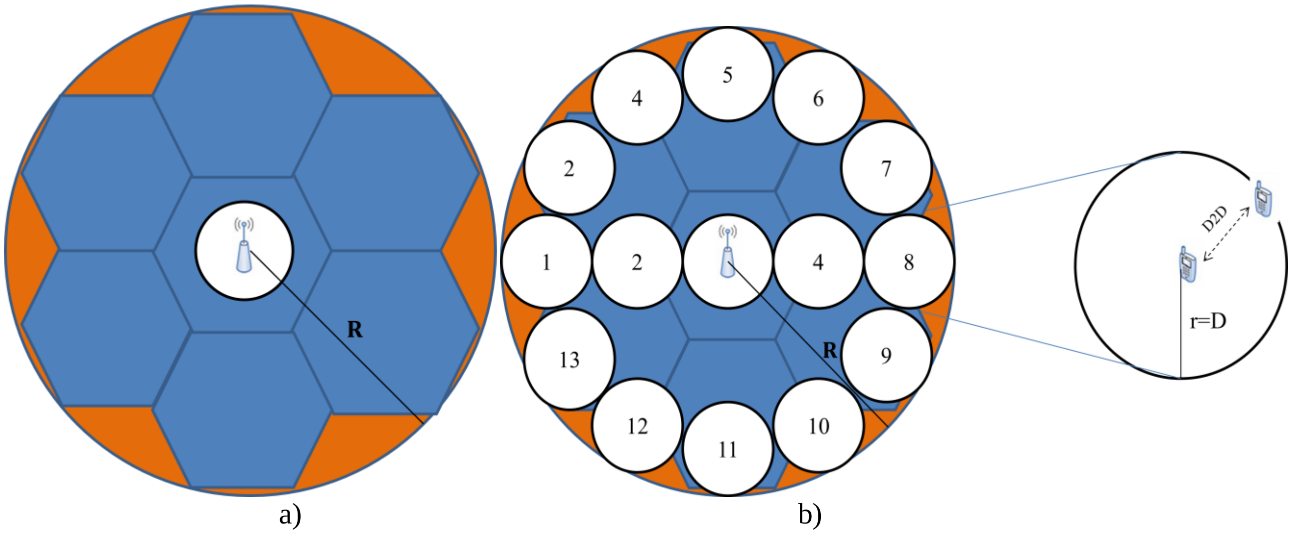
However the distance between communicating D2D pairs can be randomly distributed, and less than the targeted distance between UEs can also be observed. Assuming that the UEs are distributed in the area Λ with a radius r and are scattered of the two dimensional space according to Poisson point process (PPP) with a parameter τ, the probability to find k nodes in the region $\underset{\cdot}{\bar{R}}$ is given by Eq. (3.1) [23].

$$P\{X=k\} = \frac{(\tau * \Lambda)^k}{k!} e^{-\tau * \Lambda} \quad , \tag{3.1}$$

where X denotes a set of all nodes in the vicinity and Λ is the measure of the region, in our case is mentioned as an area which is a circular area of a radius r. Since the Poisson distribution is valid in time and in space, thus the number of busy channels at a random point of time and the number of calls within a fixed period T are Poisson distributed. The arrival process with a rate λ consists of the events also which occur according to Poisson distribution and the service time with intensity φ follows the exponential distribution corresponding to the mean value $1/\varphi$.

3.3 System Model for our Study and Resource Allocation for D2D Traffic

In this model below, we assume a cell with a large number of users S and they are assumed to be Poisson distributed. Using the probability of nearest neighbor in [8] and the user density we can calculate how many UEs have at least one neighbor within a minimum targeted distance D. The D2D UEs are assumed in the outer part of the cell edges and are distributed in small cells of radius r. We assume that each UE is centralised in the centre of the small cell, and its radius $r = D$ meters in which its nearest neighbor can be found. D denotes the targeted distance within a node and its nearest neighbor. The number of UEs able to communicate through D2D links equals to the total number of UEs within one small circle times the total number of the possible circles in the outer part of the cell. The remaining UEs in inner part use traditional communication via the BS. The system model is shown in Fig.3.1 with the BS in the centre of the cell.



a) b)

Fig.3.1 System model a) cellular alone b) cellular (inner) and D2D (outer) traffic.

Fig.3.1a indicates a circular cellular cell in which we use a reuse factor equals to 7. We split the cell into two parts, inner and outer part. Fig.3.1b shows that we can have 13 small cells in the outer region and 5 small cells across the diameter of the big cell considered. This model is used as an example where we can withdraw our real model, by comparing the ratio of the big radius R to the small cell radius r and the total number of small cells in the outer region. Now we can see that the ratio R/r is equal to 5 and corresponds to 13 small cells in outer region of a radius equal r. Therefore, if we assume a big cell of radius $R = 1000\,m$, divided into small cells of radius $r = 50\,m$ where r equals the targeted distance D. That means we assume that a centralised UE at the centre of the small cell will have a neighbor in D meter around itself; this will result in a ration R/r equal to 20. Thus, if a ratio of 5 corresponds to 13 small cells then a ratio of 20 will correspond to 52 small cells in our region. We can conclude that, if we use a big cell with D2D UEs distributed in 52 small cells of the outer region; the remaining UEs in inner region will be served by the BS. We assume that a UE located in uncovered area communicates via BS, as long as there is no neighbor in D meter form itself. Otherwise, we assume that each user can have at least one neighbor since they are either uniformly distributed or are distributed according to Poisson point distribution.

In our system model we use dedicated resource for D2D pairs in order to avoid the interference to other cellular UEs. D2D UEs in the outer part are assigned $\alpha\%$ of the total available resource and the remaining $(1-\alpha)\%$

resource is assigned to cellular UEs in the inner part of the cell and UEs uncovered area of the outer part. More specifically, α is small since D2D pairs need resource only for ProSe discovery and ProSe communication control only and they will use direct communication after successful discovery. However, we suggest a spatial reuse of orthogonal resource in small cell of the outer part. This will increase the transmission rate for the UEs. In this case same resource can be used by different D2D pairs which are not located in adjacent cell.

3.4 Blocking Probability for Infinite Number of Sources

Our aim in this section consists of exploring the case where we have a large number (assumed to be infinity) of UES which are distributed according to Poisson distribution. If all the UEs are generating traffic either by requesting the service or by replying to the advertisement broadcasted by the BS, some of UEs will be blocked since we have limited resources. The number of available channels is less than the number of sources to be served. We analyse the blocking probability for both cellular and D2D UEs in inner and outer part of the cell respectively.

3.4.1 Analysis of the scenario for infinite number of sources

First we assume that all UEs are communicating via the BS and the available resources are divided into only control channels and communication channels used by UEs for both data and voice transmission. The arrival process is a Poisson process with intensity τ. Whenever a UE attempts a call and all the channels are occupied, this will results in call congestion and the UE is not served. One approach to solve this problem is to use a strategy known as channel borrowing [24], where a cell is allowed to borrow a channel from a neighboring cell if all of its channels are occupied. However a hand-off strategy must be agreed [25],[26]. To improve the capacity we use frequency reuse also and the number of channels is calculated with respect to the reuse factor used. Knowing the number of channels and the busy hour traffic, the Erlang's B formula is used to calculate the blocking probability $B_C(A)$ and is related to the offered traffic A as shown in Eq. (3.2) and it is taken as a grade of service (GOS).

$$B_C(A) = \frac{\frac{A^C}{C!}}{\sum_{i=0}^{C} \frac{A^i}{i!}} \,, \tag{3.2}$$

Where C denotes the number of channels and the above equation is used where the blocked call is cleared.

Secondly, we consider the D2D UEs in small cells in the outer region and the cellular UEs in the inner region. The available resources for communication are shared between D2D UEs and Cellular UEs. Each part is assigned a separated resource in order to avoid interference. Here the control channels are separated from the communication channels. In this case $\alpha\%$ of the resource is assigned to D2D users and $(1-\alpha)\%$ resource is assigned to cellular users. Since the UEs are uniformly distributed in space, the number of UEs in a small cell is equal to the cell density τ times the area of the small cell. Then the total number of UEs in the outer region communicating using direct links is the number of UEs in a small cell times the numbers of small cells. Since these UEs using D2D is a finite number of sources, Eq. (3.3) is used to calculate the blocking probability B_{D2D} for D2D links according to Engset distribution. The remaining UEs will use cellular communication via the BS and since they are still a large number, the Eq. (3.2) is applied to calculate the blocking probability B_c for UEs in inner part.

$$B_{D2D}(\beta) = \frac{\binom{S_{D2D}-1}{C_{D2D}} \beta^{C_{D2D}}}{\sum_{i=0}^{C_{D2D}} \binom{S_{D2D}-1}{i} \beta^i} \,, \tag{3.3}$$

Where S_{D2D} and C_{D2D} represent the number of D2D sources (UEs) and the number of channels dedicated to D2D communication respectively. The offered traffic per idle sources is denoted by β and its relationship with the total offered traffic is shown in the Eq. (3.4).

$$A = S * a = S * \frac{\beta}{1+\beta} \tag{3.4}$$

Where $a = \frac{\beta}{1+\beta}$ represent the offered traffic per source and S is the number of sources.

3.4.2 Network configuration and results

The traditional communication alone is compared with the case where the D2D communication is used in the outer part of the cell and the remaining UEs in inner part use cellular communication. The following u network parameters in Table 3.1 below are used for simulation.

Table 3.1 Parameters for Poisson distribution for cellular UEs and Engset distribution for D2D UEs

Parameters	*Symbol*	*Value*
Number of all UEs in a cell	S	*1000*
Number of cellular UEs in inner part	S_c	$S - S_{D2D}$
Total number of D2D UEs in outer part	S_{D2D}	*j * 52*
Big cell radius	R	*1 km*
Small cell radius	R	*50 m*
Big cell area	Λ	$\Lambda = \pi R^2$
Small cell area	Λ_s	$\Lambda_s = \pi \mathrm{r}^2 = \pi D^2$
Offered traffic	A	*1 to 100*
Cell user density	τ	S/Λ
Reuse factor	Q	*7*
Number of D2D users in a small cell	j	$\Lambda_s * \lambda$
Targeted distance	D	*50 m*
Total number of channels	C	*25/cell*
Number of D2D channels	C_{D2D}	*18*
Number of cellular channels	C_c	*23/cell*
Number of iterations	i	*0 to C*
Total bandwidth	W	*10 MHz*
Bandwidth per duplex channel		*50 KHz*
Bandwidth for communication	BW	*9 MHz*
Dedication coefficient	α	*0.1*
Bandwidth for control channel		*1 MHz*

The trend in curves shows the variation of the blocking probability with respect to the offered traffic and it is shown in Fig.3.2.

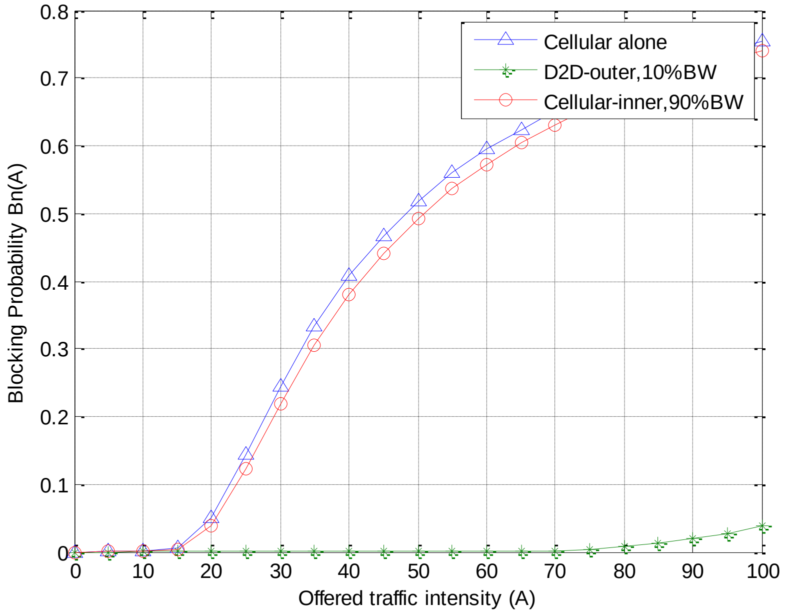


Fig.3.2 Blocking probability for cellular (Poisson distribution) and D2D (Engset distribution).

As shown in Fig.3.2, when D2D links are used in small cells at the cell edges together with cellular links in the inner part of the cell, the blocking probability is improved. The traditional communication encountered congestion since the number of channels is limited. As long as all the channels are occupied the incoming UEs requesting the service are blocked. When D2D links are enabled in small cells and the number of UEs requesting the channels to the BS is reduced because they are using direct communication. The blocking probability of D2D UEs is calculated according to Engset distribution since it is a small number i.e. it is a finite number of sources (only UEs within *D* meters). A large number of the remaining UEs in inner part are modelled using Poisson distribution. Results show that, when D2D communication is used with cellular, less number of UEs is blocked. The blocking probability for D2D links it is less than 1% for offered traffic intensity equal to 30. For cellular UEs in inner part, the blocking probability is 21% which better compared to traditional alone (25%) for the offered traffic is 30. However, the blocking probability increase with the increase in offered traffic intensity in general. Since the D2D links are using dedicated resources in small cells, the interference is reduced. This is a great benefit since the UEs at the edges of the cell are the one which normally have congestion problems. The results shows that these UEs in outer parts have small blocking probability compared to cellular UEs in the inner part and UEs in the whole cell in general.

3.5 Blocking Probability for Finite Number of Sources

We consider the system model with the same structure in Figure 3.1 and the strategy also is same i.e. the blocked calls are lost. However, in this case we have a limited number of sources. The Engset distribution is used with a constant call intensity γ for each source when it is idle. The number of channels is less than the number of sources requesting the services. Therefore, some of the call attempts may be blocked.

3.5.1 Analysis of the scenario for finite number of sources

Despite other studies in [18] which have considered the infinite number of sources, in our study we consider a limited number of sources. This has been considered in Section 3.4 but only for D2D UEs in small cells at the edges of the cell where the blocking probability was calculated according to Engset distribution. Here we also consider Engset distribution for the remaining cellular UEs in the inner part of the cell. We assume a few numbers of UEs to deal with this distribution. The number of remaining cellular UEs is reduced, compared to the density of the whole cell. The blocking probability B_c for each cellular group is treated as an Engset distribution as shown in Eq. (3.5).

$$B_c(\beta) = \frac{\binom{S_c-1}{C_c}\beta^{C_c}}{\sum_{i=0}^{C_c}\binom{S_c-1}{i}\beta^{i}} \quad , \tag{3.5}$$

where S_c and C_c represent the number of cellular sources (UEs) and the number of channels respectively dedicated to cellular UEs communication in inner part.

3.5.2 Network parameters and results

The comparison between traditional communication, D2D communication in the outer part of the cell and the cellular communication in the inner part is done using the network parameters in Table 3.2.

Table 3.2 Parameters for Engset distribution for both cellular UEs and for D2D UEs.

Parameters	*Symbol*	*Value*
Total number of all UEs in a cell	S	*200*
Number of cellular UEs in inner part	S_c	$S - S_{D2D}$
Number of D2D UEs in outer part	S_{D2D}	*k * 26*
Big cell radius	R	*500 m*
Small cell radius	r	*50 m*
Big cell area	Λ	$\Lambda = \pi R^2$
Small cell area	Λ_s	$\Lambda_s = \pi \mathrm{r}^2 = \pi D^2$
Offered traffic	A	*1 to 100*
Cell user density	τ	S/Λ
Reuse factor	Q	*7*
Number of D2D users in a small cell	k	$\Lambda_s * \lambda$
Targeted distance	D	*50 m*
Total number of channels	C	*25/cell*
Number of D2D channels	C_{D2D}	*18*
Number of cellular channels	C_c	*23/cell*
Number of iterations	i	*0 to C*
Total bandwidth	W	*10 MHz*
Bandwidth per duplex channel		*50 KHz*
Bandwidth for communication	BW	*9 MHz*
Dedication coefficient	α	*0.1*
Bandwidth for control channel		*1 MHz*

In these parameters using the density of the cell, the number of UEs in small cell is 52 and these UEs are able to use D2D communication. Since we have 200 users in the whole cell then the remaining UEs in inner part is 148 and this number is not large for calculating the blocking probability using Engset distribution. Therefore each group has a limited number of sources which is treated as Engset distribution. The variations in curves for blocking probability with respect to the offered traffic are shown in Fig.3.3.

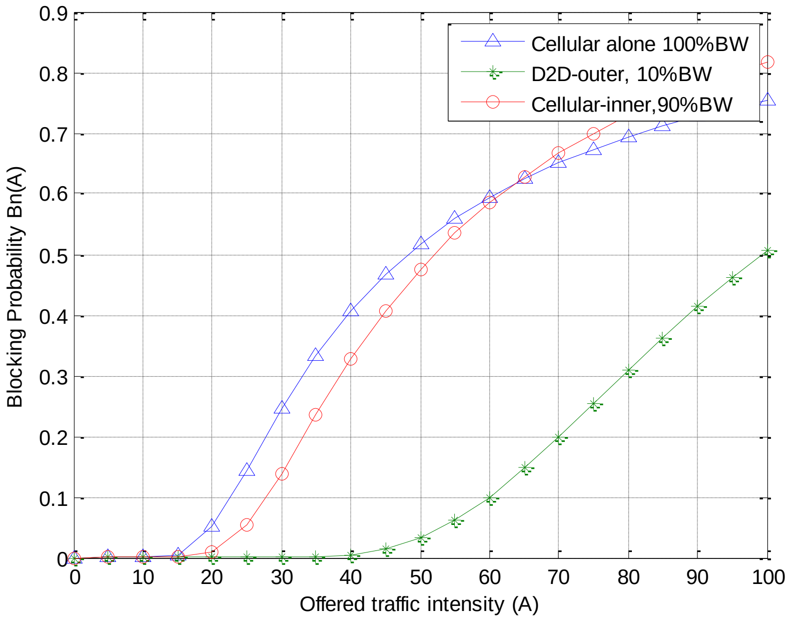


Fig.3.3 Blocking probability with Engset distribution both for cellular and D2D UEs.

The results in Fig.4.3 show that considering the Engset distribution for both cellular user inner part and D2D in outer part is more beneficial since all the UEs are experiencing the low congestion. This can be observed for $A = 30$ where the blocking probability is less than 1% and 15% for D2D UEs and cellular UEs respectively, whereas for traditional alone the blocking probability is still 25%. It is possible to consider a limited number of sources in order to use efficiently both the available resource and the number of channels. The remaining UEs in inner part have better communication than the traditional communication alone. However, once the offered traffic is beyond 60 there are no benefits for cellular users in inner part; since traditional communication outer performs the cellular one in inner part. On the other hand, the D2D UEs have great advantage in that they still keep the lowest blocking probability compared to traditional communication. This is because D2D need resource for discovery and control only. In addition, the traffic flood is reduced since some UEs are offloaded from the BS. Note that in our calculation we used a separate resource for control channel; therefore the results compared are for communication and discovery.

3.6 Chapter Summary

This chapter has discussed the D2D-enabled cellular network where a whole cell is split into two parts, namely, the inner part and the outer part. The inner part contains the UEs who are closer to the BS and are communicating via BS using traditional cellular communication. The outer part contains UEs located at the cell edges, far from the BS and these UEs have most of the time connections challenges. That is why we take them to consideration. These UEs are grouped in small circular cells, where each UE is located at the centre of the small cell and have at least one neighbor in D meters away from it and then can communicate via D2D link. Dedicated resource is assigned to each part and there is a possibility for the UEs in these small cells, to reuse cellular resource with a certain reuse factor to avoid the interference.

In both parts blocking probability is examined and is compared with the blocking probability of cellular communication alone. Two distributions are envisaged with regards to the calculation of the blocking probability. The Poisson distribution which reflects to Erlang distribution is used to model the system when the number of sources is assumed to be infinite. It is used for the UEs in cellular alone mode and UEs in inner part since it is a huge number of UEs taken as infinite number. The new thing here is the Engset distribution is used to model the system when limited number of UEs is concerned. In this case Engset distribution is mostly used for the UEs in outer part of the cell.

When the infinite number of sources is considered results showed that the network congestion is reduced when D2D links are used in the outer part together with cellular UEs in the inner part compared to cellular alone.

However the blocking for D2D links is much lower than the one for cellular links in general. This is because UEs using D2D are considered as a limited number and they are using direct links. There are no much network limitations for the UEs in proximity unless discovery resource is exhausted. The blocking probability for UEs in inner part is also reduced compared to cellular alone.

On the other hand, when a finite number of sources is considered, UEs in both parts are modelled using Engset distribution and the network congestion is more reduced compared to an infinite number of sources. However, the offered traffic intensity increases, the blocking probability increases as well and for instance when it is more than 60 (see Fig.3.3) the traditional communication outperforms than cellular communication in inner parts and the blocking probability for D2D links is higher than 10% in this case. This is because the amount of traffic generated is high than the UEs considered in outer part. For UEs in inner part the higher blocking probability can be caused by the mean holding time which is high compared to cellular alone.

In general, when D2D links are used at the cell edges together with cellular links inner part, as shown in Fig.3.1 the blocking probability is improved. The remaining resource when D2D UEs successfully discover their neighbors and use direct links; is beneficial to other UEs which are not in proximity and are far from the BS, so that they can as well communicate via BS. This is about UEs which are located in uncovered area; they can get benefit from the remaining resource. Since D2D UEs in outer part are grouped in small cell within D meters, frequency reuse techniques can also be applied and this can as well improve the capacity and the transmission rate of the cellular network.

4 Protocol Design for Neighbor Discovery

This chapter focuses on protocol and frame structure design for neighbor discovery for D2D communication. Two protocols, namely reactive and proactive, are proposed. The main idea of the reactive protocol is that *the neighbor discovery request is initiated by a UE* which intends to establish D2D communication with another UE. This is a *pull* service discovery mechanism. On the other hand, the proactive protocol is *initiated by the BS* serving all the UEs before any D2D requests arise; hence it is a *push* service discovery mechanism. With this mechanism, the BS sends a broadcast message periodically to all UEs for D2D neighbor and service discovery, but only interested UEs reply to the advertisement. More details about these two protocols are given below. For both cases, UEs need to register for ProSe discovery at ProSe Function which in our case is assumed to be at the BS. The registration of UE for ProSe, have been shown in Section 2.6 and in this Chapter it is assumed to be a precondition. We later design reactive and proactive message format and frame structure. Note that the term *ProSe discovery* is mostly used in this chapter, not only to refer to proximity service discovery but to neighbor discovery as well in our context.

4.1 System Model for Neighbor Discovery

Consider the D2D communication in cellular networks coordinated by a BS. The system model illustrated in Fig. 4.1 consists of one cell which is assumed to be a circular cell with S UEs uniformly distributed. The BS is in the centre of the cell of radius r and coordinates all UEs within the cell including both traditional and D2D communication. UEs in proximity can communicate through the direct D2D link. For instance, from UE1 and UE2 are using D2D communication and they form a D2D pair separated within a distance D.

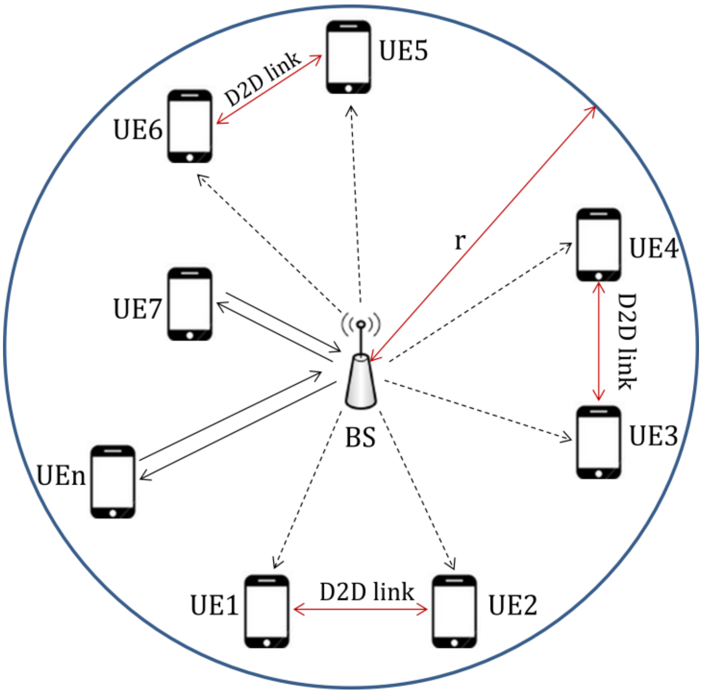


Fig.4.1 System model for proximity discovery.

Before the two devices in proximity start D2D communication they have to discover each other, through the discovery messaging and the BS assesses whether the direct communication is possible by monitoring their location and report about their proximity. The BS will allocate resources for discovery and control to these D2D pairs. After successful ProSe discovery through handshakes, D2D pairs communicate with each other via a direct links bypassing the BS. The remaining UEs will communicate via the BS based on traditional communication. Note that enabling direct links in cellular network will cause interference to other cellular UEs; therefore techniques to avoid interference are required. However, the topic of interference management is out of the scope of this thesis.

To enable D2D communication, UEs need to register for ProSe discovery and D2D services beforehand. We assume in this study that for these procedures like registration and authentication have already been performed for all UEs and consider only unicast user traffic. After registration, the ProSe application at each device may start triggering the requests or start monitoring other UEs' proximity services. The BS may also advertise the service so that all D2D-enabled UEs can access the services. We further assume in the envisaged scenario that both Open ProSe and Network ProSe are supported by all UEs as well as the BS.

4.2 Reactive Neighbor Discovery Protocol

The main idea of reactive protocol is based on *network ProSe* use case. With network ProSe a UE can be discovered and can decide to discover other UEs provided that they are on the list of its friends. For the reactive protocol, a UE initiates an on-demand (means that the service discovery request is initiated only when the UE has D2D traffic to send) service discovery procedure when it intends to establish D2D communication with another UE on its contact list. However before starting the discovery of its neighbors, UE needs to contact the BS since only the BS has an overview about all other UEs. So the discovery process is coordinated by the BS, after the discovery request is initiated by the UE. Fig. 4.2 illustrates the exchange of signaling messages for reactive ProSe discovery.

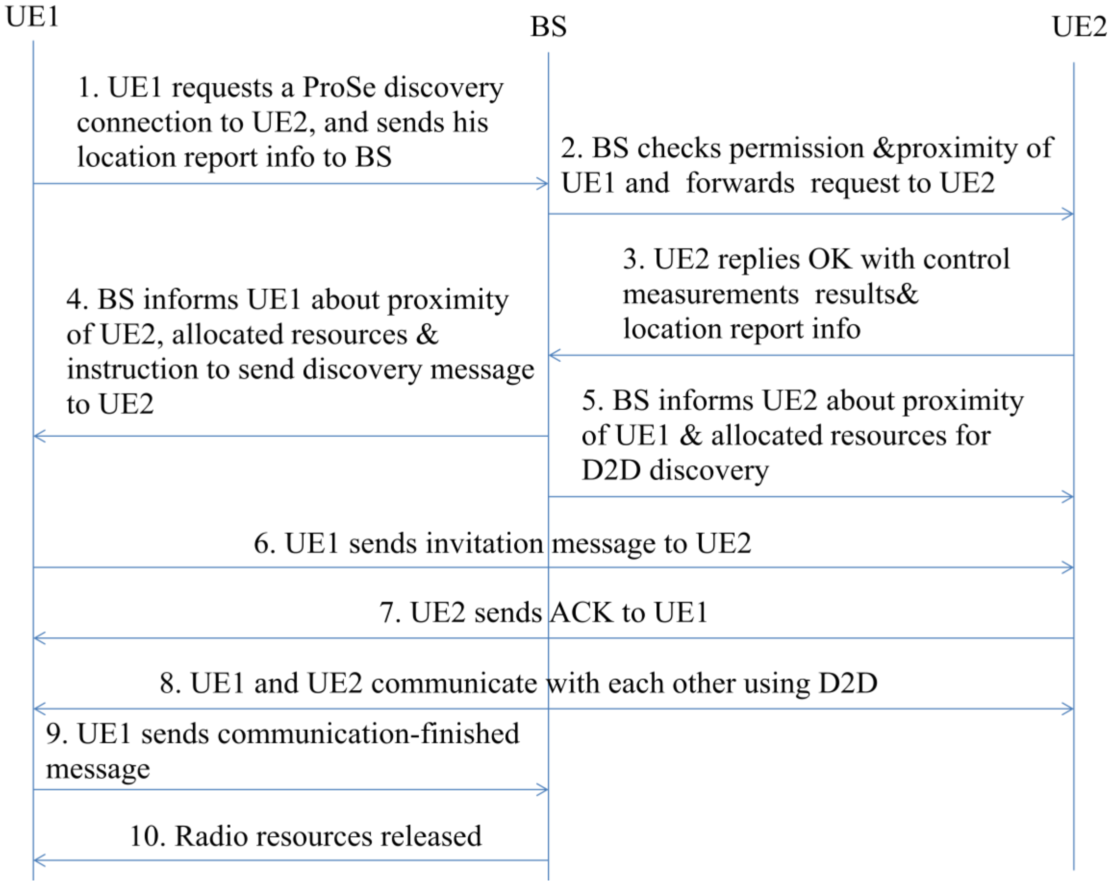


Fig.4.2 Neighbor discovery signalling messages using reactive protocol.

The discovery happens in the following steps:

- ✧ Step 1: When the UE1 want to communicate with UE2 using D2D, UE1 initiates firstly the discovery process by enabling the ProSe application on its device and sends a request message to BS requesting a

ProSe discovery connection to UE2. UE1 send as well the information about its own ID, position and the ID of the targeted D2D peer.

- Step 2: After receiving the request message from UE1, the BS checks the permission for discovery whether UE1 has registered for ProSe Service. Then the BS looks up the address and the proximity of UE2, and forwards the request to the peer device, UE2. Note that the BS keeps monitoring the location of all UEs in his cell so that any request will be forwarded to the requested device.

- Step 3: If UE2 is willing to communicate using D2D communication, it replies an OK message along with other necessary info to the BS. In the case where the BS forwards the message to UE2 and UE2 is not interested, if it doesn't reply by ignorance then the discovery process fails and it's finished. Here the successful D2D discovery is interested so that we assume that any request is positively acknowledged. It is also possible that, if the UE2 is not interested in D2D communication, replies with negative response and then the discovery process is over. Then the BS may give feedback to UE1 that the addressed candidate is not interested and UE1 will have to start over or quit. On the other hand the BS may decide to initiate a traditional local path via the BS communication between UE1 and UE2. This can happen when the BS assess that D2D communication is not possible depending to certain network parameters such transmission power and so on.

- Step 4: The BS informs UE1 about the proximity of UE2, allocated resources and instructs UE1 to send discovery message to UE2. At this step the BS knows all the control information, location, transmission power, gains, interference, and how much resources required for guiding the ProSe discovery for these D2D UEs in order to communicate.

- Step 5: The BS also informs UE2 about the proximity of UE1 and the allocated resources for D2D communication.

- Step 6: When the UE1 got a response in Step 4 that ProSe discovery is possible, UE1 sends an invitation message to UE2 directly. In this case if the transmission power is sufficient then the discovery is successful. Otherwise the BS will instruct the UE1 to increase its transmission power in order to reach UE2. Since the transmission power management is not the objective of this study, we assume that UE1 have enough power for direct discovery and of course in this context the invitation message will reach UE2.

- Step 7: Once the UE2 receive the invitation message, UE2 replies with an acknowledgment (ACK) message to UE1 confirming that they start D2D communication.

- Step 8: Ongoing D2D communication session between the two UEs and the radio resource is managed by the serving BS.

- Step 9: When the D2D session is terminated, a D2D communication-terminated message is sent to the BS by one of them. For instance, since UE1 was responsible for the ongoing communication, it sends communication-finished message to BS because this communication was under control of the BS.

- Step 10: The BS after getting the message in step 9, will release the radio resources and the D2D communication is now over.

In general this reactive protocol is a fully network dependent protocol where the BS continuously monitors the D2D UEs by assigning control radio resources to this communication. Note that the reactive ProSe discovery and communication procedure requires in total ten messages between the two UEs and the BS among them seven handshakes are necessary for each successful D2D session. We count accordingly these seven handshakes (from Step 1 to Step 7) in our protocol overhead calculation in Chapter 5, since the other three steps are for D2D communication and are the same in the proactive procedure.

4.3 Proactive Neighbor Discovery Protocol

The protocol in this section is designed based on an Open ProSe use case in [2]. In this use case and scenario, the UEs can discover others or can be discovered by others without permission. With the proactive protocol, all the authenticated UEs with D2D-enabled applications will be notified by the BS about the availability of the ProSe services through a multicast message sent periodically. This implies that radio resources might be wasted if no UEs have D2D requirements. Once a UE has D2D traffic to send, it replies to this advertisement, informing the BS about ProSe discovery. Afterwards, the handshake steps are similar to the ones presented above. Note that the D2D peers may be served by the same or different BSs. Here small change can be added when UEs are served with different BSs. In the latter case, more handshakes are needed among BSs. For simplicity, only one BS is considered in our model.

Fig.4.3 shows the exchange of signalling messages for discovery using proactive protocol. UE1 and UE2 are both UEs ProSe-enabled so that they can discover each other without permission.

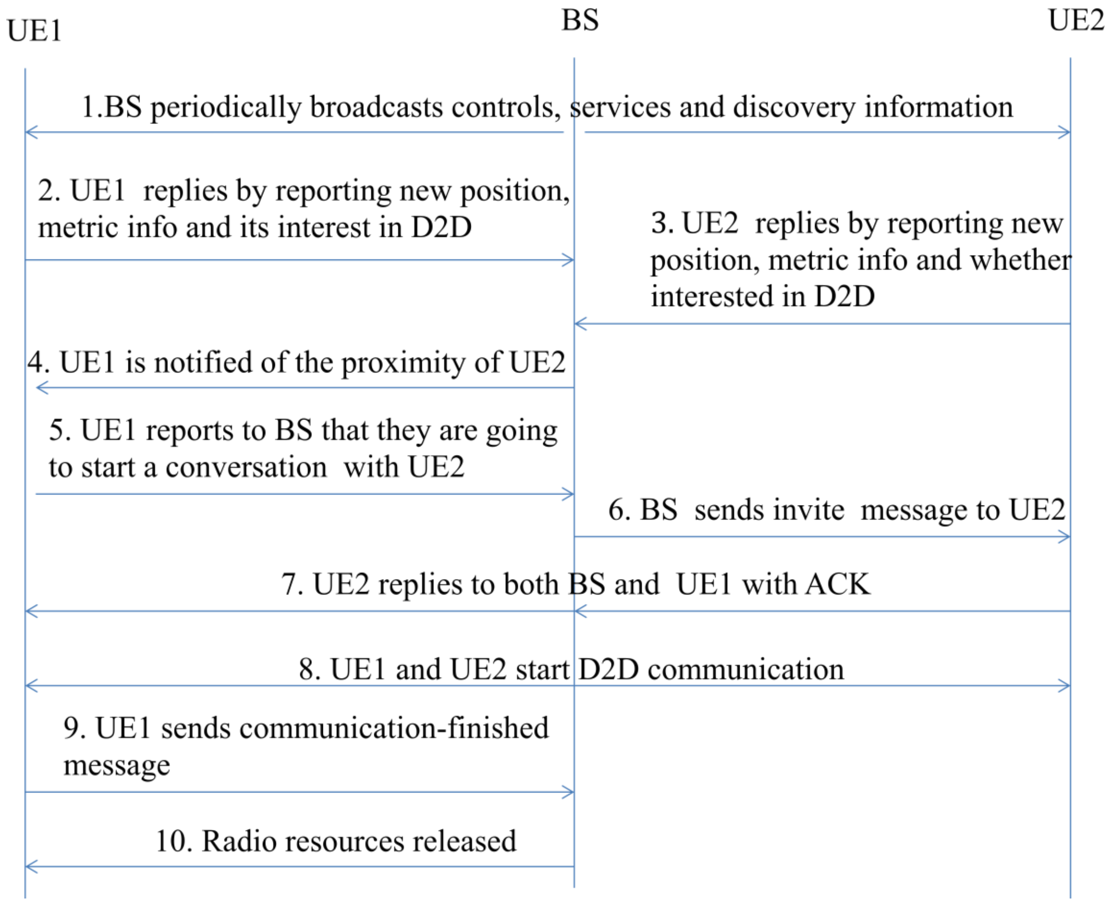


Fig.4.3 Neighbor discovery signalling messages using proactive protocol.

The neighbor discovery is achieved in the following steps:

- Step 1: At the starting the BS periodically multicasts to all subscribed UEs for ProSe about the list of proximity services available and discovery information. If there is a service that they can access, the advertisement contains all the information of which service is available.

- Step 2 and Step 3: The UEs that have D2D requirement, for example UE1 and UE2 as illustrated in Fig.4.3; reply to the BS reporting their new position, metric information and the IDs of the targeted D2D peers.

- Step 4: BS updates the information list and looks for location information of UE1 and UE2 to assess whether the D2D communication criterion is met. This criterion includes the necessity of the UEs to be friends; it means that each appears on the list of the other and whether they are subscribed to a given service. If yes, the BS compares the location and sends a notification to one of them about the proximity of the other D2D peer. For instance, the BS sends a proximity notification to UE1.

- Step 5: After receiving the notification about its nearby friend, then UE1 reports to BS that they intend to start D2D session with UE2. Here UE1 sends the invitation through the BS so that the BS can allocates required resources for discovery and forwards the invitation message to UE2 on behalf of UE1.

- Step 6: The BS forwards invitation message to UE2. The BS allocates as well required radio resources to prepare D2D communication.

- Step 7: After receiving the invitation and configuration information with relevant parameters UE2 replies to both BS and UE1 with ACK accepting to communicate with UE1 via D2D communication. Meanwhile the BS updates with fresh information about the calling party and called party, whether UE1 and UE2 are in the same cell or not, resources blocks allocated etc in its D2D database [7].

- Step 8: UE1 and UE2 have discovered each other; they setup a D2D link and start communicating trough the direct path in the given resource.

- The last two steps in Fig.4.3 are the same as in Section 4.2 for reactive protocol. In Step 9 UE1 decides to end the conversation and sends communication-finished message to BS. In Step 10 the BS releases the radio resources and the D2D communication is ended.

The proactive ProSe discovery is also achieved using seven handshakes, from Step 1 to Step 7. However proactive protocol differs from the reactive protocol in which the first message is a multicast message sent periodically as an advertisement no matter there is ongoing or potential D2D traffic or not. The last three handshakes are the same as in the reactive protocol, therefore not included in our overhead calculation.

4.4 Message Format and Frame Structure of the Designed Protocol

There exist different types of messages depending to the type of protocol traffic. For example, hello message and Topology control (TC) messages are used for link establishment and dissemination of network route advertisements in Optimized Link State Routing (OLSR) protocol. In this part, we use *unicast* messages such as Request (REQ) and Response (RSP) and *broadcast/multicast* messages such Announce (Ann) in the discovery process. These messages are exchanged between UEs and BS as handshakes and discovery signalling resource needs to be assigned. Radio resources are assigned to D2D communication by the BS both in space, time and as well in frequency. As introduced in Section 2.6, these resources can be allocated either dynamically or statistically. When dynamic allocation is used for D2D discovery, UEs need to be active continuously and this leads to high energy consumption. In contrast, when static allocation for discovery is used, UE battery is saved. For example a frame structure may be organized considering many subframes, in a way that only 1% of the resources is reserved for discovery and UEs engaged in discovery may sleep for a time equivalent 99% of the total resources, and wake up only when they are going to transmit/receive the discovery signal in predefined subframes. However, due to the variation of the fluctuation of D2D traffic, dynamic allocation may be preferred than static allocation [21]. All will depend to which performance evaluation is interested.

Due to the above requirements we propose a frame structure format for reactive and proactive, based on the protocol format for discovery messages suggested by 3GPP in [3]. We take into consideration two ways of performing discovery, broadcasting own information periodically without expectation of the receiver response and exchanging request/response. Concerning the frame structure in general, a subframe consisting of 10 frames of two types is used. Type 0 which includes region for synchronization, discovery, peering and data. Type 1 contains only synchronization and data regions [27], [28].

3GPP TR 23.703 proposes three fields in the protocol format. *Discovery mode* field which indicates whether the message is for discovery response, discovery request or announce only. For example a message in Mode A can be “I am here” or/and in Model B, “Who is there?” The next field is *Type* which indicates whether the ProSe Identity is a ProSe UE Identity, and/or whether it is used for Open discovery or Restricted discovery. The last field is *Content*. If the Type field is set to ProSe UE Identity Content field indicates ProSe UE Identity and with the Type field set to restricted discovery or open discovery the content field contains the ProSe Application Identity. The general idea of how our protocol format is shown in Fig. 4.4. The message and packet info field will contain all information regarding the message itself and the packet which will be explained in later sections.

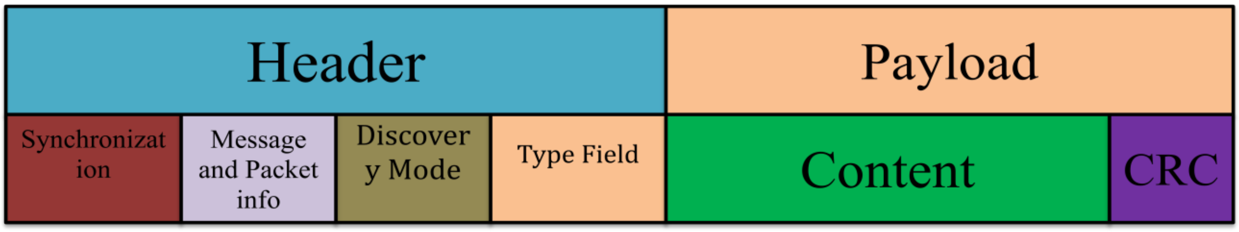


Fig.4.4 Example of protocol format for discovery message.

The detailed protocol format is shown in Fig. 4.5 with each field detailed and the number of bits is specified. Note that the same format can be used for both in coverage and out of coverage scenarios, open ProSe and Restricted ProSe [3]. Note that the number of bits assigned to each field can be revised depending on the application and use case.

The *synchronization* field is an essential region of the frame structure. UEs willing to be involved in discovery need to be synchronized in a distributed manner. D2D with infrastructure mode has an advantage that the BS provides a synchronization beacon. The synchronous discovery has many advantages over asynchronous discovery such as less energy consumption for search and discovery, fast detection and large number of discoverable UEs. However, multiple D2D transmission links make synchronization more challenging. Different UEs transmit signals to other different receiving UEs in a contrary manner to usual uplink/downlink situations where the signals pass via the BS before it reaches other UEs. In out of coverage synchronization is hard to achieve and cluster-head control mode is used where the cluster-head transmits a reference signals [21]. The synchronization signal includes information about transmission period, radio resources; transmitting power, frame and subframe number and so forth.

When synchronisation is achieved, each device initiates and continues the discovery process to detect other nearby devices and available services in proximity. We adopt two discovery mechanisms: a *push* mechanism corresponding to proactive protocol in our study; where UE can advertise its presence or just BS broadcasts the available services or the presence of UEs in proximity whereas in a *pull* mechanism, interested UEs initiate the discover by requesting discovery services from the BS. The mechanism is used for discovery is indicated by the discovery mode field. Its three subfields include the *Discovery Request (DREQ), Discovery Response (DRSP)* and *discovery Announce (DA)*. DREQ indicates the request from UE to the BS, willing to know who is there. More than one request can come at the same discovery period and collision can occur. To avoid this problem, DREQs are scheduled so that each request can be identified by its distributed number. For example, when the Distributed Schedule Numbers (DSN) are from 0 to 7 and if a UE choose 1 as its DSN its request will be handled before the

UE who chooses a DSN of 3. In the next period, the delayed one will be the first one to be served. For simplicity, we assume only one request at once.

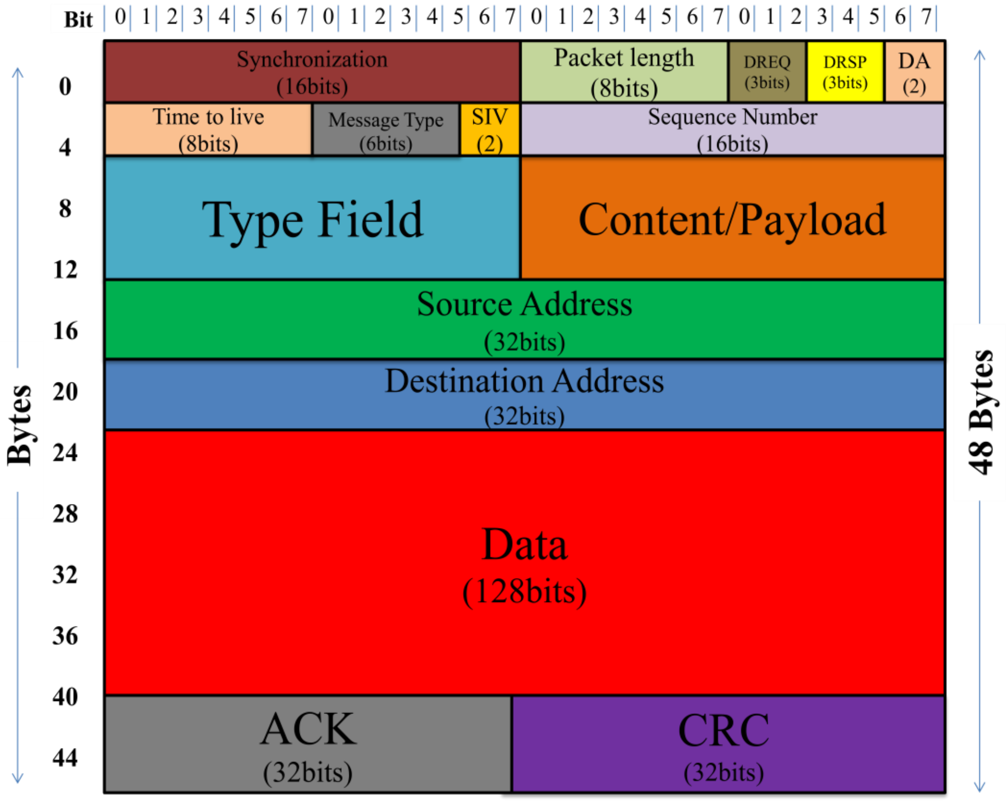


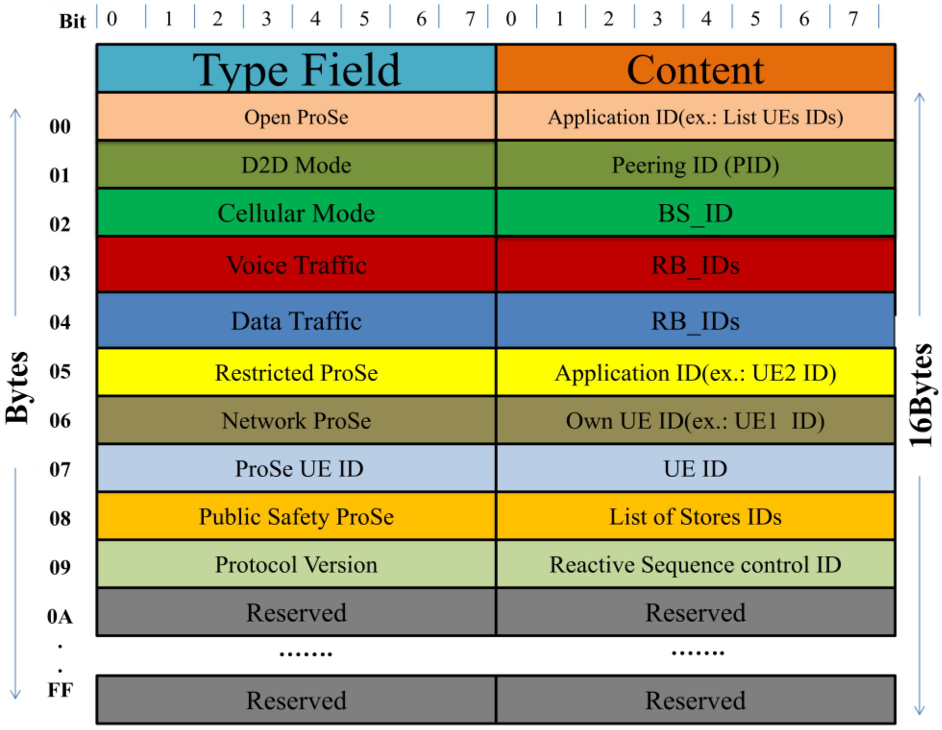
Fig.4.5 Discovery protocol format and frame structure.

On the other hand, DRSP includes a response by a recipient UE who is interested in D2D discovery and D2D communication, in response to the DREQ. DSN are as well used for many DRSPs from different UEs. The DA indicates the case where a UE can advertise its own ID and/or application ID by announcing the discovery message. In our case, DA field indicates if a BS is advertising the discovery by sending a broadcasting message to all.

The *packet length field* indicates how many D2D pairs in the vicinity and the length of the packet generated by a UE involved in D2D discovery. The sequence of the packet is specified in the *Sequence number field* whereas the *Service Information Version (SIV)* indicates what version of the discovery protocol is being used. SIV also is used to indicate the status of the service configuration in the device of a UE, which allows for example deletion or addition of an application as well as the changes which can be made. The *message type* field of the protocol format, includes whether a message is unicast or/and is a broadcast or a multicast message. It shows also whether a message is in uplink or downlink situation. This field is related also to reactive and proactive protocols where the size and the number of exchanged messages are reflected therein. The *Time to Live (TTL*) field indicates the limiting time of a unicast message (request and/or response) or how long a broadcast message can last. Note that TTL also can show how many UEs the intended message can reach within a certain range of time.

The *source* and *destination* address fields indicate the addresses of the UE sending a request and the recipient UE address respectively. Note that this address is an IP address which can be translated for example to Permanent/Temporary Mobile Subscriber Identity (MSI/TMSI) or International Mobile Subscriber Identity (IMSI) of each UE [29]. *Type* field indicates whether an ID is for ProSe UE ID or/and whether it is for open or restricted ProSe. Other specification parameters in this field are shown in Fig. 4.6 and each of them reflects what will be included in content field which contains IDs. For example if the type field contains open ProSe discovery then Content field will include the application ID such as BS_ID and/or list of UEs IDs.

Once synchronization is done and discovery signals have been exchanged successfully; UEs may establish a D2D link and exchange the data burst. The information regarding the data transmission, message and talk bust as well as the Maximum Transmission Unit (MTU) are included in *Data* field. After each successful transmission, the recipient sends ACK to the originator. Dedicated resource needs to be assigned after each transmission of DREQ and DRSP. Note that ACK is not necessary in case of broadcasting discovery, only interested D2D candidates will reply to the advertisement. The last field is the *Cyclic Redundancy Check (CRC)* which is an error detecting code appended to the transmitted data. Its length indicates how many errors can be detected in the block of data appended to, upon the reception. Each D2D UE can be allocated a Discovery Radio Network Identifier (D-RNTI) based on the location information of the UEs in proximity, which can be used for scrambling the CRC part attached to D2D specific control information [30] and [4].



	Type Field	Content
00	Open ProSe	Application ID(ex.: List UEs IDs)
01	D2D Mode	Peering ID (PID)
02	Cellular Mode	BS_ID
03	Voice Traffic	RB_IDs
04	Data Traffic	RB_IDs
05	Restricted ProSe	Application ID(ex.: UE2 ID)
06	Network ProSe	Own UE ID(ex.: UE1 ID)
07	ProSe UE ID	UE ID
08	Public Safety ProSe	List of Stores IDs
09	Protocol Version	Reactive Sequence control ID
0A	Reserved	Reserved
. .	…….	…….
FF	Reserved	Reserved

Fig.4.6 Example of information included in Type and Content field of the protocol format.

As it is shown in Fig. 4.6, Type field contains all the information regarding the mode selection, D2D mode or cellular mode; traffic carried, voice or data traffic; which use case adopted and their corresponding IDs are specified. However, some bytes are reserved for other identification which can be later specified.

4.4.1 Frame structure format based on reactive protocol

With respect to reactive protocol, we propose how the protocol format can look like. Recall that the reactive protocol is based on pull mechanism where UE initiates the discovery by sending a request to the BS. Fig. 4.7 shows the example of the reactive protocol frame structure where each field is filled with only the necessary information. DREQ and DRSP subfield are in this case activated indicating that the discovery is an exchange of queries. DA subfield is empty (00bits because is a two bit field) since the discovery procedure in this case is not an announce discovery. TTL shows the specific time period the request is valid (for example 60seconds). SIV indicates that a reactive protocol is concerned. The message type is showing that the request is a unicast and uplink message. Since reactive discovery is based on network ProSe, therefore it shown in Type field and Content field contains the ProSe UE1 ID. Meanwhile D2D mode and voice traffic are included in this field with their Peer Identity (PID) and Resource Block Identity (RB_ID) respectively in the content field. This is to specify that UE1 wants to talk to UE2 using D2D communication over direct link. UE1 needs to specify its own address and the recipient address (UE2 ID). Both addresses are IP based and network translation can be used to map them to their specific Mobile subscriber Number (MSI). Data field shows a talk burst and ACK and CRC field are activated, because in reactive protocol the UEs will confirm that the data is correctly received.

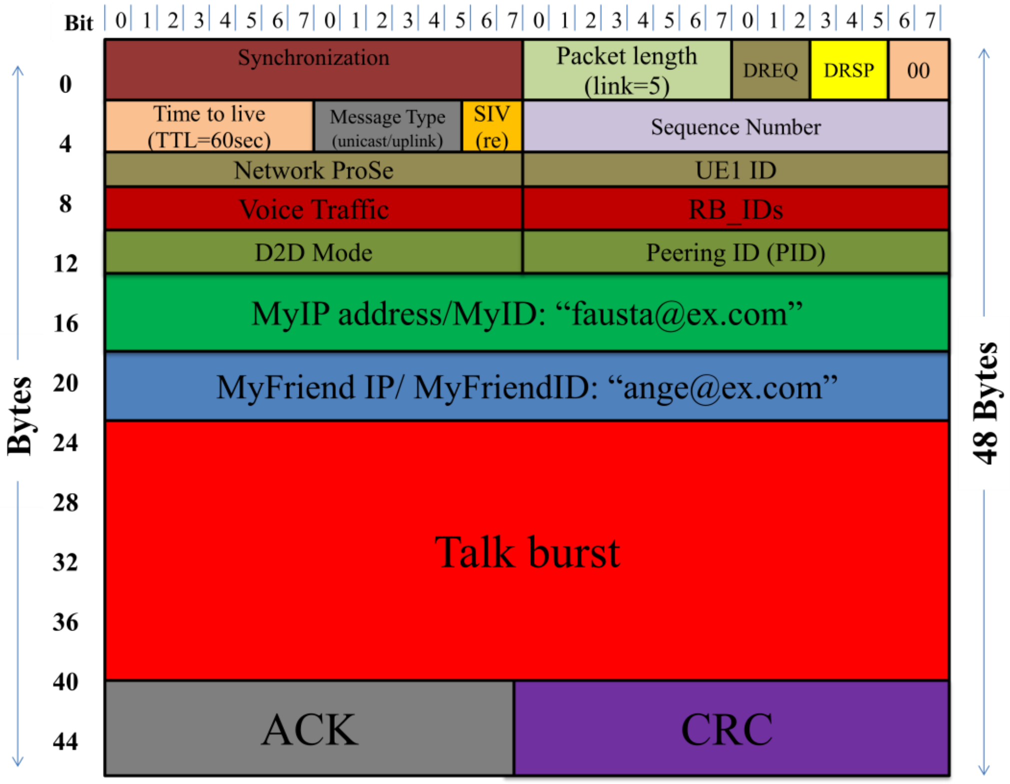


Fig.4.7 Example of reactive protocol frame structure format.

The exchange of messages for the ProSe request procedure with respect to reactive protocol format is shown in Fig. 4.8. Note that this is different from the one showed in Fig. 4.2 which shows the reactive protocol design. Here we want to show how messages are disseminated through all necessary network functionalities. It is a more detailed handshaking. This is in accordance with 3GPP in [3], where different call flows are suggested for different uses of ProSe discovery. Since our study is based on D2D communication with infrastructure mode, where BS coordinated the discovery process; we assume that once a UE device is switched on, the device starts synchronizing with the BS beacon. The BS has three functionalities, the ProSe function in charge of UE1 and ProSe Function 2 in charge of UE2 where they have registered for ProSe. Besides the Application Server (App Server) is used which contains all UEs IDs and their network information. They all participate in ProSe discovery to help UE1 finding UE2. Therefore, UE initiates ProSe discovery asking if its friend is there. After synchronization the ProSe request procedure is achieved in the following steps.

1. UE1 initiates the discovery by sending a ProSe Request message to ProSe Function1 specifying its ProSe ID (ProSe1: MyID= "fausta@ex.com"), the application ID, its application-specific ID (App1), the targeted user UE2's application-specific ID (App2), and potentially a TTL period to specify the time in which the request is valid.
2. Since all ProSe IDs are stored at the App Server, ProSe Function1 sends a Map request message (Map REQ) to App Server in order to know the ProSe ID for UE2. Note that both App1 and App2 must be specified in this message.
3. The App Server sends an ACK Map RSP to Prose Function1 after checking the UE2's application-specific permissions and whether UE1 is allowed to discover UE2. The App Server provides then the ProSe ID of UE2 (ProSe2: ID= "ange@ex.com") to ProSe Function1.

4. ProSe Function1 forwards the ProSe REQ to ProSe Function2 providing as well the ProSe IDs for both UE1 and UE2 (ProSe1, ProSe2) and the link layer identifier of UE1 (Link1)
5. Prose Function2 and UE2 validate the ProSe REQ by checking the discovery permission for UE1. In this case UE2 decides based on its application specific ProSe permission and ProSe permission to be discovered with respect to UE1.

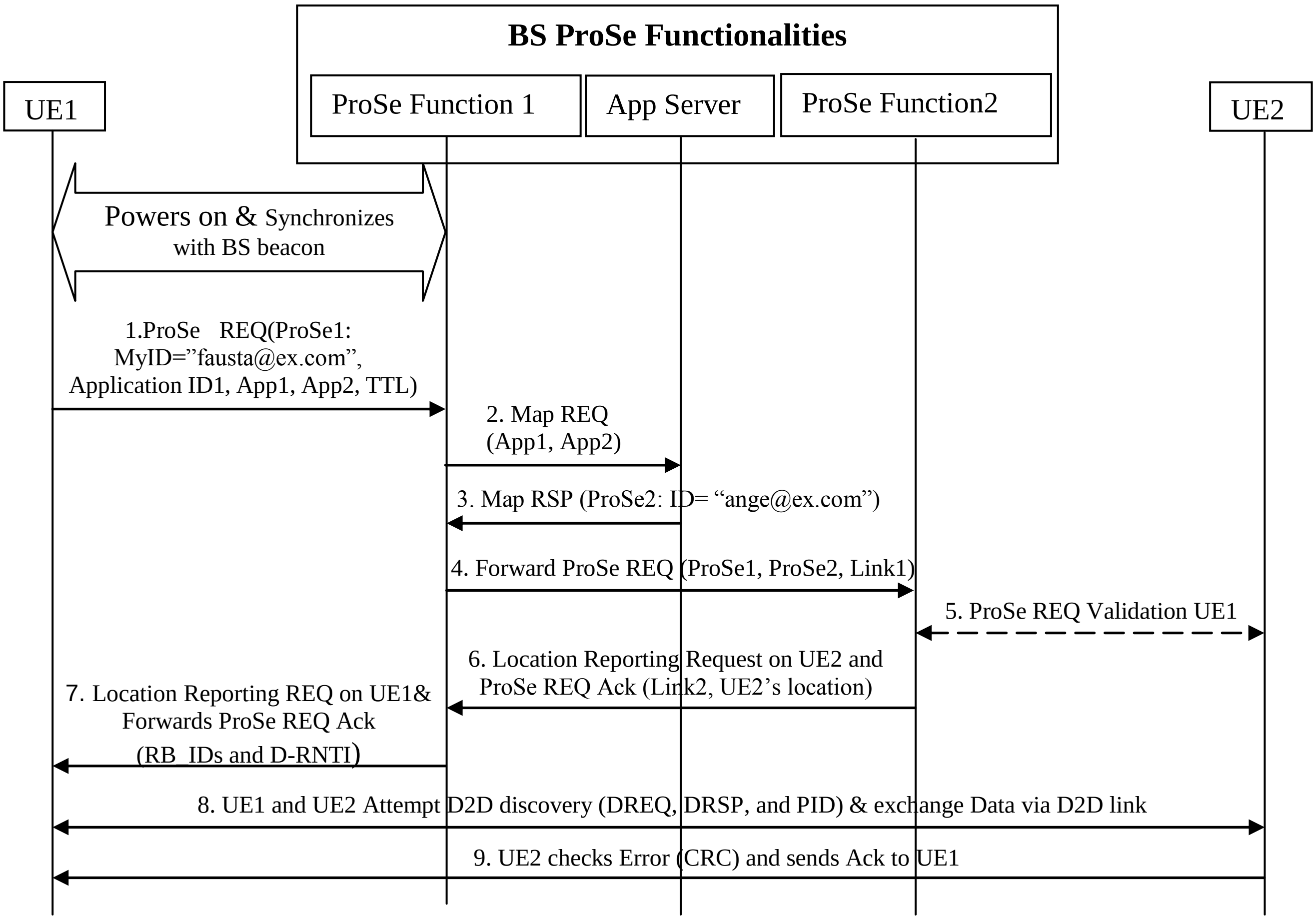


Fig.4.8 Discovery message flows in reactive protocol format.

6. ProSe Function2 reports the current location of UE2 and sends a ProSe REQ ACK to ProSe Function1. It provides as well the link layer ID for UE2 (Link2).
7. UE2's location report and REQ Ack are forwarded to UE1 by the ProSe Function1. UE1 is as well informed about the discovery resources and a discovery radio network identifier allocated to them (RB_IDs and D-RNTI). Note that D-RNTI will be used for error checking so far when the discovery is successful and the data is transmitted.
8. Both UE1 and UE2 Attempt D2D discovery by exchanging DREQ, DRSP and PID. When the two peers are connected they may exchange data via D2D link.
9. UE2 checks whether the data is correctly received and acknowledges the correct reception to UE1. Otherwise instructs UE1 to retransmit the data.

4.4.2 Frame structure format based on proactive protocol

As a push mechanism, proactive protocol involves the initiation of the BS for service discovery. That is the BS broadcasts the discovery (ProSe discovery message) to all regardless to whether UEs are interested or not. Fig. 4.9 shows the example of how a frame structure format looks like as long as proactive protocol is concerned. The information in some fields is the same as in reactive protocol frame structure format and here we describe the fields which have been changed.

As we can observe in the following figure, the packet length does not show any D2D link. This means that currently there are no direct links in the cell, and it can include other parameters which are not specified here. The DREQ is not activated because there is no request for Prose discovery from UEs. DRSP and DA are active to indicate that the BS announces a service discovery and some of the interested UEs may respond to its advertisement. The TTL shows the duration of the broadcasted message and in this case it is 5 seconds. That is after 5seconds when there is no response, radio resources are wasted and the advertisement will be expired. Since the BS broadcasts it periodically then it will send another one in next timeslot. The message type now is set to downlink broadcast message. SIV is set to proactive as a version of the ongoing protocol.

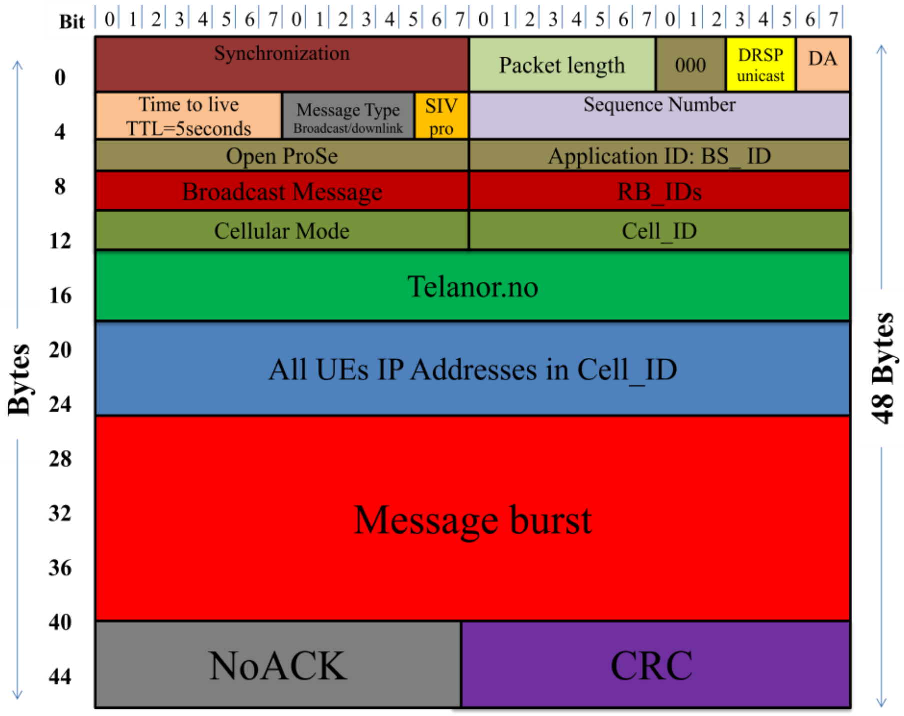


Fig.4.9 Example of proactive protocol frame structure format.

The main difference between reactive format and proactive is in Type and Content field. Now it is set to open ProSe to indicate that every UE is allowed to discover others without permission. Then Content field includes at this moment, the application ID which is the BS_ID. The communication is from BS and the communication mode is set to cellular mode where Content field contains the cell ID. The BS allocates resource for the broadcast message and its RB_ID is given in Content field. The operator address is given as source address (for example "Telanor.no") and IP addresses for all UEs intended to receive this broadcast message are included in destination address field. The data field includes the message burst. The broadcast message is not replied, thus there is no ACK. CRC is used only when a UE is interested in D2D communication and has sent a RSP to BS and has successfully discovered a friend to exchange the data. If no one responds to the advertisement the resource are lost.

The messages flow exchange based on proactive protocol frame structure format is illustrated in Fig. 4.10. All UEs are exchanging synchronization signals with the BS which sends a beacon for control information. In this case the BS informs the UEs when they enter into proximity region. That is the BS keeps monitoring all UEs and sends them a notification for ProSe when one is nearby another. The figure used shows the ProSe discovery for only two UEs for simplicity and for many other pairs the procedures are the same as far as proactive protocol format is concerned.

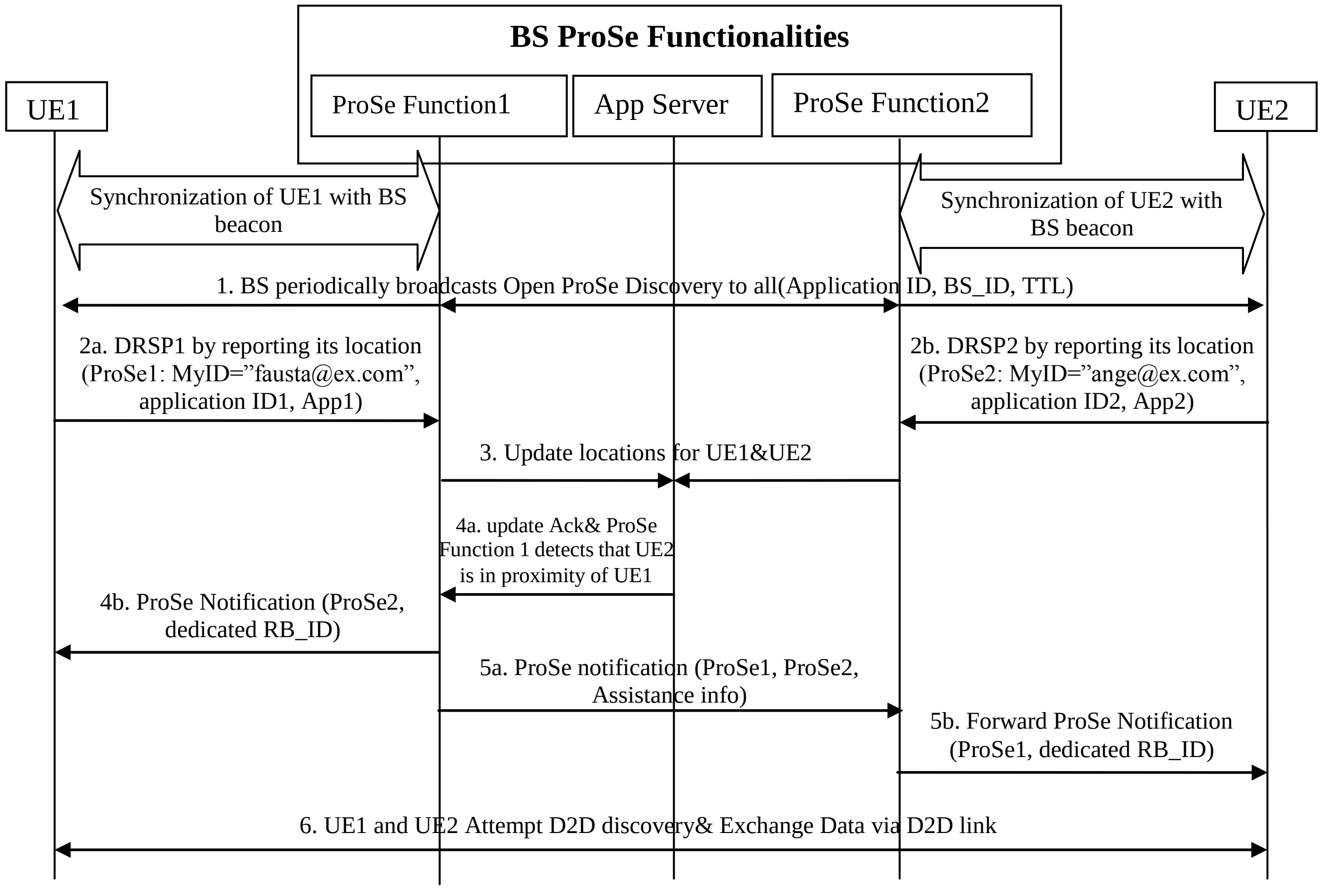


Fig.4.10 Discovery message flows in proactive protocol format.

After the synchronization is achieved, discovery handshakes procedure is shown in the following steps:

1. BS periodically broadcasts Open ProSe discovery to all in the vicinity and provides the application ID and the BS_ID as own identity together with the time period in which the advertisement has to live (Application ID, BS_ID, TTL).
2. Both UEs reply DRSP to the advertisement by reporting their location to their ProSe Function respectively. They as well provide their identifications, UE1 (ProSe1: MyID="fausta@ex.com", application ID1, App1) and UE2 (ProSe2: MyID="ange@ex.com", application ID2, App2)
3. ProSe Function 1 and ProSe Function 2 Update locations information for UE1&UE2 from the App Server.
4. App Server acknowledges both ProSe functions with update Ack and ProSe Function1 detects that UE1 and UE2 are nearby each and notify UE1 by sending a ProSe notification message containing the identification of UE2 and dedicated resources for discovery (ProSe2, dedicated RBS_ID).
5. On the other, ProSe Function 1 may instruct the ProSe Function 2, to send a notification to UE 2 about the proximity of UE1. The message contains as well the IDs of both UE1 and necessary assistance information. ProSe Function forwards then, the message to UE2 together with identification of UE1 and dedicated resources for discovery (ProSe1, dedicated RBS_ID).
6. UE1 and UE2 Attempt D2D discovery and if successful they exchange Data via D2D link.

Note that for Proactive there is no ACK to broadcasted message. Only interested D2D candidates sent a response to the BS, but UEs who are not interested in D2D communication and/or UEs who haven't registered for ProSe discovery ignore the broadcast message.

4.5 Chapter Summary

This chapter proposes two protocols for neighbor discovery, namely reactive and proactive protocol and both of them are based on D2D communication with infrastructure mode. Reactive protocol is based on an on-demand manner where a UE initiates the neighbor discovery by sending firstly the request to the BS. It is a pull mechanism. Reactive is designed based on network ProSe discovery use case suggested by 3GPP TR-22.803, where the network assists the UEs to discover its neighbors in proximity. Proactive protocol is based on multicast message sent by the BS to all UEs notifying them about the proximity of their neighbors and services available in the vicinity. It is initiated by the BS and is a push mechanism. It is designed based on Open ProSe use case where a UE is allowed to discover its neighbor without permission.

Both protocols have an advantage that few handshakes are used for ProSe discovery and this reduces the network flooding. The advantage of reactive protocol over proactive protocol is that UEs only activate proximity application in their devices and send discovery messages when they only have D2D requirement to send. This saves the UE battery. On the other side, when there is a high D2D traffic load, proactive protocol is recommended on both UEs and BS perspective. UEs are easily notified for their friend in proximity and this saves the uplink resources for UEs since they are not required to send a request to BS. They get all necessary information from the BS advertisement. An advantage for the BS is observed when many UEs reply to its advertisement and use D2D links; the network is offloaded. However the resource is wasted when no one is interested in D2D ProSe discovery.

Moreover, the message format and frame structure for both reactive and proactive protocols was suggested. It includes all the necessary fields such as the synchronisation field, type field, discovery mode and content field and other subfields as shown in Fig.4.5. All the required exchange of messages between UEs and BS functionalities are presented and explained in details. In general, in our message format, UEs can either exchange discovery queries (Requests/Response) or respond to the BS announce. However, it is also possible that a UE announces its own discovery.

5 Analysis of Protocol Overhead

D2D ProSe discovery and Communication needs to be analysed in terms of the parameters which clarify the benefits of using D2D communication under cellular networks. These parameters include the transmission rate, the throughput and network offloading as well as the control overhead and so on. Based on the protocol design introduced in Chapter 4, we calculate the control overhead using the number of signalling messages exchanged between D2D pairs and BS. The introduction on control overhead in cellular network with D2D pairs is provided in Section 1. In Section 2 we discuss the neighborhood calculation in which the proximity of nearby devices is taken into consideration and we assess the number of D2D UEs which can form D2D pairs with respect to the targeted distance between communicating peers. Lastly, analysis of the designed protocols is done in three different cases comparing them in terms of protocol overhead when the incoming D2D requests for ProSe discovery follows different distributions.

5.1 Introduction and Our Previous Work on Protocol Overhead

In cellular network systems, the BS allocates resources to communicating UEs. These resources are both for control information and for data or voice transmission. The required resources for control information and connection establishment purposes are taken as overhead. As long as protocol design is concerned, the control overhead needs to be calculated. In our context the control overhead is defined as the cost required for control and service discovery handshakes. It is calculated in terms of the number of handshakes exchanged between two UEs for discovery when the two UEs are nearby each other and BS which coordinates them. That means UEs are in proximity and are trying to discover each other to form a D2D pair. When D2D communication is introduced in a cellular network, then things look different and the requirements change as well. The BS needs in this case to allocate resources to both normal cellular UEs and D2D pairs. For cellular users, BS allocates resource for both control and data communication. In case of D2D, BS allocates only resources for discovery or just for path establishment and control only. Since D2D UEs communicate through a direct path, the remaining resources which were supposed to be used by D2D pairs for data/voice transmission are reserved. These resources are beneficial for the remaining cellular UEs communicating using the traditional communication.

We consider M pairs in our system model. Recall that for reactive protocol, seven handshakes for each pair are required, then for M pairs it results in $7M$ handshakes. For proactive seven handshakes are required, among them one is a multicast message transmitted periodically to all UEs resulting in ($T+6M$) handshakes for M D2D pairs. T denotes the total period, i.e. the total number of timeslots with or without a D2D request which as well corresponds to the number of times the multicast advertisement is repeated. D2D requests for ProSe discovery can come within different timeslots as shown in Fig.4. The total number of timeslots in which we experience the requests is given by L.

In our previous work [31], we have calculated the control overhead with respect to reactive and proactive protocols based on three cases of number of D2D UEs requesting the service discovery and the number of available timeslots; as well as the number of signalling messages and the broadcasting message transmitted periodically.

In the first case, we assumed that only one D2D pair can request the ProSe in each timeslot. The control overhead for reactive and proactive protocols was calculated respectively. We took in consideration the number of D2D pairs which is equivalent to the number of available timeslots. The relationship between the results showed that when $L \leq T$, reactive protocol performs better than proactive protocol. And when $L > T$ then proactive is preferable over reactive protocol.

In the second case we considered multiple requests within one timeslot. Both the number of D2D pairs M and the number of available timeslots L were taken into consideration, since they have impacts on how many requests can be done in each timeslot. The control overhead calculation for reactive and proactive protocols respectively gave the curves showing that for $L \leq \frac{T}{M}$, reactive protocol can be chosen. When $L > \frac{T}{M}$, proactive is preferable. The reason behind is the increase in number of UEs with the distance shorter than the targeted distance between UEs.

In the third case, we combined the ratio of presented D2D UEs to the total number of UEs ($R = \frac{k}{n}$) within the cell and the multiple requests in one timeslot. A representation of control overhead for both reactive and proactive protocols respectively by curves was given. In this case proactive protocol performed better in general. However, it holds that, if $L \leq \frac{T*n}{M*k}$ reactive can be chosen, and when $L > \frac{T*n}{M*k}$ then proactive is preferable over reactive protocol. It is reasonable that BS broadcasts/multicasts the service discovery if the ratio between D2D UEs to all UEs in a cell is high. This is in accordance to our sense because when many UEs are requesting to access or to use a service, it is better to send them a notification; so that whoever interested in that service and have subscribed for it; be aware that the service is available. However, the control overhead increases with the increase in D2D pairs requesting the service discovery in general.

In this research we try to develop the idea by combining the first two cases and suggest more other cases comparing reactive and proactive protocol. Random number of incoming D2D requests following different distribution of UEs are represented as well in this research work.

We first consider the neighborhood calculation. Secondly we consider three case cases for calculation of control overhead and compare both reactive and proactive protocols when different number of D2D pairs is presented.

- ✧ In Case I, we assume that incoming D2D requests for ProSe discovery are identically the same in different timeslots. That is the number of D2D requests is the same in each timeslot. We consider both single ($M = 1$) and multiple ($M > 1$) D2D requests within one timeslot. We calculate the how much control overhead is required for both protocols.

- ✧ In Case II, we consider random distribution of UEs and the probability of having a neighbor within the targeted distance away from a selected node is taken to account. The control overhead is calculated for both single and multiple D2D requests in terms of transmission range.

- ✧ In case III, we assume different D2D requests in different timeslots. That is the number of D2D requests is varying for each timeslot ($V(i) \sim 0 \ to \ M$) and is not the same in all timeslots. We examine the circumstances where the coming D2D requests follow different distributions depending to the network parameters such as call rate, traffic intensity, transmission distance and so on. For instance, Gaussian distribution, Exponential distribution, lognormal distribution, and Rayleigh distribution Erlang distribution are envisaged. For each distribution the analysis and formulation are provided in terms of the number of handshakes (exchanged signaling messages) and the observation period (timeslots experiencing the requests).

5.2 Neighborhood Calculation

We consider the system model in Fig.3.1 where S nodes are uniformly distributed within the cell and two nodes within the distance D can communicate with each other using D2D. We are interested in how many of them can form D2D pairs. However the distance between communicating D2D pairs can be randomly distributed, and less than the distance D can be observed as well. Given the user density parameter τ within the area of the cell, the neighborhood calculation can be done [8].

As far as proximity services are concerned, we try to define what proximity means here. When the distance d between two nodes are smaller than D (which is the targeted nearest distance), then we can say that the two nodes are in proximity with each other. The probability $P(d \leq D)$ that the nearest distance d between two nodes forming the D2D pair is shorter than or equal to the targeted distance D within a given area is shown in Eq. (5.1). In other words, this is a probability that a UE has at least one nearest neighbor in D meters.

$$P(d \leq D) = 1 - e^{-\tau * \pi * D^2} . \tag{5.1}$$

If we pick up randomly n UEs and we calculated how many k users have at least a neighbor which is located D meters away from the selected node. These k UEs can form D2D pairs and we need to know how many D2D UEs can be found in that area considered. The binomial distribution expresses the number of possible ways to choose k “successes” from n observations [9]. However we need to take in consideration also the nearest distance probability. The probability $\mathrm{P}(k)$ that among randomly n users picked up, k users have at least a neighbor within D meters is given in Eq. (5.2).

$$\mathrm{P}(k) = 1 - \sum_{j=0}^{k} \binom{n}{j} (1-p)^{j}\, p^{n-j}, \tag{5.2}$$

where $j = 1,2,3, \ldots.$ up to k, and $p = 1 - P(d \leq D)$ which refers to the probability that there is no nearest neighbor within D meters. The number of D2D UEs within a certain transmission range with respect to the probability they have, is related to the number of D2D pairs which can be used in different cases. Table 5.1 shows the configuration parameters used for simulation.

Table 5.1 Parameters for random distribution of UEs where some use D2D communication.

Parameters	*Symbol*	*Value*
Number of all UEs in a Cell	S	100
Number of users pickup randomly	n	100
Cell radius	r	$1\ km$
Number of possible D2D UEs	k	$2,4,6,8,10,12\ and\ 30$
Targeted distance	D	$0\ to\ 100\ m$
Timeslot for requests	L	2
Number D2D pairs	M	$1, 2,3,4, 5,6\ and\ 15$
Number of current observed D2D users	j	$1\ to\ k$

The trends in curve indicating how many D2D UEs can be found considering different targeted distance D is illustrated in Fig.5.1 with respect to network parameter described in Table 5.1.

The number of D2D users increase with the increase in transmission range. That means if we increase the transmission range, according to the user distribution within the cell, more we can we find more D2D pair, and if they can easily discover each other, they may communicate through D2D link.

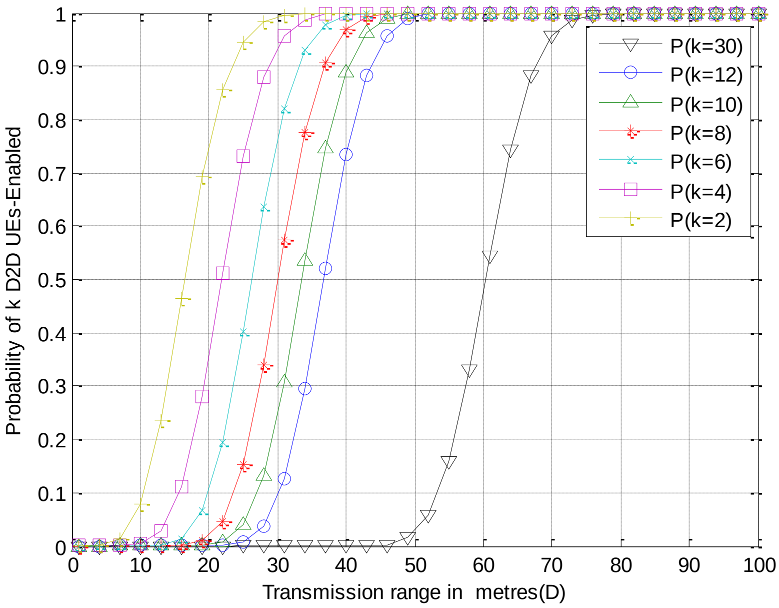


Fig.5.1 Probability function for random distribution of D2D UEs.

In general for a fixed transmission range, we can know how many D2D UEs can communicate with a certain chance of having a successful D2D link corresponding to a high probability. If the transmission range D increases, then the number of UEs forming D2D pairs increases. For instance, when D=40m, we can find 10 out of 100UEs who can form D2D links with probability of more than 90% $(P(k) > 0.9)$. Successful D2D link will depend to how much higher is the probability in correspondence of a certain value of the targeted distance.

5.3 Case I: Single and Multiple D2D Pairs Requests

In this case, we assume that same number of D2D pairs can request the ProSe discovery in each timeslot. The control overhead for reactive and proactive protocols is calculated according to Eq. (5.3) and Eq. (5.4) respectively. We take in consideration the number of D2D pairs and the number of available timeslots in which we experience the D2D request.

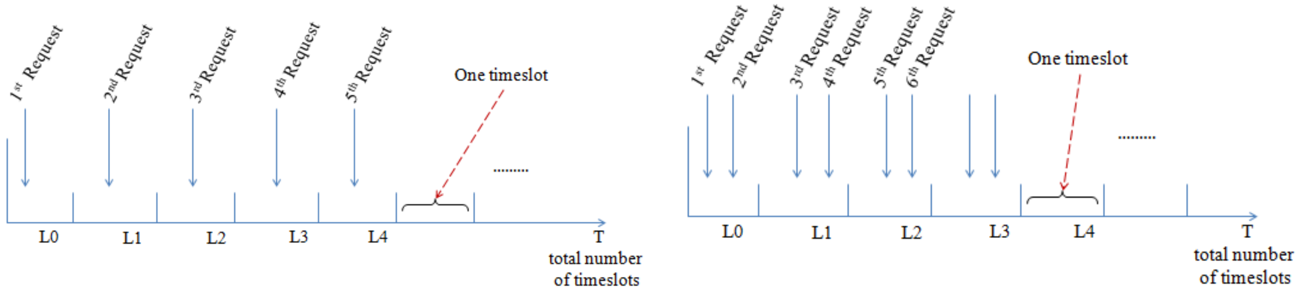
$$\mathrm{OH}_I^{re} = \frac{7*L*M}{T} \tag{5.3}$$

$$\mathrm{OH}_I^{pr} = \frac{T+6*L*M}{T}\ , \tag{5.4}$$

where $L \leq T$ describes the number of timeslots in which we experience D2D ProSe discovery requests. The number of D2D pairs requesting the ProSe discovery is given by $M = 0,1,2,3, \ldots$. We consider the case of single request per timeslot where $M = 1$ and multiple requests within one timeslot for $M > 1$. However for simplicity, we assume that M is fixed and identical in each timeslot. This means if $M = 2$, then we assume that the incoming requests for each timeslot are two pairs identically.

5.3.1 Network configuration for Case I

Here we assume that one and/or more than one D2D requests can happen in one timeslot as shown in Fig.5.2. If the number of requests/timeslot increases, we can compare the two protocols using MATLAB simulation environment results. The number of D2D pairs in one timeslot is recorded for each timeslot up to 20 timeslots.



a) b)

Fig.5.2 D2D requests for service discovery a) single D2D request/timeslot & b) multiple D2D UEs requests/timeslots.

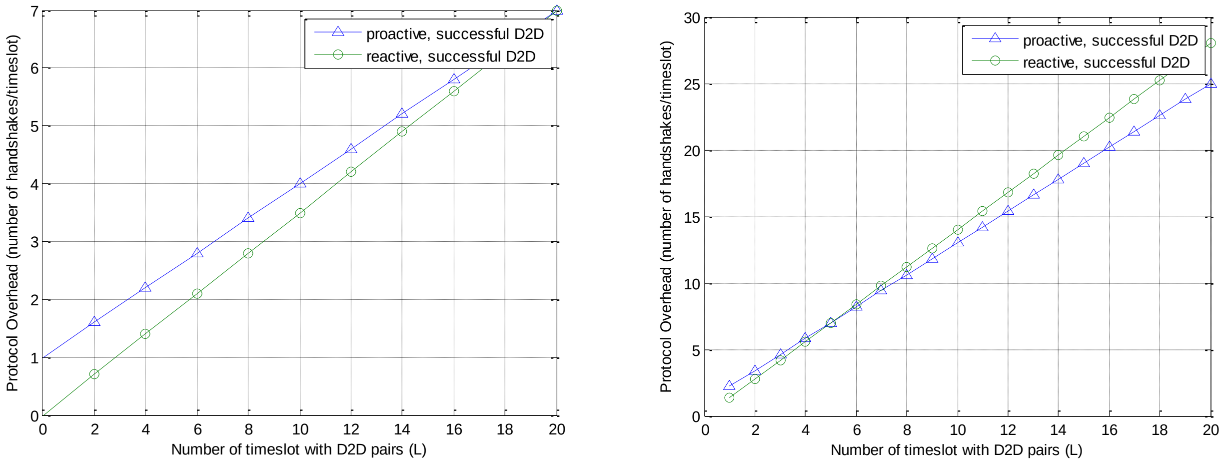
Table 5.2 shows the parameters used in order to plot the graph showing the variation of control overhead for both protocols.

Table 5.2 Parameters for control overhead for Case I.

Parameters	*Symbol*	*Value*
Number of D2D pairs	M	$1\ and\ 4$
Period (total number of timeslots)	T	20
Timeslot for requests	L	20
Number of all UEs	n	100
Number D2D UEs	k	$2\ and\ 8$

5.3.2 Results for Case I

Fig.5.3a and 5.3b show the comparison between reactive and proactive protocols with respect to the number of timeslots which experience the requests.



a) b)

Fig.5.3 Control overhead for T=20 a) single D2D request/timeslot with M=1 & b) multiple D2D requests/timeslot with M=4.

In accordance to the relationship between Eq. (5.3) and Eq. (5.4); we can see that when $L \leq T$, reactive protocol performs better than proactive protocol otherwise proactive is preferable over reactive protocol. The trend in curves is shown in Fig.5.3a when $M = 1$, and the lower the control overhead, the better is the protocol. For few numbers of D2D pairs we can easily observe that it is more beneficial to use reactive protocol since few handshakes are exchanged among the involved devices and the BS. As the number of D2D pairs requesting the service discovery increases, BS needs to send an advertisement to all UEs. In this case proactive protocol begins to exhibit its advantage over its reactive counterpart.

As can be observed in Fig.5.3b with $M = 4$ proactive protocol generates lower control overhead if D2D requests happen in greater than 7 out of 20 timeslots. In general, if $L \leq \frac{T}{L}$ reactive protocol performs better. Otherwise proactive protocol is recommended.

5.4 Case II: Random Distribution of Users

In this case, the probability in Eq. (5.2) is also used to calculate the control overhead as shown in Eqs. (5.5) and (5.6). UEs exchanging discovery messages should first have a high probability of having their neighbors within D meters. Both the number of D2D UEs with neighbors in D meters and the effect of the number of timeslots having D2D requests are taken in consideration.

$$\mathrm{OH}_{II}^{re} = \frac{7*P(k)*k*L}{T} \tag{5.5}$$

$$\mathrm{OH}_{II}^{pr} = \frac{T+6*P(k)*k*L}{T}. \tag{5.6}$$

In previous case (Case I) we compared the two protocols in terms of control overheard versus the number of D2D pairs. In this case, we still consider that D2D requests may happen in L out T timeslots, but only among these k devices which are D meters away from each other. The number of D2D UEs is fixed and the total observation period T is fixed. We present the results for single request in one timeslot and for multiple requests in one timeslot.

5.4.1 Network configuration parameters for Case II

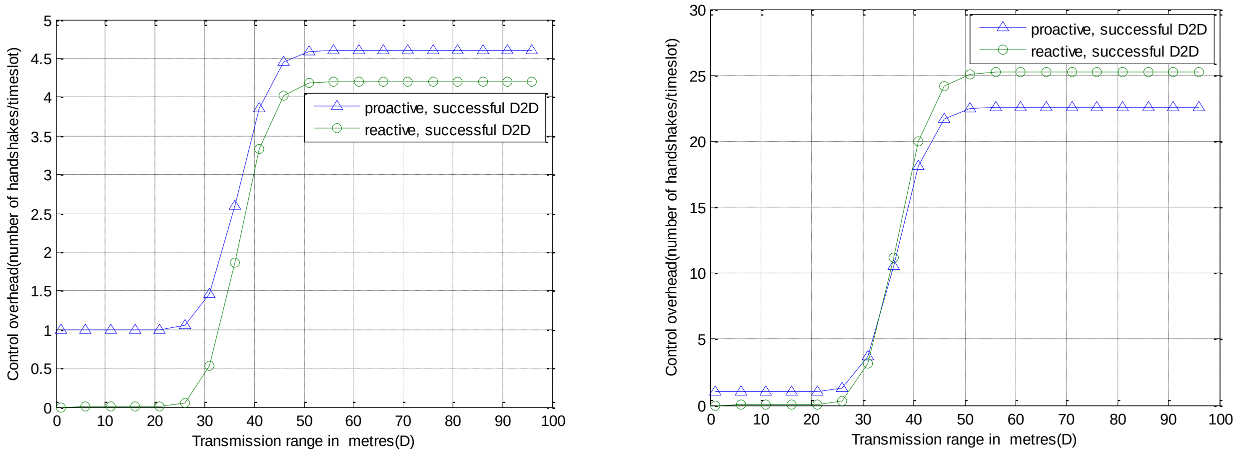
Parameters in Table 5.3 are used to implement the results. The control overhead is calculated with respect to the number of D2D UEs and the distance between them. The target distance D varies from 1 to 100 m and since a fixed D2D UEs number corresponds to a certain distance is taken into account; we only compare the case where $k = 12$ and for $L = 1$ and $L = 6$ corresponding to 40m target distance with a target probability higher than 0.9 as shown in Fig. 5.4.

Table 5.3 Parameters for random distribution of D2D communication for Case II.

Parameters	*Symbol*	*Value*
Number of all UEs in a Cell	S	100
Number of users picked-up randomly	n	100
Cell radius	r	$1\ km$
Number of timeslots experiencing requests	L	$1\ and\ 6$
Number of D2D users	k	12
Target distance	D	$1\ to\ 100\ m$
Target probability	$P(k)$	0.90
Period (total number of timeslots)	T	20

5.4.2 Protocols comparison results for Case II

The curves in Fig. 5.4 show the variation in control overhead for both reactive and proactive protocols with respect to the targeted distance. Single and multiple requests per timeslot are presented.



a) b)

Fig.5.4 Control overhead versus transmission range for a) single D2D request/timeslot with L=1 & b) multiple D2D requests/timeslot for L=6.

As illustrated in Fig.5.4, the larger the distance D, the higher the probability to find a given number of D2D pairs. Given $n = 100$ and $D = 40$ meters, the probability to find 12 and 10 neighbors is 73 and 89% respectively. We adopt these values for our simulations in this case and the results are plotted in Figs.5.4a and 5.4b respectively. For single request per timeslot, reactive performs better than proactive when there are fewer number of D2D UEs presented within D meters, as shown in Fig.5.4a. In case of multiple requests per timeslot, proactive is preferable as shown in Fig.5.4b. Using the proactive protocol, the uplink D2D service request step could be skipped by UEs, resulting in lower overhead when there are a large number of D2D requests. Comparing Fig.5.4a and Fig.5.4b, the control overhead is much higher in Fig.5.4b, due to the fact that there are many UEs requests and many resource blocks are required for ProSe discovery.

Finally, the curves show that when D is too small, no D2D peer can be found in the vicinity. Correspondingly, the overhead for reactive is zero since D2D is not possible under this situation. However, a small amount of overhead is nevertheless needed for proactive discovery since the BS is still disseminating the ProSe advertisement periodically.

5.5 Case III: Different D2D Pairs Requests in Different Timeslots

In this case, we assume that more than one D2D requests can happen in one timeslots and the incoming requests are varying in different timeslots as shown in Fig. 5.5. That is the number of D2D requests is varying for each timeslot ($V(i) \sim 0 \ to \ M$). For example, we can have two D2D requests in the first timeslot and in the second timeslot, four or five D2D requests can be observed. Therefore, the number of D2D users in each timeslot is changing and the UEs which are not served in a certain timeslot, they can still attempt to be served and send requests in a next timeslot. We investigate which distributions, the D2D requests can follow depending on how much traffic they are generating. The distance between the communicating UEs and which parameters required are studied both in time, space and frequency.

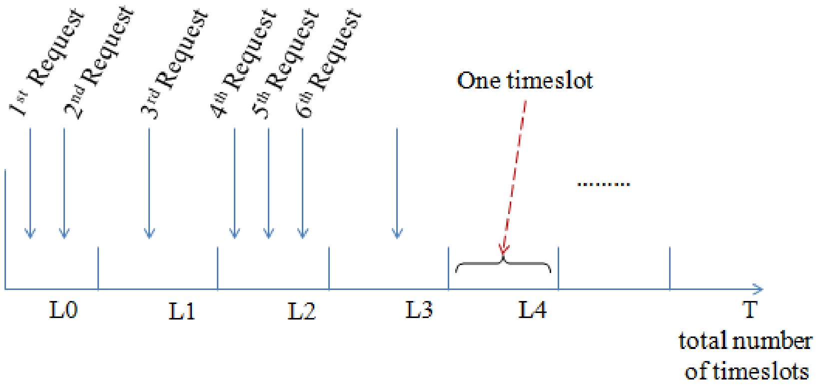


Fig.5.5 Different D2D requests for service discovery in each timeslot.

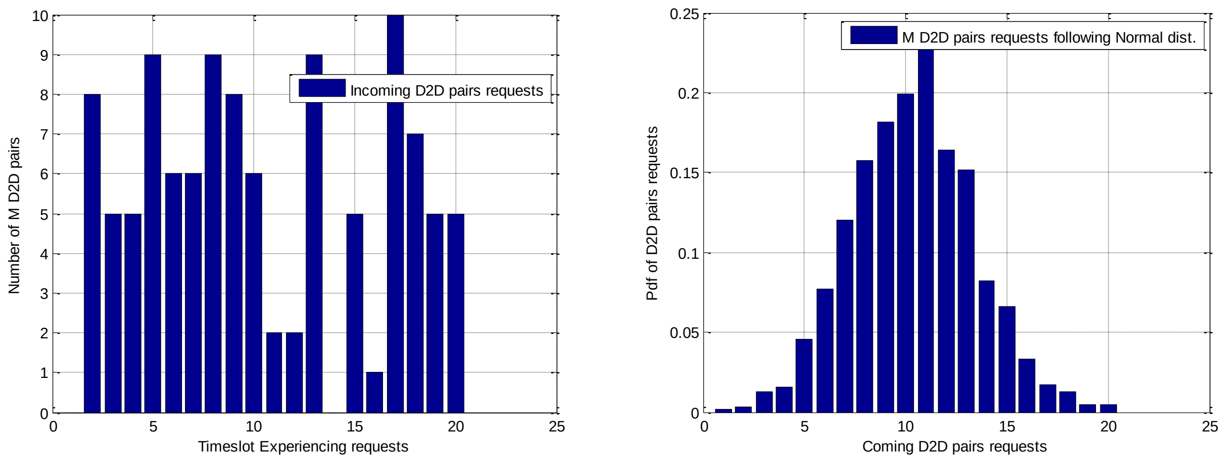
We envisage Gaussian distribution, Exponential distribution and lognormal distribution as well as Rayleigh distribution and Erlang-k distribution for different D2D requests. For each distribution we generate random incoming request in each timeslot and the control overhead is calculated in terms of incoming D2D requests and probability function of each distribution.

5.5.1 Case III.a: D2D pairs requests follow Gaussian distribution

Gaussian distribution is strongly related to the traffic events with the probability of an observation that fall between any two values, the mean and the variance. We assume M D2D pairs which are distributed within the cellular network including other cellular UEs communicating through the BS. These M pairs are not generating the same traffic always. It is varying within different timeslots. Let V be the number of random D2D request in each timeslot. The probability that D2D requests follow the Normal (Gaussian) distribution is given in Eq. (5.7). Fig. 5.6 shows the random incoming D2D requests and the probability density function for a big sample following Gaussian distribution for M D2D pairs with respect to Eq. (5.7).

$$P(n|V) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(V-\mu)^2/2\sigma^2}, \tag{5.7}$$

where μ is the *mean* of the incoming requests and σ^2 is the *variance* of the normal Gaussian distribution. The number of incoming request is within the interval $[0 \ M]$ and is denoted V.



a) b)

Fig.5.6 Random incoming D2D requests a) different D2D in each timeslot b) pdf for these D2D requests following Gaussian distribution.

From Fig.5.6a we can observe that we have different D2D request in different timeslots. For instance in timeslot number 10 we have 6 D2D requests for ProSe discovery whereas in timeslot number 14 we experience 0 D2D request. When we take a big sample of possible M D2D pairs ($M = 1000$) we can simply see that they follow Gaussian distribution as shown in Fig. 5.6b. Based on this analysis we calculate the control overhead for the designed protocols when the incoming M D2D requests is varying. In Eq. (5.8) and (5.9) the calculation of control overhead for both reactive and proactive protocols is given. Note that Gaussian probability function for M D2D pairs is reflected in since $V(i)$ describes the number of incoming D2D pairs in each timeslot generated randomly with Gaussian distribution. The number of signalling messages for each protocol is also reflected in.

$$\mathrm{OH}_{III.a}^{re} = \sum_{i=0}^{T} \frac{7*V(i)}{T} \tag{5.8}$$

$$\mathrm{OH}_{III.a}^{pr} = \frac{T+\sum_{i=0}^{T} 6*V(i)}{T}\ , \tag{5.9}$$

where, $V(i)\sim 0 \text{ to M}$ denotes the number of random incoming requests for ProSe discovery in each timeslot L experiencing the requests and L varies from i to T.

The following table shows the parameters used in order to plot the graph showing the variation of control overhead for both protocols.

Table 5.4 Parameters for Gaussian distribution of D2D UEs requesting for neighbor discovery, Case III.a.

Parameters	*Symbol*	*Value*
Number of D2D pairs	V	$Normal\ Random\ [0\ to\ M]$
Period (total number of timeslots)	T	20
Number of time experiencing requests	L	$i\ to\ T$
Mean	μ	10
Variance	σ^2	2
Number iterations	i	$0\ to\ T$

Fig.5.7 shows the comparison between reactive and proactive protocols while the number of D2D requests for each timeslots is varying and follow Gaussian distribution.

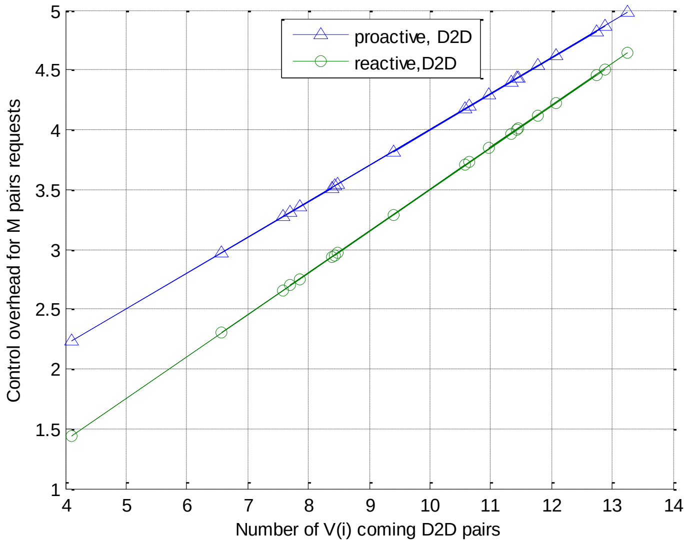


Fig.5.7 Control overhead for different D2D requests with Gaussian distribution.

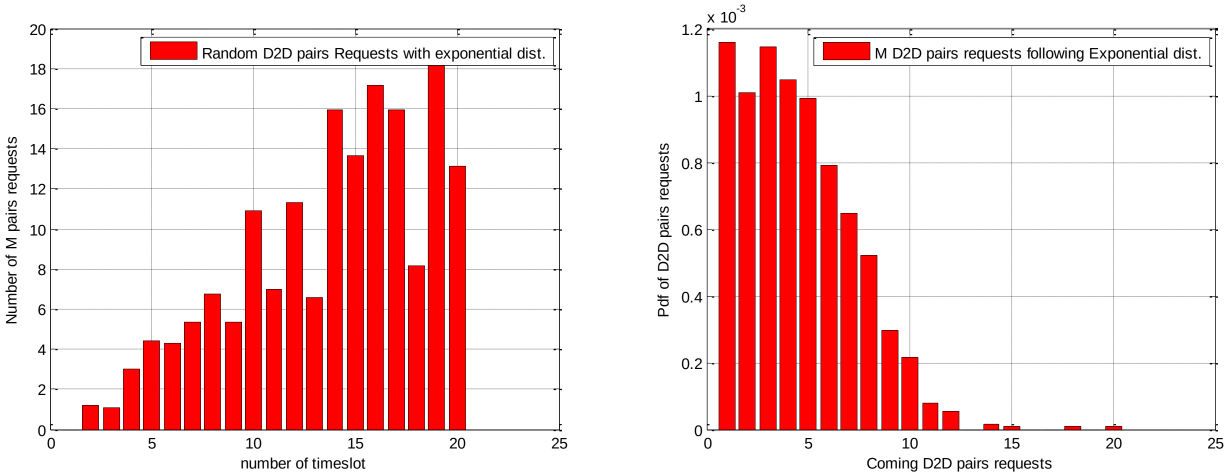
The observation of the plotted results is that reactive protocol always performs better than proactive. This is because requests are generated randomly and for instance there are few requests for ProSe discovery (maximum total D2D requests are 14). When the maximum number of D2D pairs requesting ProSe discovery is less than 20 (since we used T=20 timeslots), in this case reactive performs well. In other words, it is important that the BS does not waste its resources by sending a periodic broadcast message to all UEs while there are few UEs interested in D2D communication; instead the BS can wait and serve a request which arises. However if the number of requests increases at a high rate, then proactive protocol outer performs over reactive protocol. The highest control overhead is observed when we have many requests corresponding to the highest probability of Gaussian distribution function.

5.5.2 Case III.b: D2D pairs requests follow Exponential distribution

In network traffic analysis, call inter-arrival time is exponentially distributed [32]. Exponential distribution is described as one of the mathematical model which fits the real data [33]. In this section we assume that the incoming D2D UEs requesting the ProSe discovery in different timeslots follow Exponential distribution with respect to Eq. (5.10) describing the probability density function (pdf). The results are plotted in Fig. 5.8 below representing the number D2D pairs requesting the service discovery in each timeslot.

$$P(\rho) = \rho e^{-\rho t} \tag{5.10}$$

Where ρ describes a *holding parameter* in the sense that if a random variable X is the duration of time that a given call system manages to last and $X \sim Exp(\rho)$ then the expected value is $E[X] = \rho$. That is to say, the expected duration of the system service is ρ units of time. This is inversely proportional to the *rate* parameter which arises in the context of events arriving at a rate λ, when the time between events (which might be modelled using an exponential distribution) has a mean of $\rho = \lambda^{-1}$. In Eq. (5.10), t represents the time which reflects to the number of timeslots in our study. The Number of random D2D requests in different timeslot is illustrated in Fig.5.8a and we can see that these requests follow Exponential distribution in Figure 5.8b where a sample of $V = 500$ is used to generate random distribution.



a) b)

Fig.5.8 Random incoming D2D requests a) different D2D in each timeslot b) pdf for these D2D requests following Exponential distribution.

The control overhead is calculated taking in account the exponential distribution function in Eq. (5.10) included in $V(i)$ which indicates the calculation of random D2D requests with Exponential distribution. Eqs. (5.11) and (5.12) show the calculation of control overhead for reactive and proactive protocols respectively.

$$\mathrm{OH}_{III.b}^{re} = \sum_{i=0}^{T} \frac{7*V(i)}{T} \tag{5.11}$$

$$\mathrm{OH}_{III.b}^{pr} = \frac{T+\sum_{i=0}^{T} 6*V(i)}{T}, \tag{5.12}$$

Where $V(i) \sim P(\rho)$ with random integers generated with Exponential distribution. The main job here is to know which protocol can be used when a number of D2D UEs are requesting the ProSe discovery. Table 5.5 shows all configuration parameters used for plotting the results.

Table 5.5 Parameters for Exponential distribution of D2D UEs requesting for neighbor discovery, Case III.b.

Parameters	*Symbol*	*Value*
Number of D2D pairs	$V(i)$	$Random\ [0\ to\ M]$
Period (total number of timeslots)	T	20
Timeslot for requests	L	$i\ to\ T$
rate	λ	$1\ to\ 19$
Number iterations	i	$0\ to\ T$

Fig.5.9 shows the changes in curves when different D2D users are used as described in Table 5.5. The figure plots the number of D2D requests versus the total number of incoming D2D UES. The parameters used are relevant to the system model with the probability function of the Exponential distribution corresponding to curves given in Fig.5.8.

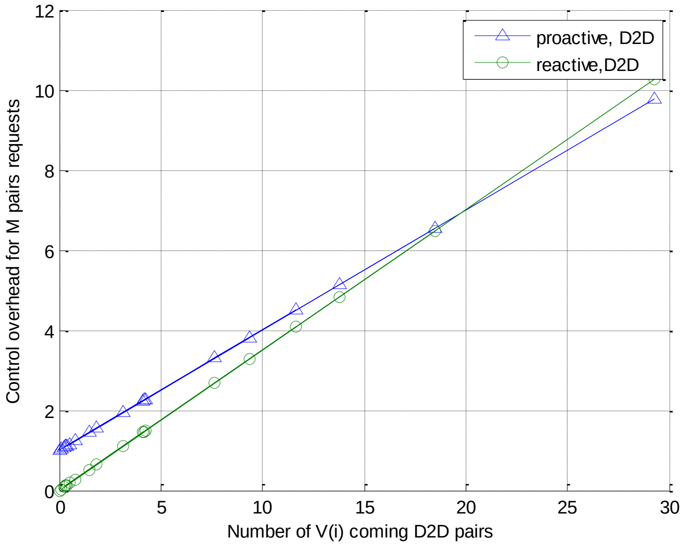


Fig.5.9 Control overhead for different D2D requests with Exponential distribution.

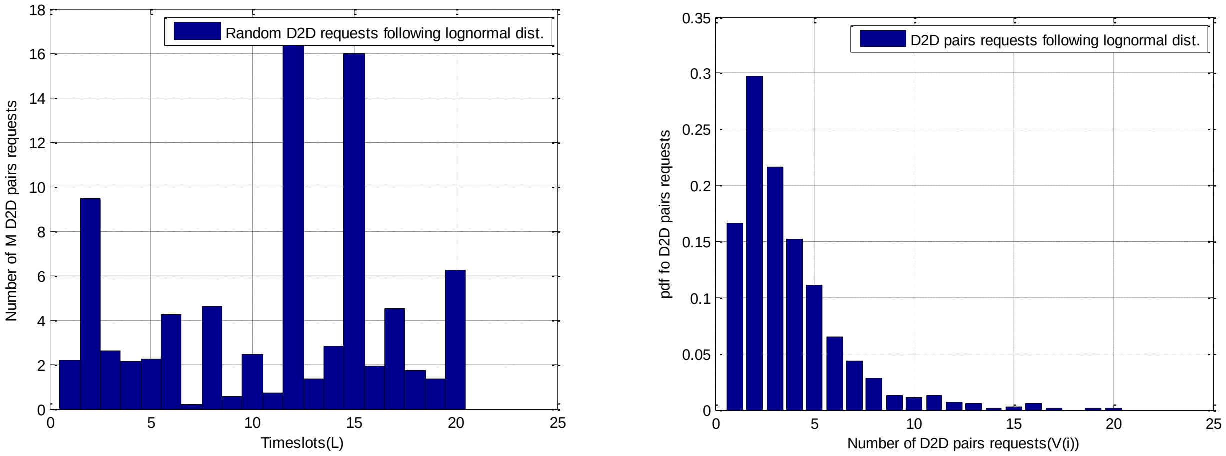
The resulting curves show that as long as the number of D2D is less than 20 (equivalent to the case of at most one request per timeslot) reactive is preferred. Once the number of D2D requests increases, for instance $V(i) > 20$ proactive protocol outperforms than reactive protocol. Due to this behaviour, BS helps the UE to skip the uplink resources and directly assists them for service discovery, which is shown by the proactive curve with less control overhead than reactive after 20 requests.

5.5.3 Case III.c: D2D pairs requests follow Lognormal distribution

The call holding time in network traffic fits the lognormal distribution [32]. The D2D requests for ProSe discovery may follow the lognormal distribution based on the holding time a request can last and how many of them requesting the ProSe discovery in a given timeslot. In most of the candidate functions in [33], lognormal-3 distribution has proven to have the best fitting to the real data. The behaviour of the lognormal distribution can be shown in Fig. 5.10 with respect to the probability density function in Eq. (5.13).

$$P(t) = \frac{1}{t\sigma\sqrt{2\pi}} e^{-(\ln(t)-\mu)^2/2\sigma^2}, \tag{5.13}$$

Where μ and σ are the mean and variance of the lognormal distribution and t describes the parameter of time for the incoming requests. For the inter-arrival time, if the lognormal distribution is used as an approximating function to predict the number D2D requests for ProSe discovery occurring after a given time the lognormal gives more accurate data than the exponential distribution. The number of incoming $V(i)$ D2D requests in different timeslots following lognormal distribution and their histogram are illustrated in Fig. 5.10.



a) b)

Fig.5.10 Random incoming D2D requests a) different D2D in each timeslot b) pdf for these D2D requests following Lognormal distribution for $\boldsymbol{\mu = 0.8432}$ and $\boldsymbol{\sigma^2 = 0.7147}$.

To compare the two protocols, the control overhead is calculated taking in account the lognormal distribution reflected in $V(i)$. Eqs. (5.14) and (5.15) show the calculation of control overhead for reactive and proactive protocols respectively.

$$\mathrm{OH}_{III.c}^{re} = \sum_{i=0}^{T} \frac{7*V(i)}{T} \tag{5.14}$$

$$\mathrm{OH}_{III.c}^{pr} = \frac{T+\sum_{i=0}^{T} 6*V(i)}{T}\ , \tag{5.15}$$

The number of random D2D is following lognormal $V(i) \sim P(t)$. The network parameters are presented with respect to lognormal distribution with mean and variance in Table 5.6.

Table 5.6 Parameters for Lognormal distribution of D2D UEs requesting for neighbor discovery, Case III.c.

Parameters	*Symbol*	*Value*
Number of D2D pairs	M	$Random\ [0\ M]$
Period	T	20
Timeslot for requests	L	$i\ to\ T$
Time parameter	t	$1\ to\ 18$
Mean	μ	0.8432
Variance	σ^2	0.7147
Number iterations	i	$0\ to\ T$

Fig. 5.11 shows the trend in curves when different D2D users are requesting the service discovery randomly in different timeslots as described in the Table 5.6. The figure plots the control overhead versus the number of incoming D2D requests. The parameters used are relevant to the Fig. 5.10 describing the lognormal distribution and the curves are plotted comparing reactive and proactive protocols.

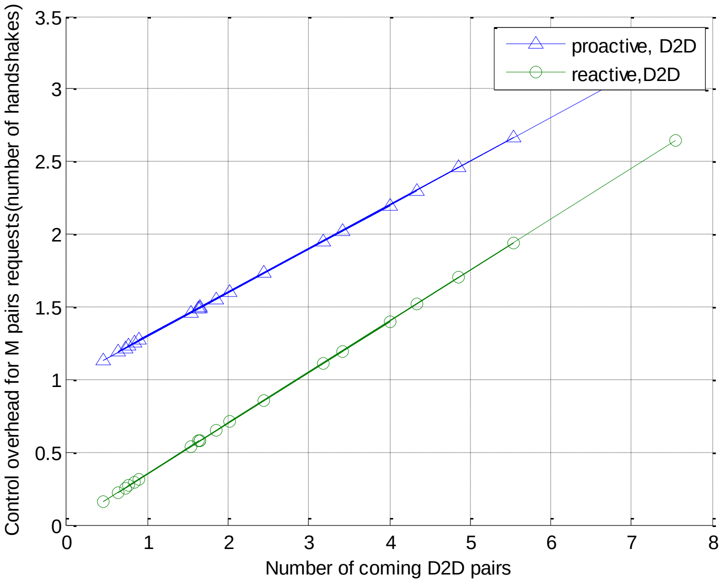


Fig.5.11 Control overhead for different D2D requests with Lognormal distribution.

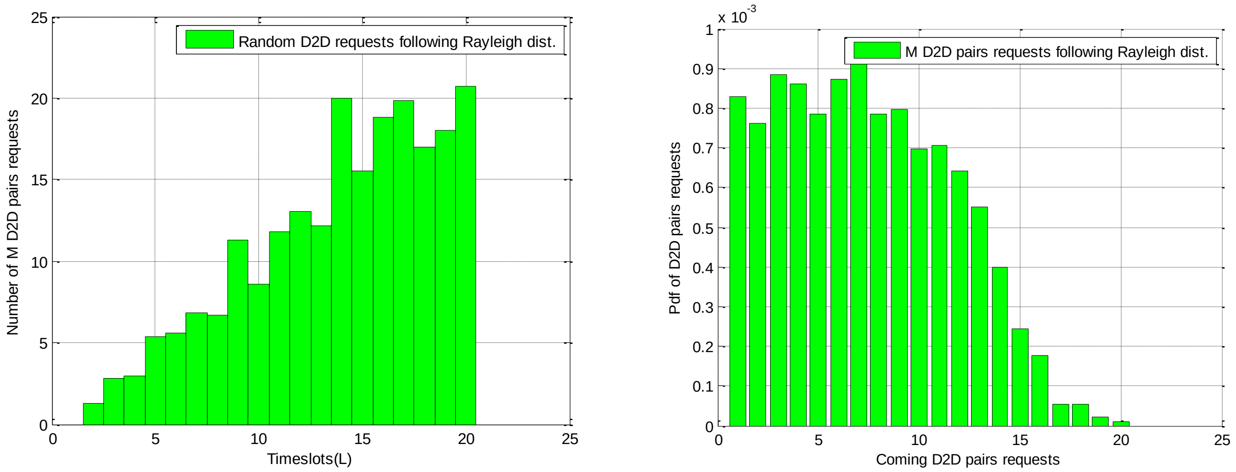
Comparing the two curves, we can simply observe that reactive always outperforms over proactive as along we have few D2D requests which are interested in D2D communication. For example the number of incoming D2D requests appearing frequently does not exceed eight (see Fig. 5.10a) even if sometimes we can suddenly have more than eight (For example in Fig.5.10a, timeslot 12 we observe 16 D2D requests), we observe few requests. That is why reactive protocol remains the best choice. This also results in lower control overhead. However, if the total number of D2D requests becomes more than 20, then proactive will be better choice than reactive protocol. Another observation is that as the number of D2D requests increases, the required control overhead increases as well. In accordance to lognormal distribution, the pdf reduces with the increases of the concerned time parameter. This is equivalent in our case to the holding time of D2D UEs, if it increases more we will have less probability of having many D2D pairs.

5.5.4 Case III.d: D2D pairs requests follow Rayleigh distribution

For the UEs to exchange discovery messages they have to be in proximity. Thus the distance between them needs to be modeled by allowing other assumptions as well rather than only uniform distribution. Since there is no commonly agreed D2D distance distribution exists [34], for concreteness we can assume that the targeted distance D of a typical potential D2D pair is Rayleigh distributed with probability density function (pdf) given by Eq. (5.16). We assume that for the UEs to be involved in successful discovery they have to be within the targeted distance. Therefore, the number D2D requesting the service discovery on the other hand follows the Rayleigh distribution.

$$P_D(x) = 2\pi\tau x e^{-\tau\pi x^2}, \tag{5.16}$$

where, τ describes the density when the transmitting UEs are Poisson point process (PPP) distributed; and D represents the distance from a typical UE to its nearest neighboring UE. Further, this Rayleigh distribution to some extent agrees with the statement that the larger the UE density, the closer the targeted receiver may be. The random incoming D2D requests following Rayleigh distribution and their pdf when many observation samples are used is shown in Fig. 5.12.



a) b)

Fig.5.12 Random incoming D2D requests a) different D2D in each timeslot b) pdf for these D2D requests following Rayleigh distribution.

In fact the idea is that we take random D2D UEs separated within a distance D and are generating different requests for ProSe discovery. The control overhead is calculated taking into account the random D2D requests and a function of the Rayleigh distribution. Eqs. (5.17) and (5.18) show the calculation of control overhead for reactive and proactive protocols respectively.

$$\mathrm{OH}_{III.d}^{re} = \sum_{i=0}^{T} \frac{7*V(i)}{T} \tag{5.17}$$

$$\mathrm{OH}_{III.d}^{pr} = \frac{T+\sum_{i=0}^{T} 6*V(i)}{T}\ , \tag{5.18}$$

where $V(i) \sim P_D(x)$, follow Rayleigh distribution. We assume that the UEs located within distance D can request the services discovery when the proximity condition is fulfilled. To know which protocol can be used when a number of D2D UEs are requesting the ProSe discovery we set the network parameters presented in Table 5.7.

Table 5.7 Parameters for Rayleigh distribution of D2D UEs requesting for neighbor discovery, Case III.d.

Parameters	*Symbol*	*Value*
Number of D2D pairs	V	$Random\ [from\ 0\ \ to\ M]$
Period (total number of timeslots)	T	20
Timeslot for requests	L	$i\ to\ 17$
Density rate parameters	τ	2
Number iterations	i	$0\ to\ T$

The changes in curves when D2D UEs are requesting the ProSe discovery are shown in Fig. 5.13. The figure plots the control overhead versus the incoming D2D requests. The random number generated with Rayleigh distribution is used for the calculation of the control overhead and the comparison between reactive and proactive protocol is presented.

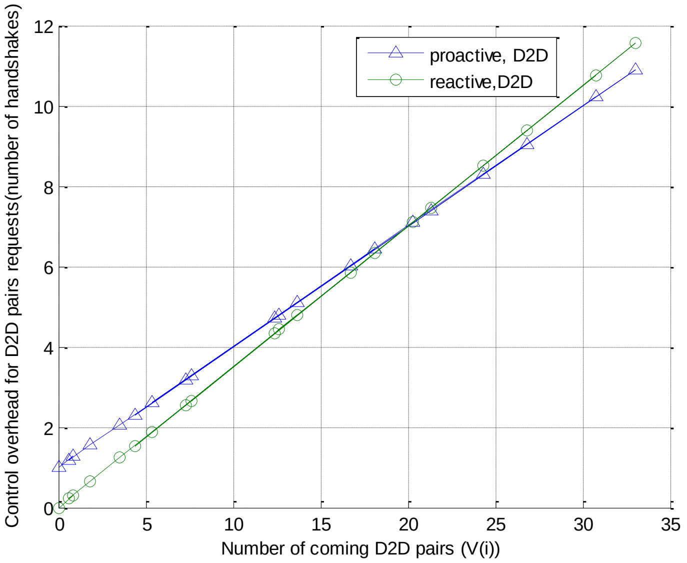


Fig.5.13 Control overhead for different D2D requests with Rayleigh distribution.

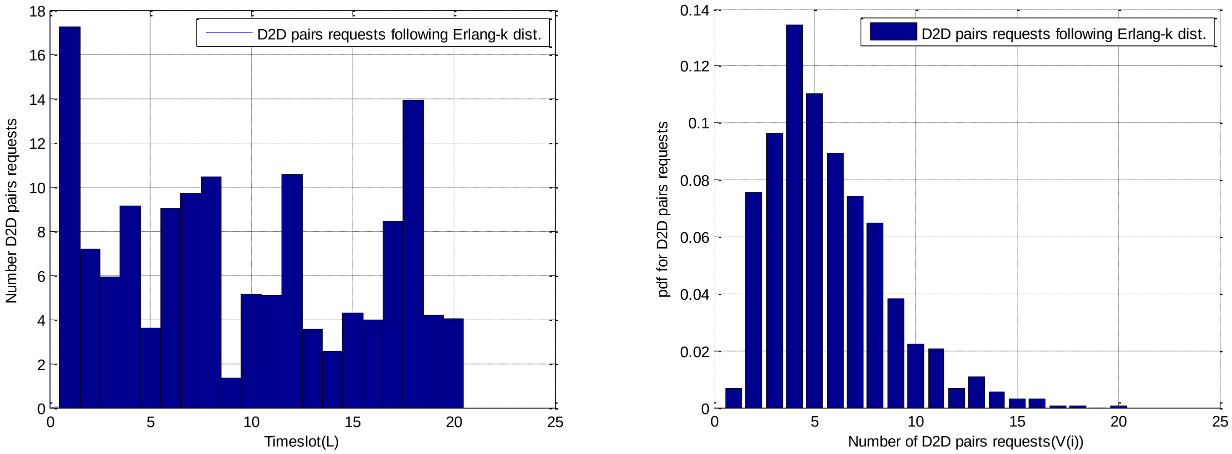
As we can observe in Fig.5.13, when the number of incoming D2D requests is less than 20, reactive protocol outperforms than proactive protocol. On the other hand, if the potential D2D UEs requesting the service discovery are increased proactive protocol performs well than reactive. When the number of requests increases as curves can show, the required overhead is high compared to the case with less number of D2D requests. When the targeted distance follows Rayleigh distribution, and the criterion for proximity for D2D communication is fulfilled more D2D UEs can request the ProSe discovery. In this case it is good to use proactive protocols for ProSe discovery and D2D link establishment so that the uplink resources are reserved for other cellular UEs.

5.5.5 Case III.e: D2D pairs requests follow Erlang-k distribution

Assuming Erlang-k distribution, with an arrival rate parameter of D2D request equals λ. This distribution is usually used to examine the number of call arriving at the same time. Therefore, it is strongly related to our assessment of the number of D2D requests coming in each timeslot at the same time. The numbers of D2D requests in each timeslot are still randomly generated as shown in Fig.5.14a and its pdf is given in Fig.5.14b with respect to Eq. (5.19). Note that to avoid parameters conflict we use m instead of k and the same idea holds and other parameters remain unchanged.

$$P(x) = \lambda^m \frac{x^{m-1} e^{-\lambda x}}{(m-1)!} \ , \tag{5.19}$$

where m represents shape parameter which is a positive integer and λ is rate parameter which is a positive real number. In the above equation x describes a set of positive value greater than zero. It represents the number of D2D requests which is equivalent to $V(i)$.



a) b)

Fig.5.14 Random incoming D2D requests a) different D2D in each timeslot b) pdf for these D2D requests following Erlang-k distribution.

The control overhead for both reactive and proactive protocols are calculated in Eq. (5.20) and Eq. (5.21) respectively. The number of D2D requests following the Erlang-k distribution is taken in consideration together with the number of signalling messages with respect to both protocols.

$$\mathrm{OH}_{III.e}^{re} = \sum_{i=0}^{T} \frac{7*V(i)}{T} \qquad (5.20)$$

$$\mathrm{OH}_{III.e}^{pr} = \frac{T+\sum_{i=0}^{T} 6*V(i)}{T}\ , \qquad (5.21)$$

where, $V(i) \sim P(x)$ denotes the number of D2D requests which are generated randomly. The simulation results are shown in Fig.5.15 with respects to the configuration parameters given in Table 5.8.

Table 5.8 Parameters for Erlang-k distribution of D2D UEs requesting for neighbor discovery, Case III.e.

Parameters	*symbol*	*Value*
Number of D2D pairs	M	$Random\ [0\ M]$
Period	T	20
Timeslot for requests	L	$i\ to\ T$
Time parameter	t	$1\ to\ 20$
Rate parameter	λ	4
Shape parameter	m	2
Number iterations	i	$0\ to\ T$

Th trend in curve in the following figure shows the variation in curves for both reactive and proactive protocols.

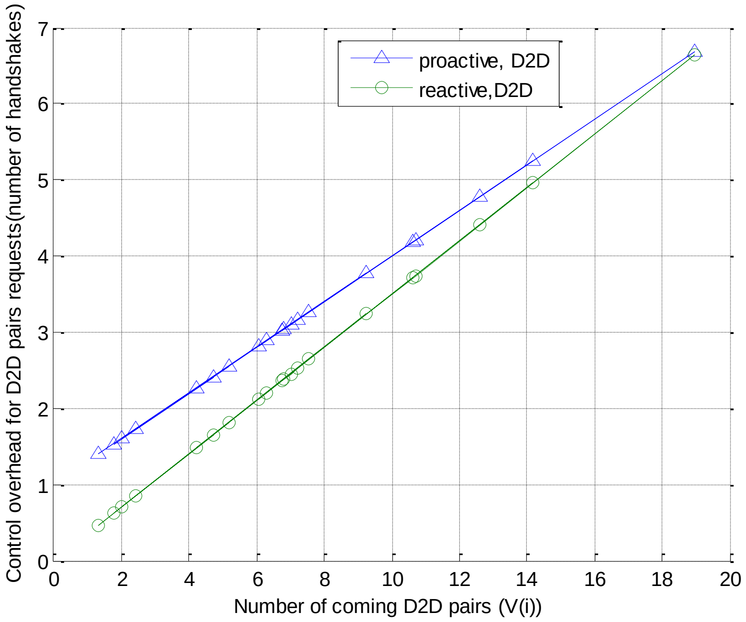


Fig.5.15 Control overhead for different D2D requests with Erlang-k distribution.

The observation from the plotted results is that reactive protocol always performs better than proactive when the number of total incoming D2D requests is less than 20. When the maximum number of D2D pairs requesting ProSe discovery is less than 20 (since we used T=20 timeslots), in this circumstances reactive performs well. However if the number of total requests increases at a high rate, then proactive protocol will generates lower overhead than reactive and in this situation proactive will be recommended.

5.6 Chapter Summary and Discussion

In this chapter we analysed the designed protocol in terms control overhead. In the two first cases, a number of fixed D2D requests in each timeslot were considered and both single and multiple requests were analysed.
In Case I, we analyze the control overhead versus the number of incoming D2D requests per timeslot. The results showed that reactive protocol performs well when there are few D2D requests per timeslot, otherwise proactive is recommended. In Case II, the control overhead was calculated in function of the transmission range. Results showed that reactive performs better than proactive when there is a few number of D2D requests presented within D meters. This is a single request per timeslot. In case of multiple requests per timeslot, proactive performs well and high control overhead is required in such situation. In Case III, D2D requests are generated randomly in each timeslot and are following different distributions. The main question here is why did we choose these distributions not others? What is their degree of fitness to our protocols designed?

We based on the fact that the considered distributions fit the real data that have been taken for cellular traffic as shown in [33]. However the normal distribution gives the better understanding of the model of event that falls between two values, the mean and the variance. Thus it has been used here to model the number of D2D requests, when these requests are falling in between two values. Results showed that, the control overhead is high when there are many requests and when these requests are few, reactive performs better than proactive protocol.

In cellular network traffic analysis, call inter-arrival time is exponential distributed [32]. For the real data analysis, different functions need to be taken into consideration to fit the information regarding the call duration and the arrival time in real experiments. The exponential distribution was one of the mathematical model used that fit the real data, as shown in [33]. Our results show that it gives as well good fitting since when the total D2D requests are few(<20 D2D requests) reactive generates low control overhead otherwise proactive have low overhead. And this is in accordance to our sense. The call holding time in network traffic fits the lognormal distribution [32]. In most of the candidate functions in [33], lognormal-3 distribution has proven to have the best fitting to the real data. Our results also show that it can give a good prediction of which protocol is recommended. For instance, reactive was generating low control overhead since there were few requests generated according to lognormal distribution, therefore it is recommended. Rayleigh distribution was used to model the distance between two nodes in proximity as shown in [34], Rayleigh distribution gives better fitting of D2D requests when requests are from two communicating party separated by a certain targeted distance as shown in Fig.5.13. Lastly, Erlang-k distribution was considered in [33], and in fact it is usually used to model the system calls when calls are arriving with call arrival rate λ at the same time. As we can observe it in Fig.5.15, it gives a good comparison for our protocols as well.

With different assumptions that these D2D requests follow the above distributions we have got good fit and we compared our protocols based on them. Which one is better than another will depends to the number of D2D in vicinity. On one side, Exponential, Rayleigh, Erlang-k distributions generate up to many D2D requests (greater than 20) and allow a deep comparison of our protocols. On the other side, Gaussian and lognormal distribution generate few random D2D requests, and results showed that reactive performs better always that proactive. However, the curves are increasing as the number of D2D requests increases and will reach where proactive generates low overhead.

Generally, reactive performs well when there are few D2D request and when demand for D2D discovery is high then proactive is the best. However when there is no D2D request, there is no resource spent for reactive protocol, and this is a benefit as long as there is no request, there is no resource lost. On the other hand, resources are wasted when the broadcast message does not find any interested D2D UE in neighbor discover and D2D communication. Therefore, the proactive protocol curve never starts from zero, since always there is resource spent for the advertisement of service discovery, periodically, with regards to the broadcasted message regardless to whether a UE is there or not.

6 Performance Analysis of Overflowed Traffic

In cellular network when all channels are occupied the remaining UEs requesting the service are blocked. This can happen also in case of limited accessibility, where a UE has access only on a limited number of channels. The blocked traffic is known as overflowed. With Erlang loss system, blocked traffic is cleared. In this chapter we assume that these blocked UEs hang around until they are served through the D2D communication. That is blocked UEs start discovering each other and when the proximity conditions are fulfilled and neighbor discovery is successful they may use D2D links. Generated traffic is separated into traffic for Cellular UEs in inner part and traffic for D2D UEs in outer part of the cell. The blocking probability is calculated based on Binomial distribution and a comparison between reactive and proactive protocols is done. In addition, we study heterogeneous traffic where data and voice traffic are envisaged.

6.1 Call Arrivals in Different Observation Period

Assume uniform distribution of nodes and the traffic generated follow the truncated Poisson distribution with mean rate λ which is a Poisson arrival process. The number of channels (C) is limited and the service time φ which is a call completion rate following exponential distribution. The number of channel corresponds to the number of calls which can be handled by the system. Fig. 6.1 shows the system model with a number of sources (S) at the input lines and the number of output lines corresponding to the number of available channels. The number of sources is higher than the number of channels($S > C$) and is limited to S.

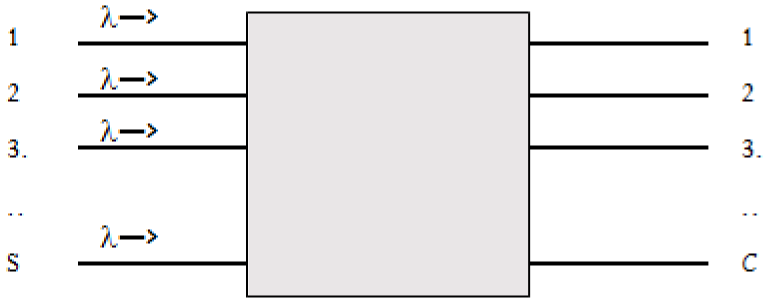


Fig.6.1 Call attempts for S sources (UEs) over C channels at the output.

For k connections in progress ($0 \leq k \leq C$) meaning that for S calls generated k calls are served, and then the number of unconnected is $S - k$. This will result in $\lambda_k = (S - k)\lambda$ total calls generation rate. Since for each call in progress is completed at rate φ then, the total call completion rate is given by $\varphi_k = k\varphi$.

Within a period T containing different observation times known as timeslots as described in previous chapters; we can observe that traffic are generated in different timeslots depending on the two parameters, calls generation rate and call completion rate. If in a given timeslot there is no idle channel, an arriving call attempts in that period will be blocked. Depending on the cell density many UEs will be blocked in different timeslots, since cellular system has limited resources. Our basic idea in this case is to allow D2D links for UEs in proximity, so that cellular congestion can be reduced. To be more specific, we proceed in two ways:

- First, we separate the available resource in two categories. A high percentage of the total resource is assigned to UEs around the BS, which can still communicate via the BS using traditional communication. The UEs in this part are called cellular UEs in inner part. Then the remaining resource is assigned to UEs located at the edges of the cell. Since this a low percentage resource, it is allocated to UEs in proximity for discovery so that they can establish D2D links. The UEs in this part are named UEs in the outer part of the cell.
- Secondly, we allow the blocked UEs to initiate the neighbor discovery with the help from the BS which coordinates this process. In this case we assume that only UEs in outer part will successfully discover

their neighbors because we reuse the system model in Section 3.2 in Fig. 3.1b; where UEs which have at least a nearest neighbor in D meters away from the selected node can form a D2D pairs. The blocked UEs in inner part will be hanging around until they are served through the BS because they do not have much chance of having a neighbor in D meters away from them.

So far we perform an evaluation by calculating the blocking probability and we as well compare reactive to proactive protocol to know which one can generates low control overhead when the blocked UEs are trying to discover each other.

6.2 Evaluation of Overflowed Traffic and Blocking Probability

6.2.1 Types of traffic considered and resource sharing

We analyse three types of traffic in order to have insight into how much traffic offered per source required and which strategy can be used to efficiently use the cellular network resources and reduce the network congestion.

- **Cellular mode traffic**: In this mode we assume that all UEs are communicating through the traditional cellular network i.e. via BS. The sources in this mode will be alternating between the idle and busy states. Normally the offered traffic per source is calculated as $a = \frac{\beta}{1+\beta}$, where $\beta = \gamma/\varphi$ denotes the offered traffic per idle source [18]. When all the channels are occupied the remaining UEs that are not served are blocked. The blocked UEs are lost according to Erlang loss system; this means that blocked calls are cleared. Instead, for our system we assume that the blocked UEs are not lost; they hang around and keep retrying until they are served and this follows the binomial distribution model [20]. The whole resources available are assigned to all UEs.

- **Cellular inner mode traffic:** In this mode we assume the cellular resource is shared between inner part and outer part UEs. We still use the system model in Fig. 3.2. Considering that $(1-\alpha)$ of the total cellular resource is used in the inner part and UEs in this part are communicating via BS; then the traffic generation will be like in cellular mode. The only difference is the number of sources which is reduced to S_c and the offered traffic per source is equal to $a_c = (1-\alpha) * a$. The number of channels in this case is C_c and $S_c - N_c$ UEs inner part will be blocked. Where N_c is the number of UEs inner part already connected (number of calls in progress) which is equivalent to the number of available resources in this region.

- **D2D outer mode traffic:** The UEs in the outer region are allocated α of the total resource and since UEs in this part are expected to use D2D communication, they use these resources for neighbor discovery. The number of UEs in this region is S_{d2d} and the number of channels assigned to them is C_{d2d}. In this case the offered traffic per source is calculated with respect to Reactive and proactive protocols. We take in consideration the Fig. 3.1b and we calculate the offered traffic accordingly. Since we assumed that the blocked UEs hang around until they are saved, in this mode we assume that the blocked UEs start neighbor discovery and if they discover each other, they can use D2D communication. The calculation of the offered traffic per source, A_{re} and A_{pr} for both reactive and proactive protocols respectively is given by Eq. (6.1) and Eq. (6.2) respectively.

$$A_{re} = \frac{(S_{d2d}+S_c-N_c)*7*L*M}{S*10*T} * a \tag{6.1}$$

$$A_{pr} = \frac{(S_{d2d}+S_c-N_c)*(T+6*L*M)}{S*10*T} * a \ , \tag{6.2}$$

where T is the total number of observation periods in which we experience all requests(or just call attempts requesting) for neighbor discovery. However, if we assume that a call attempt/request can come in time t the total number of observations is equivalent to the total number of timeslots $L = t1 + t2 + t3 + \cdots$, must be less than or equal to T $(L \leq T)$ and the following condition must be fulfilled.

$$t = \begin{cases} 1 & when\ there\ is\ a\ request \\ 0 & other\ wise\ (\ no\ request) \end{cases}$$ within each observation period $\Delta t = t_{k-1} - t_k$.

This means that if there is a request observed within an observation period, that request will contribute to the total number of timeslot, where the maximum should not exceed the total period. In case we do not observe any request, then for reactive protocol there is no resource spent for discovery at that time and therefore, offered traffic per source is equal to zero. On the other hand, if there is no request for proactive protocol, there must be some resources spent since the BS sends periodically a broadcast message to idle sources as an advertisement for neighbor discovery.

Note that the total number of UEs involved in neighbor discovery is equivalent to the blocked UEs inner $(S_c - N_c)$ part and all the UEs in outer part S_{d2d}. Here, $M = M1 + M2 + M3 + \cdots$, describes the number of pairs that exchanges discovery messages. Recall that seven out of ten handshakes for discovery are required for both protocols and especially for proactive protocol one among them is a broadcast to all. M must be greater than one $(M \geq 1)$ in outer part. That is at least one pair exists requiring a request/response message exchange. Meanwhile we assume that the blocked UEs inner part have no chance for successful discovery since the distance between them may be randomly distributed and it is can be greater than the targeted distance *D*. This is due to the fact that all the traffic in inner part are through the BS and do not require to communicate to the nearest neighbor only. Only the D2D UEs in outer part can successively discover each other since the targeted distance between them is uniformly distributed and we assume that no other traffic they are generating apart the direct D2D ones.

6.2.2 Protocols comparison in terms of blocking probability

To calculate the blocking probability we consider binomial distribution with finite number of sources. This case is different from the Engset distribution in that the blocked users are lost for Engset distribution whereas for binomial distribution the blocked users are assumed to hang around as sort of retrial so that they will eventually be served [35]. The available resources are shared between cellular UEs in the inner part and D2D UEs in the outer part. The blocking probability $\mathrm{P_b}$ for S nodes generating traffic in cellular mode alone is given by Eq. (6.3).

$$\mathrm{P_b} = \sum_{k=C}^{S-1} \frac{(\mathrm{S}-1)!}{\mathrm{k}!(\mathrm{S}-1-\mathrm{k})!} a^k (1-a)^{(S-1-k)}, \tag{6.3}$$

Where, a represents the offered traffic per source and C is the number of resource blocks (RBs) available. In the above equation k represents the number of calls in progress. Note that the UEs from $k = C$ (each UEs is allocated one RB, so that the number of calls in progress is equal to the number of available RBs for communication) up to $S - 1$ are blocked and are still hanging around trying to generate traffic (call attempts).

Regarding the traffic generated by the cellular UEs in the inner part, some of them will for sure be blocked. Consider the number of UEs S_c and the offered traffic per source a_c in inner part. The blocking probability $\mathrm{P_c}$ is shown in Eq. (6.4) for the UEs in inner part.

$$\mathrm{P_c} = \sum_{k=C_c}^{(S_c-1)} \frac{(S_c-1)!}{\mathrm{k}!((S_c-1-\mathrm{k})!} {a_c}^k (1-a_c)^{(S_c-1-k)}\ , \tag{6.4}$$

where C_c is the number of resource blocks assigned to UEs in inner part. The remaining UEs who are blocked in this part will generate traffic together with the UEs in the outer part retrying to call so that they can eventually be served.

However, we assume that all these UEs which are not served $(S_{d2d} + S_c - N_c)$, start the ProSe discovery. This means that they start discovering their neighbors in proximity, and if they successfully discover them within the nearest distance, they communicate using D2D communication. Since the distance between the blocked UEs in inner part is not determined, we are not quite sure whether they can successfully discover each other. Therefore we care more about the UEs in outer part, since we know the target distance D within two nearest neighbors. These UEs are intended to use D2D communication. The blocking probability $\mathrm{P_{re}}$ and $\mathrm{P_{pr}}$ with respect to the reactive and proactive protocols is given by Eqs. (6.5) and (6.6).

$$\mathrm{P_{re}} = \sum_{k=C_{d2d}}^{(S_{d2d}-1)} \frac{(S_{d2d}-1)!}{\mathrm{k}!(S_{d2d}-1-\mathrm{k})!} A_{re}^{k}(1-A_{re})^{(S_{d2d}-1-k)} \tag{6.5}$$

$$\mathrm{P_{pr}} = \sum_{k=C_{d2d}}^{(S_{d2d}-1)} \frac{(S_{d2d}-1)!}{\mathrm{k}!(S_{d2d}-1-\mathrm{k})!} A_{pr}^{k}(1-A_{pr})^{(S_{d2d}-1-k)} , \tag{6.6}$$

where $S_{d2d} = S - S_c$ denotes the number of D2D UEs in outer part of the cell. $\mathrm{A_{re}}$ and $\mathrm{A_{pr}}$ are offered traffic per source for both reactive and proactive protocol respectively.

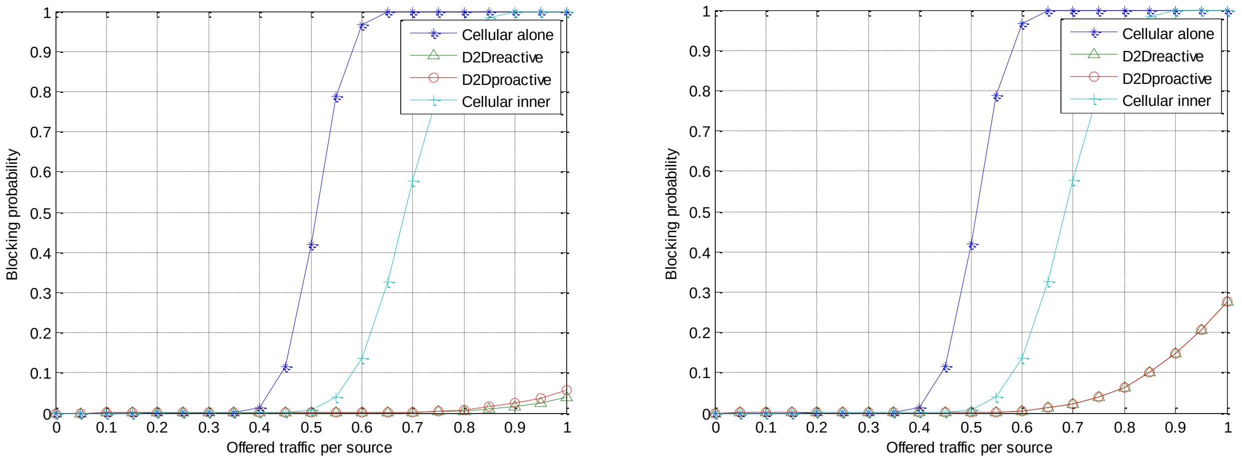
6.3 Numerical Results for Overflowed Traffic

This section presents the numerical results according to network parameters in Table 6.1. The available resources are allocated to both cellular UEs and D2D UEs in terms of RBs and the resources allocated to D2D in outer part are used for discovery after the discovery, UEs in this part will communicate through direct links. According to [23], 10 MHz corresponds to 50 RBs. Among these RBs, α are allocated to D2D UEs and $(1-\alpha)$ are assigned to cellular UEs in inner part. The following table illustrates the configuration parameters used for simulation.

Table 6.1 Parameters for overflowed traffic for cellular UEs and for D2D UEs.

Parameters	*Symbol*	*Value*
Number of all UEs in a Cell	S	100
Number of cellular UEs in inner part	S_c	74
Number of D2D users in outer part	S_{d2d}	26
Big Cell radius	R	$500\ m$
Offered traffic per source	a	$0\ to\ 1$
Small cell radius	r	$50\ m$
Targeted distance	D	$50\ m$
Total number of RBs	C	50
Number of RBs for inner Cellular	C_c	40
Number of RBs for D2D UEs	C_{d2d}	10
Number of call in progress	$k\ or\ N_c$	$0\ to\ C$
Total Bandwidth	W	$10\ MHz$
Dedication coefficient	α	0.2
Period (total number of timeslots)	T	20
Timeslot for requests	t	$0\ or\ 1$
Total number of timeslots for requests	L	$15\ and\ 20$
Number D2D UEs pairs	M	$1\ and\ 2$

The simulation results are shown in Fig.6.2 and the variation in curves for both cellular and D2D UEs are presented. The blocking probability versus the offered traffic per source is plotted.

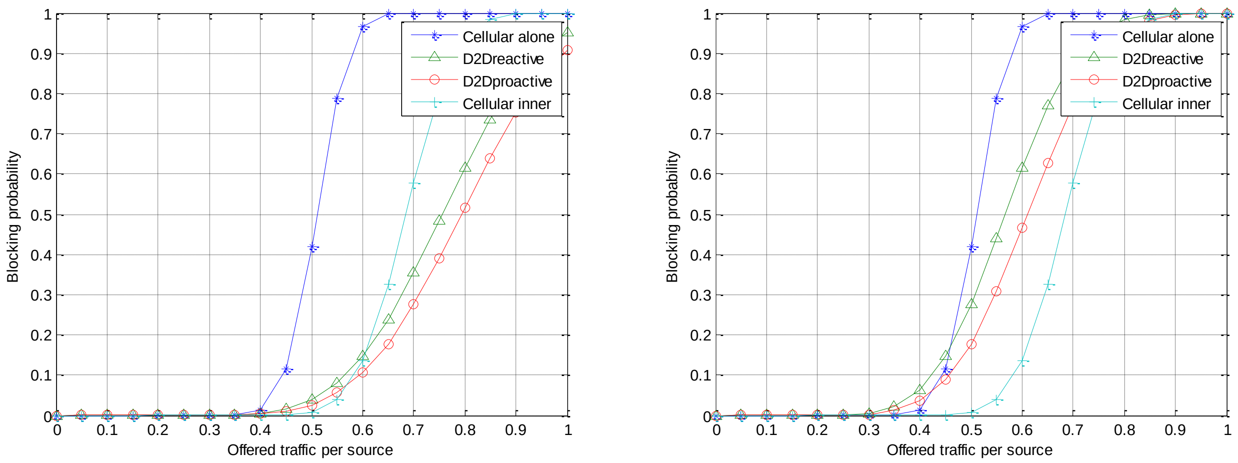


a) b)

Fig.6.2 Blocking probability a) D2D UEs pairs, M=1, L=15 & b) D2D UEs pairs, M=1, L=20.

The above figures show that when D2D communication is used in the outer part of the cell together with cellular communication in the inner part, the blocking probability is reduced. The curves also allow us to compare reactive and proactive protocols in terms of the blocking probability especially in outer part and in general for all the blocked UEs. Figure 6.2a shows that when the number of D2D pairs is limited to one per each timeslot and a few numbers of timeslots $L = t1 + t2 + t3 + \cdots$ for D2D discovery, mostly less than the total number of observation period T, reactive performs well than proactive protocol. The smaller is the blocking probability the better is the protocol. In this case we have at most one request per timeslot. When $L = T$, the two protocols result in the same blocking probability as we can observe it in Fig. 6.2b. The raison behind is that, if in each timeslot we have only one D2D request, we can just wait and serve it when it arises; instead of sending a periodically message advertising for ProSe and end up by having only UE responding to this advertisement. Therefore reactive is a better choice in this moment. On the other hand, if we use proactive protocol for ProSe discovery and at least in each timeslot we observe one D2D request, then the resources used for the advertisement are not wasted. This is because always one UE will respond on the advertisement in each timeslot. That is why in this case the benefits are the same in Figure 6.1b for both reactive protocol and proactive protocol for discovery.

However when more than one D2D pair are considered $M > 1$, things look different in this case. Here multiple pairs are possible and therefore proactive protocol performs well as shown in Figure 6.3. This is due to the fact that, the broadcast message sent periodically by the BS will always meet some UEs interested in D2D discovery. Here, more than one pair can send a request for each timeslot. Thus the resources are efficiently used. In addition the network is offloaded because UEs are aware about neighbors' availability. UEs use D2D communication as long as they have their neighbors in proximity willing to use DD2D communication as well.



a) b)

Fig.6.3 Blocking probability for M=2 a) D2D UEs, L=15 & b) D2D UEs, L=20.

The general impression from both Fig. 6.2 and 6.3; is that using D2D communication in the outer part, together with cellular communication in the inner, is more beneficial than traditional cellular alone. This is proven by the reduction of the blocking probability of both D2D UEs and cellular UES in inner part compared to cellular alone. Therefore when the available resources are shared between D2D UEs and cellular UEs, few UEs are blocked and the resources are used efficiently. Also the BS is no longer overloaded. Another observation is that the blocking probability increases with the increase in offered traffic per source. That is when UEs are more occupied, and calls take long time (the holding time is high), the congestion in a cellular system increases.

6.4 Heterogeneous Traffic: Voice and Data Traffic

Consider heterogeneous traffic where, generated traffic is either data or voice traffic. In this case the available resources are shared between D2D UEs and cellular UEs and in each part the resources can be used for both data and voice traffic alternatively. However the offered traffic is different depending to whether data or voice traffic is transmitted. We assume that 1RB per UE is used when voice traffic is concerned and for data traffic, 2RBs are assumed per UE. The total offered traffic is given in Eq. (6.7).

$$A_{tot} = A_{voice} + A_{data} \ , \tag{6.7}$$

where A_{voice} and A_{data} represent offered traffic for voice and data traffic respectively.

Our purpose in this section is to know how much resources can be assigned to both D2D UEs in outer part and cellular UEs in inner part that minimizes the network congestion. We assume that more data traffics are generated than voice traffics in general. We use Erlang formula to calculate the blocking probability in traditional cellular alone case and Engset distribution is used for the cellular inner and D2D in outer area since we assume a limited number of UEs. Given the offered traffic in the inner part and in the outer part of the cell, the following equations are used to calculate the blocking probability.

$$B_c(\beta_{inner}) = \frac{\binom{S_c-1}{C_c}\beta_{inner}^{C_c}}{\sum_{i=0}^{C_c}\binom{S_c-1}{i}\beta_{inner}^{i}} \tag{6.8}$$

$$B_{d2d}(\beta_{outer}) = \frac{\binom{S_{d2d}-1}{C_{d2d}}\beta_{outer}^{C_{d2d}}}{\sum_{i=0}^{C_{d2d}}\binom{S_{d2d}-1}{i}\beta_{outer}^{i}} \tag{6.9}$$

In Eq. (6.8) and Eq. (6.9), β_{inner} and β_{outer} represent the offered traffic per idle sources in the inner part and outer part of the cell respectively and according to [18, pp.139], are calculated as follow :

$$\beta_{inner} = \frac{A_{inner}}{(S_c - A_{inner})} \tag{6.10}$$

$$\beta_{outer} = \frac{A_{outer}}{(S_{d2d} - A_{outer})} \ , \tag{6.11}$$

Where, A_{inner} and A_{outer} are the offered traffic in inner part and in outer part of the cell respectively and their values are obtained from Eq. (6.12) and (6.13) below.

$$A_{inner} = (1-\alpha)A_{voice} + (\alpha)A_{data} \tag{6.12}$$

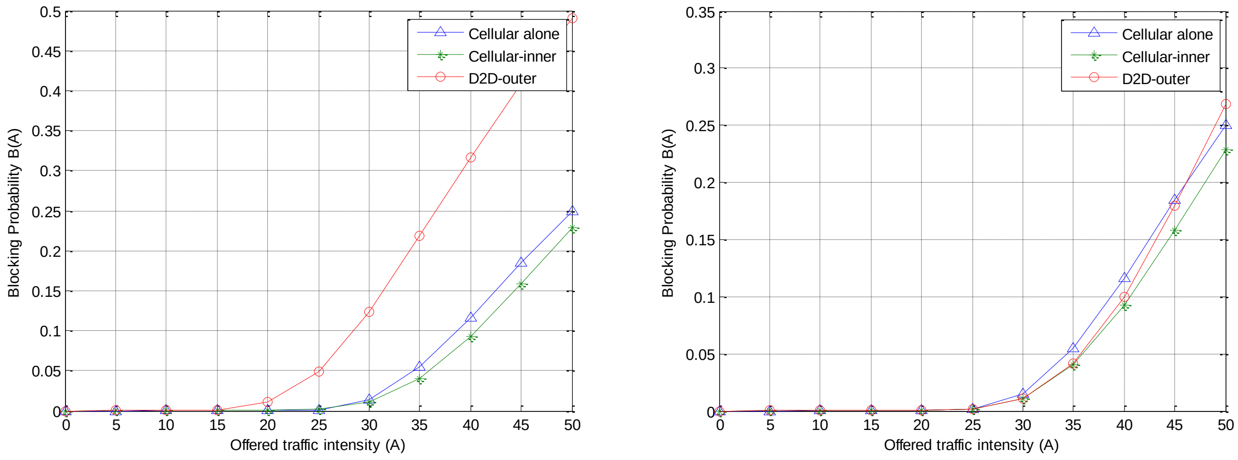
$$A_{outer} = \alpha A_{voice} + (1-\alpha)A_{data} \ , \tag{6.13}$$

Where, A_{inner}+$A_{outer} = A_{tot}$ which is represented in Eq. (6.7) as total offered traffic in the whole cell. From above equation $\alpha \in [0\ 1]$ and denotes the percentage coefficient.
The network configuration parameters used to plot the simulation results are presented in Table 6.2.

Table 6.2 Configuration parameters for heterogeneous traffic.

Parameters	*Symbol*	*Value*
Total number of all UEs in a Cell	S	200
Number of cellular UEs in inner part	S_c	148
Number of D2D UEs in outer part	S_{D2D}	52
Total Offered traffic	A	$1\ to\ 50$
Total number of Channels	C	$40\ RBs$
Number of channels in outer part	C_{outer}	$15\ and\ 25$
Number of channels in inner part	C_{inner}	$25\ RBs$
Total Bandwidth	W	$10\ MHz$
Number of total resources blocks	RBs	50
for communication	*BW*	*9 MHz*
Dedication coefficient	α	0.8
Offered traffic for data traffic	A_{data}	$0.6 * A$
Offered traffic for voice traffic	A_{voice}	$0.4 * A$

Fig. 6.3 illustrates the simulation results for heterogeneous traffic. The blocking probability is plotted in function of offered traffic intensity.



a) b)

Fig.6.4 Blocking probability for heterogeneous traffic a) D2D, 15RBs & b) D2D, 25RBs.

The above figure represents blocking probability when 15RBs are assigned to D2D links and 25RBs to cellular links where $\alpha = 0.8$ (in Fig. 6.4a) and when equal resources (25RBs) are allocated to both D2D UEs and cellular UEs (in Fig. 6.4b). Recall that we assumed more data traffic than voice traffic as shown in Table 6.2 and 1RB per UE for voice whereas for data we use 2RBs per UE for transmission. As we observe from Fig. 6.4a, the blocking probability is quite high for D2D links compared to cellular alone and cellular in inner part when fewer resources are assigned to D2D UEs. On the other hand, remaining UEs in inner part experience low congestion compared to traditional UEs in cellular alone communication. This is a benefit since in inner part most of the traffic is for data transmission; hence the transmission will be smoother.

However, when we increase the resources assigned to D2D links as shown in Figure 6.3a; it is more beneficial than in cellular alone. For instance, when the offered traffic intensity is equal to 40 we can experience a blocking probability less than 0.1. That is only 1% of subscribers are blocked and this is a great improved in cellular network congestion. In general, these simulation results show that the number of RBs can be optimized so that the blocking probability may be kept at a minimum value which is more reasonable.

6.5 Chapter Summary

In this chapter we analyzed the overflowed traffic where the blocked UEs are not lost, but hang around until they are served. We aim at enabling these blocked UEs to use D2D communication. We split the whole cell in inner part and outer part where cellular communication and D2D communication take place respectively. We assume that the UEs in outer part grouped in small cells as shown in Fig.3.1b, have high probability to discovery each other, since they are within D meters away from each other. The performance evaluation of the blocking probability is done using binomial distribution. We calculate the offered traffic per idle source for each part, when each part is assigned dedicated resources. We compare the blocking probability for both parts with respect to cellular network alone. In addition, we allow UEs in outer part to discover each using reactive and proactive protocol and we compare the two protocols in terms of blocking probability.

Results show that when the overflowed UE are allowed to discover each other the cellular blocking probability is reduced compared to legacy communication alone. When Reactive protocol is used for discovery low blocking probability is observed compared to proactive protocol for single request per timeslot, otherwise proactive is recommended. That is for multiple D2D request proactive protocol is chosen. Heterogeneous traffic also is presented and results show that, when more data traffics are assumed for inner part than voice traffic, resources are exhausted and the blocking probability is high. This results also in high probability for D2D voice traffic. Then more resources are recommended to be assigned to D2D links to reduce the blocking probability. However, the UEs in inner part experience low blocking probability compared to traditional alone. Therefore, optimizing the available RBs may lead to better use of D2D links efficiently for data or voice traffic.

7 Conclusions and Future Work

This chapter presents a summary of our final results. Moreover, a performance evaluation of blocking probability and resource allocation in D2D-enabled cellular network is performed. Design and analysis of our ProSe discovery protocols is given. Furthermore, contributions of this thesis are analysed based on our findings. Finally, suggestion for future work is provides.

7.1 Summary

This Thesis presented the infrastructure coordinated D2D-Enabled cellular network. The main focus was the neighbor discovery and resource allocation for D2D communication. We propose to use D2D links at the cell edges and cellular links in inner part of the cell where D2D links use dedicated resource for neighbor discovery. We suggest an orthogonal resource allocation where spatial reuse in small cell can be done. The performance evaluation in terms of blocking probability was envisaged. Numerical results show that when available resource is shared between cellular links and d2D links; the cellular network blocking probability is reduced especially for the UEs located at the cell edges. If Engset distribution is used for D2D pairs, the blocking probability for D2D part is less than 2%, while at least 80% of the total UEs at cell edge are connected through D2D links. The remaining cellular UEs also experience lower blocking probability compared to cellular alone.

Moreover, two protocols for neighbor discovery in cellular network have been proposed by this work. The reactive protocol works on an on-demand manner and it is initiated by a UE who request a service discovery from the BS. It is pull mechanism where the UE starts the first contact to BS whenever UEs want to discovery each other. The proactive protocol employs a multicasts discovery message periodically sent to all UEs by the BS. With regards to the two protocols, a message format and frame structure was proposed. These protocols are very important since they show necessary steps for UEs to discover each other and establish a direct D2D session. Using our protocols less signalling messages between UEs and the BS are required and this is a benefit in terms of network flooding and less delay. The advantage of reactive protocol over proactive protocol is that UE does not have to active continuously the ProSe application in its device. UE only enables ProSe discovery application when it has D2D requirements to send. This is more energy efficient. On the other side, proactive protocol is very important on both UEs and BS perspective, when there is a high demand for communication and there are many D2D UEs in proximity. The uplink resources are saved for UEs since they are not required to send requests to BS. Instead they get all necessary information about nearby UEs and available services in the vicinity from the BS advertisement. An advantage for the BS is observed when many UEs reply to its advertisement and use D2D links; the network is offloaded. However the resource is wasted when no one is interested in D2D ProSe discovery.

The control overhead was calculated with respect to the two protocols and the comparison between them has been evaluated. The numerical analysis and MATLAB results in different cases considered show that reactive performs better if D2D traffic is low and proactive protocol is preferable if there are many D2D UEs in the vicinity. Considering different UEs distributions, results showed that the number of potential D2D UEs decreases with shorter transmission range since the probability of finding another D2D peer is lower.

Finally we propose how the overflowed traffic might not be lost, instead they may be allowed to initiate the neighbor discovery within dedicated resource, and communicates through D2D links. Results show that, if our protocols are used for discovery, the blocking probability is improved compared to cellular alone.

7.2 Contributions

This thesis has the following contributions:

1. Two of the existing use cases for neighbor and ProSe discovery suggested by 3GPP for D2D communication have be investigated, namely network ProSe and Open ProSe discovery.

2. Two new protocol of ProSe discovery for D2D communication has been proposed and their corresponding frame structure based on suggested use cases and scenarios described by 3GPP. These protocols provide an overview of how discovery can be done in order to communicate using a D2D link.

3. The thesis suggests how available cellular resource can be shared between D2D pairs and cellular UEs so that the challenges associated with network congestion are mitigated.

4. Previous studies model the traffic of the cellular network system using Erlang loss system which assumes an infinite number of sources. However, this thesis also considered Engset distribution for finite numbers of sources and this is a great improvement.

5. The thesis provides the formulation of calculating the control overhead for D2D neighbor discovery and many distributions were considered to emphasis their roles in modeling of the cellular network traffic. In addition the means of calculating the number of D2D UEs in the vicinity which have a chance to communicate through direct path for a given transmission range was provided.

6. The thesis suggests how the overflowed traffic may not be lost but may initiate the discovery and use D2D links. Finally, assuming the use of D2D in small cell at the cell edge, may result in frequency reuse which can improve the system capacity of the cellular network.

7.3 Future Work

This thesis proposes protocols design and their message format and frame structure for D2D neighbor discovery, but due to the time limitation, they are not implemented. It would be a good suggestion to implement them. We have suggested the use of D2D links in small cell at the cell edges; however orthogonal resource allocation with spatial frequency reuse in those small cells can be deeply investigated. It would be very interesting to apply spatial reuse in those small cells in order to improve the system throughput. In addition, this can allow as well the study of the interference management which was out of the scope of this thesis. More accurate results are needed for future work by extending the scenario for random distributions of UEs and calculating the control overhead for new schemes suggested by 3GPP since we have only considered two use cases. Finally, heterogeneous traffic was presented in this thesis, where we suggested a dedication of resource depending to whether D2D is going to be used for data or voice traffic. Therefore, heterogeneous traffic need to be more explored in order to know whether D2D communication can be more efficient if used for data or voice transmission.

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Appendices

Appendix A: Example of some of the MATLAB codes used for simulation

1. Random UEs distribution proximity probability.

```
D=1:3:100;% targeted distance
N=100; % total user in cell
n=100; % pickup n user randomly
R=1000; % radius of the cell picked up with N user
X= N/R^2; % cell density/pi
L=10;
p=1-exp(-X.*(D.^2)); % proximity probability in cell

k0=30; % d2d user in cell
k1=12;
k2=10;
k3=8;
k4=6;
k5=4;
k6=2;
T=20;
Y0=1-binocdf(k0,n,p); % targeted probability
Y1=1-binocdf(k1,n,p);
Y2=1-binocdf(k2,n,p);
Y3=1-binocdf(k3,n,p);
Y4=1-binocdf(k4,n,p);
Y5=1-binocdf(k5,n,p);
Y6=1-binocdf(k6,n,p);
plot(D,Y0,'-kv',D,Y1,'-o',D,Y2,'-^',D,Y3,'-*',D,Y4,'-x',D,Y5,'-s',D,Y6,'-+');
legend('P(k=30)','P(k=12)','P(k=10)','P(k=8)','P(k=6)','P(k=4)','P(k=2)');
xlabel('Transmission range in  metres(D)');
ylabel('Probability of k D2D UEs-Enabled');
grid on;
```

2. D2D requests following Normal distribution

```
mu=5;
sigma=6;
n=10;
i=0;
x=[1 20];
y=0;
size(y);
while i < n
  y=normrnd(mu,sigma,[1 1000])+y;
  i=i+1;
end
   p=y./n;
M=length(p);
nbin=20;
[val,out]=hist(p,nbin);
dout = out(2) - out(1);
pdf_pp = 1*val/(M*dout);
pp=out;

bar(pdf_pp)
```

```
sigma=6;
mu=10;
sigma=2;
itt=20;
for k=1:itt;
 p(k)=mu+sigma*randn(1);
end
T=20;
esum=zeros(size(p));
for ii=0:T;
    V1=esum+(6.*p);
    V2=esum+7.*p;
end
K1=(T+V1);
K2=(V2);
f1=K1./T;
f2=K2./T;
hold on
plot(p,f1,'-^',p,f2,'-o');
legend('proactive, D2D','reactive,D2D');
xlabel('Number of V(i) coming D2D pairs');
ylabel('Control overhead for M pairs requests');
grid on;
```

Appendix B

The following paper has been submitted to the conference:

Paper title: “*Proactive versus Reactive Protocols for Service Discovery in D2D-enabled Cellular Networks”*
Authors: *Faustin Ahishakiye* and *Frank Y. Li*
Conference name: IEEE PIMRC 2014,
2014 IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC): Mobile and Wireless Networks - Mobile and Wireless Network

Pdf of the paper attached:

Proactive versus Reactive Protocol for Service Discovery in D2D-enabled Cellular Networks

Faustin Ahishakiye and Frank Y. Li
Dept. of Information and Communication Technology, University of Agder (UiA), N-4898, Grimstad, Norway
Email: {fausta12@student.uia.no, frank.li@uia.no}

***Abstract*—Device-to-Device (D2D) communication, which is able to access services offered by nearby devices bypassing the base station, has been regarded as an essential part of next generation cellular networks. Many advantages can be provided by this direct communication paradigm such as high data rate, traffic offloading, range extension, as well as proximity services and social networking. In such a context, service discovery approaches need to be investigated. In this paper we propose two protocols for service discovery, namely, reactive (pull) discovery and proactive (push) discovery in infrastructure-coordinated D2D networks. The protocol overhead is calculated and numerical results are provided in order to compare these two protocols. The performance evaluation and simulation results show that the reactive protocol performs better when there are few D2D users whereas the proactive protocol is preferable if the D2D communication demand is high.**

I. INTRODUCTION

As one of the 5G mobile communication enabling technologies, Device-to-Device (D2D) communication has attracted lots of attention recently in both academia and industry. D2D enables tremendous advances with respect to communication technologies that provide higher transmission data rates, better spectrum efficiency and emerging networking applications. 3GPP has introduced D2D communication as a striking solution for many scenarios that require direct access, both with and without infrastructure. In the infrastructure mode, the initiation of a D2D conversation is coordinated by a base station (BS). That is, the BS assists users to discover their D2D peers and then let them communicate with each other directly. On the other hand, without the assistance from infrastructure, user equipment (UE) searches and transmits to its neighbor in the proximity in a self-organized manner.

Proximity Service (ProSe) is an essential feature of D2D communication when a UE is nearby to another UE and the proximity criterion such as geographical distance is fulfilled. ProSe discovery is the procedure how the UEs in proximity find each other. Various use cases and scenarios of ProSe discovery have been identified by 3GPP in [1] with an overview on how discovery can be performed given the requirements, preconditions, service flow and post-conditions. Furthermore, different approaches have been proposed in [2] on how to support proximity-based services. These solutions cover proposals from protocol design for ProSe discovery to ProSe communication. All necessary functionalities to be supported by the BS in order to enable UEs perform ProSe discovery are highlighted therein. In [3], Qualcomm proposes techniques and design principles for performing D2D discovery. In [4] and [5], different strategies are studied for service and neighbor discovery in D2D communication, proposing network-assisted algorithms for neighbor discovery and interference management. However, no numerical analyses for D2D discovery are given by [1] - [3] and no protocol overhead is calculated in [4] and [5].

In this study, we identify two scenarios for D2D service discovery. The first one is referred to as *Network ProSe* in which the network provides discovery assistance for ProSe-enabled UEs requesting services. The second use case is referred to as *Open ProSe* and it is a ProSe discovery procedure in which UEs discover each other without any prerequisite knowledge on the reachability of other UEs. In both cases, the BS is assisting service discovery of UEs. More specifically, we propose two protocols for service discovery in D2D communication where the exchange of discovery messages is either UE-initiated or BS-initiated. The UE-initiated protocol follows the principle of reactive (pull) mechanism where the UE starts the first contact to the BS, requesting for ProSe discovery in an on-demand manner. The BS-initiated protocol instead follows the idea of proactive (push) mechanism, multicasting an advertisement periodically to all D2D subscribers no matter there is a ProSe request or not. The comparison of these two protocols is performed with respect to control overhead under two different cases of D2D UE requests. The performance of the proposed protocols is evaluated through both numerical analysis and simulations.

The rest of this paper is organized as follows. Sec. II describes the system model and assumptions. Then Sec. III presents the designed protocols and Sec. IV performs protocol overhead analysis. Sec. V illustrates the numerical and simulation results, before the paper is concluded in Sec. VI.

II. SYSTEM MODEL AND ASSUMPTIONS

Consider D2D communication in cellular networks coordinated by a BS. The system model illustrated in Fig.1 consists of one cell with a number of UEs uniformly distributed in the cell. The BS is located at the center of the cell with radius r and coordinates all the UEs within the cell, including both traditional and D2D communications. UEs in the proximity of each other can communicate through the direct D2D link. For instance, UE1 and UE2 are within D2D communication distance D and therefore form a D2D pair.

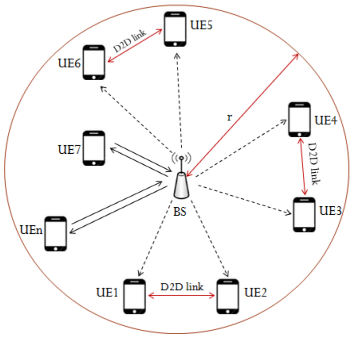

Fig. 1. System model for ProSe discovery.

The BS assesses whether the direct communication is possible by monitoring the location of the UEs and then helps them to establish D2D communication if required. Correspondingly, the BS needs to allocate resources for discovery and control information exchange. After successful ProSe discovery handshakes, D2D pairs communicate with each other via a direct links bypassing the BS. The remaining UEs will communicate via the BS based on traditional communication. Note that the enabling of direct links in cellular network will cause interference to other cellular users, therefore techniques to avoid interference are required. However, the topic of interference management is out of the scope of this study.

To enable D2D communication, UEs need to register for ProSe discovery and D2D services beforehand. We assume in this study that for these procedures like registration and authentication have already been performed for all UEs and consider only unicast user traffic. After registration, the ProSe application at each device may start triggering the requests or start monitoring other UEs' proximity services. The BS may also advertise the service so that all D2D-enabled UEs can access the services. We further assume in the envisaged scenario that both Open ProSe and Network ProSe are supported by all UEs as well as the BS.

III. PROTOCOL DESIGN FOR SERVICE DISCOVERY

Two protocols, referred to as reactive and proactive, are proposed in this study. The main idea of the reactive protocol is that *the ProSe discovery request is initiated by a UE* which intends to establish D2D communication with another UE. That is, this is a *pull* service discovery mechanism. On the other hand, the proactive protocol is *initiated by the BS* serving all the UEs before any D2D requests arise, hence it is a *push* service discovery mechanism. With this mechanism, the BS sends a broadcast message periodically to all UEs for D2D services discovery, but only the interested UEs reply to the advertisement. More details about these two protocols are given below.

A. Reactive Protocol for Service Discovery

With the reactive protocol, a UE initiates an on-demand [1] service discovery procedure when it intends to establish D2D communication with another UE on its contact list. However before starting the discovery of its neighbors, the UE needs to contact the BS since only the BS has the overview about the other UEs. So the discovery process is coordinated by the BS, after the discovery request is initiated by the UE. Fig. 2 illustrates the exchange of signaling messages for reactive ProSe discovery. The discovery happens in the following steps:

- Step 1: When D2D communication is needed, UE1 initiates firstly the discovery process by activating the ProSe application on its device and sends a request message to the BS, with information about its own ID, position and the ID of the targeted D2D peer.
- Step 2: The BS checks the permission for ProSe discovery of the UE and forwards the request to the peer device, UE2. Note that the BS keeps monitoring the location of all UEs.
- Step 3: If UE2 is willing to communicate using D2D, it replies an OK message along with other necessary information to the BS.
- Step 4: BS informs UE1 about the proximity of UE2 and instructs UE1 to send a request to UE2.
- Step 5: BS also informs UE2 about the proximity of UE1 and the allocated resources for D2D communication.
- Step 6: UE1 sends an invitation message to UE2 directly.
- Step 7: UE2 replies with an acknowledgment (ACK) to UE1 directly confirming that they can start D2D communication.
- Step 8: Ongoing D2D communication session between these two UEs.
- Step 9: When the D2D session is terminated, a D2D communication-terminated message is sent to the BS by one of them, e.g., UE1.
- Step 10: Finally, the radio resources are released.

Note that the reactive ProSe discovery and communication procedure requires in total ten exchanged messages between two UEs and the BS, and among them seven handshakes are necessary for each successful D2D session. We count accordingly these seven handshakes (from Step 1 to Step 7) in our protocol overhead calculation in Sec. IV, since the other three steps are for D2D communication and are the same in the proactive procedure.

B. Proactive Protocol for Service Discovery

With the proactive protocol, all the authenticated UEs with D2D-enabled applications will be notified by the BS about the availability of the ProSe services through a multicast message sent periodically [2]. Once a UE has D2D traffic to send, it replies to this advertisement, informing the BS about ProSe discovery. Afterwards, the handshake steps are similar to the ones presented above. Note that the D2D peers may be served by the same or different BSs. In the latter case, more handshakes are needed among BSs. For simplicity, only one BS is considered in our model. The proactive ProSe discovery

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[1] On-demand means that the service discovery request is initiated only when the UE has D2D traffic to send.

[2] This step implies that radio resources might be wasted if no UEs have D2D requirements

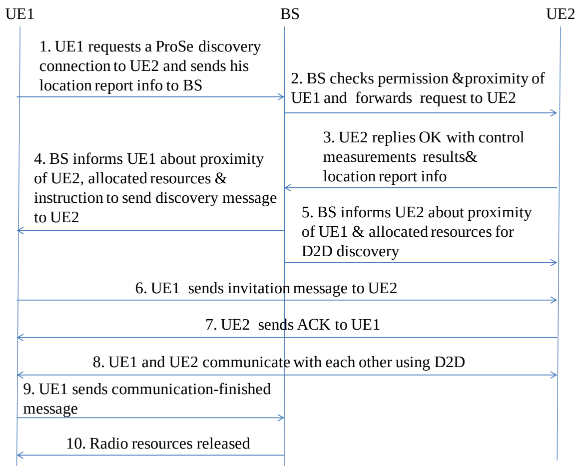

Fig. 2. Service discovery messages using the reactive protocol.

procedure is presented in Fig.3, consisting of the following steps.

- Step 1: The BS periodically multicasts to all ProSe subscribers about the list of available proximity services and discovery information.
- Steps 2 and 3: the UEs that have D2D requirement, e.g., UE1 and UE2 as illustrated, reply to the BS, reporting their new position, metric information and the targeted D2D peer.
- Step 4: BS updates the information list and looks for location information of UE1 and UE2 to assess whether the D2D communication criterion is met. If yes, the BS sends a notification about the proximity of D2D peer to one of them.
- Step 5: One of the UEs, e.g., UE1, reports to the BS that they intend to start a D2D session.
- Step 6: The BS forwards the invitation message to UE2 on behalf of UE1 and allocates radio resources to prepare D2D communication.
- Step 7: UE2 sends an ACK message to both UE1 and the BS, accepting to communicate with UE via D2D. Meanwhile the BS updates with fresh information on the calling party and the called party, whether UE1 and UE2 are in the same cell or not, resource blocks allocated etc in its D2D database [6].
- Step 8: Ongoing D2D communication session between the D2D pair, i.e., UE1 and UE2.
- Step 9: The same as in the reactive procedure.
- Step 10: The same as in the reactive procedure.

The proactive ProSe discovery is also achieved using seven handshakes, from Step 1 to Step 7. However, the proactive protocol differs from the reactive one such that the first message is multicast to all D2D subscribers periodically as an advertisement, no matter there is ongoing or potential D2D traffic or not. The last three handshakes are the same as in the reactive protocol, therefore not included in our overhead calculation.

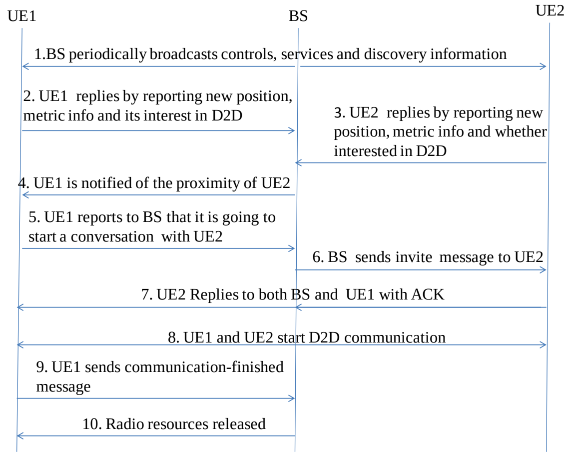

Fig. 3. Service discovery messages using the proactive protocol.

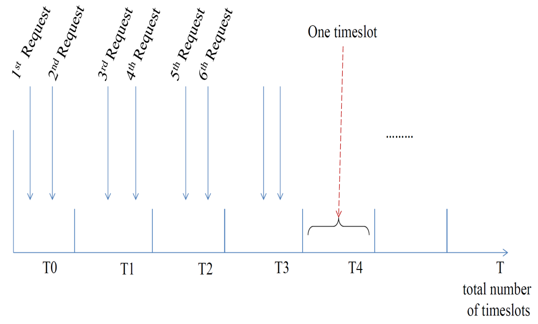

Fig. 4. Number of D2D requests for service discovery with T timeslots.

IV. PROTOCOL OVERHEAD ANALYSIS

The control overhead of the proposed protocols is calculated in terms of the required number of service discovery messages required to establish a D2D session between two UEs, i.e., one D2D pair. Consider N UEs in the system and $M \leq N$ of them form D2D pairs which require ProSe discovery. Recall that in the reactive protocol, seven handshakes for each pair are required. Then for M pairs it results in $7M$ handshakes. For the proactive protocol, six handshakes are required for each D2D session establishment. Additionally, there is a multicast message transmitted periodically by the BS to all UEs, resulting in totally $(T + 6M)$ handshakes for M D2D pairs. Herein the total observation duration for our calculation is divided into T timeslots [3]. Within each timeslot there will be one multicast message advertised, regardless of the number of D2D pairs in a timeslot. The number of D2D pairs within each timeslot may vary from zero to M.

To start our analysis, we take firstly node distribution into account and calculate the number of D2D pairs in the vicinity. Then we consider two cases for calculating control overhead for both the reactive and the proactive protocols. In Case I, both single and multiple D2D requests could happen within one timeslot. In Case II, we consider the probability of having

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[3] In this study, timeslot is a terminology used to represent a period within which a D2D multicast message is generated and it is hence different from the timeslot in traditional cellular networks.

k neighbors within a given distance from a randomly selected node, before performing overhead calculation. For each case the analysis and formulation are provided in terms of the number of handshakes (exchanged signaling messages) during the observation period.

A. *Nodes Distribution and Neighborhood Calculation*

Consider n nodes uniformly distributed within the cell as shown in Fig.1 and that two nodes within the distance D can communicate with each other directly using D2D. Given node density, λ, within the coverage of a cell, the neighborhood and k connectivity can be calculated [8]. Given uniform node distribution, the probability that two randomly selected nodes are within distance D away from each other, thus forming a D2D pair, is obtained as follows.

$$P(d \leq D) = 1 - e^{\lambda \cdot \pi \cdot D^2}. \tag{1}$$

In other words, this is a probability that a UE has at least one neighbor within D. Furthermore if we pick up randomly n UEs, the probability that there are k users which are within D meters away from a selected node can be obtained from the binomial distribution [7].

$$P(k) = 1 - \sum_{j=0}^{k} \binom{n}{j} (1-p)^j p^{n-j}, \tag{2}$$

where $j = 1, 2, ..., k$, and $p = 1 - P(d \leq D)$ refers to the probability that there is no UE within D meters from the selected node.

Based on the network parameters configured in our simulations to be presented later, the probability indicating how many D2D UEs can be found within different targeted distances is shown in Fig. 5.

B. *Case I: Single and Multiple D2D Pairs Requests*

In this case, we assume that D2D pairs can request ProSe discovery within any timeslot but not necessarily within all timeslots. Among total number of T timeslots, there are $L \leq T$ timeslots in which D2D ProSe discovery requests occur. Therefore, the control overhead for the reactive and proactive protocols is calculated respectively as follows.

$$O_I^{re} = \frac{7 \cdot L \cdot M}{T}, \tag{3}$$

$$O_I^{pr} = \frac{T + 6 \cdot L \cdot M}{T}. \tag{4}$$

In the above expressions, we consider that within each timeslot there may be $0, 1, 2, ..., M$ D2D pairs requesting ProSe discovery and, for simplicity, this number is fixed.

C. *Case II: Random Distribution of Users*

In this case, we still consider that D2D requests may happen in L out of T timeslots, but only among these k devices which are within D meters away from each other. Correspondingly, the control overhead is calculated as follows.

$$O_{II}^{re} = \frac{7 \cdot P(k) \cdot k \cdot L}{T}, \tag{5}$$

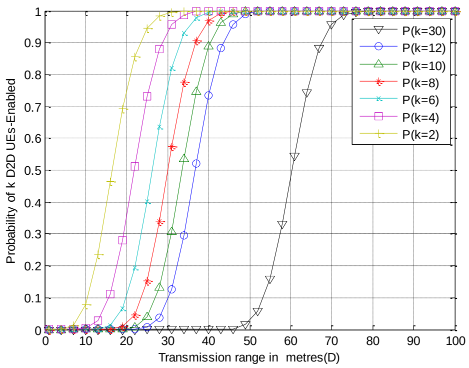

Fig. 5. Probability of finding k D2D UEs as a function of transmission range.

$$O_{II}^{pr} = \frac{T + 6 \cdot P(k) \cdot k \cdot L}{T}. \tag{6}$$

V. NUMERICAL RESULTS AND DISCUSSIONS

To compare the performance of the proposed ProSe discovery protocols, we performed simulations based on Matlab. The parameters configured in our simulations are listed in Tab. I.

TABLE I
PARAMETERS FOR RANDOM DISTRIBUTION OF D2D COMMUNICATION.

Symbol	Parameter	Value
n	Number of randomly selected UE pairs	100
r	Cell radius	1 km
k	Number of D2D UEs	2, 4, 6, 8, 10, 12 and 30
D	Targeted distance	0 to 100 m
L	Number of available timeslots	0, 1, 2, ..., 20
j	Number of observations	1 to k
M	Number of D2D pairs	1, 2, 3, 4, 5, 6, and 15
T	Total number of timeslots (Periods)	20

A. *Results for Case I*

Two sets of simulations are performed in this case, as 1) Case Ia - single request per each timeslot; and 2) Case Ib - multiple ($M = 4$) requests over an increasing number of non-empty D2D request timeslots. The results are illustrated in Figs. 6 and 8 respectively.

As expected, when the number of D2D requests is low, the reactive protocol outperforms the proactive protocol since few handshakes are exchanged among the involved devices and the BS, as shown in Fig. 6. As the number of D2D requests increases, the proactive protocol begins to exhibit its advantage over its reactive counterpart. As can be observed in Fig. 8, proactive generates lower control overhead if D2D requests happen in more than 7 out of 20 timeslots. In general, if $L \leq T/M$, reactive performs better. Otherwise practive is recommended.

B. *Results for Case II*

As illustrated in Fig. 5, the larger the distance D, the higher the probability to find a given number of D2D pairs. Given $n = 100$ and $D = 40$ meters, the probability to find 12 or 10 neighbors is 73% and 89% . We adopt these values for our

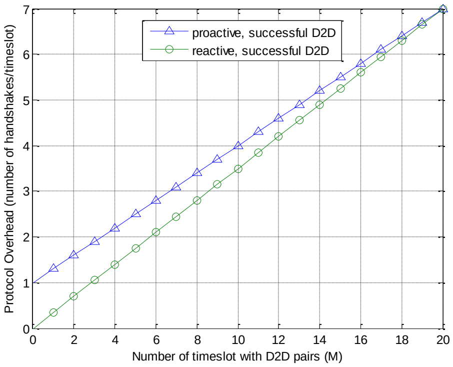

Fig. 6. Case Ia: Protocol overhead for single D2D request/timeslot with $M = 1$, and $T = 20$.

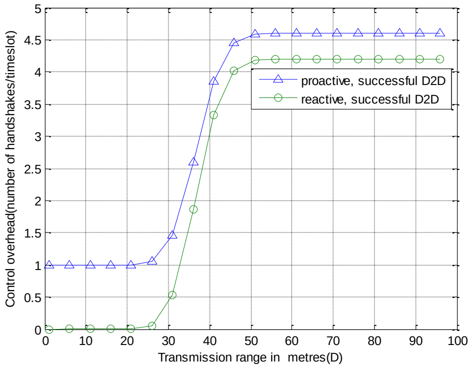

Fig. 7. Case IIa: Protocol overhead for single D2D request/timeslot with $n = 100, k = 12, L = 1$ and $T = 20$.

simulations in this case and the results are plotted in Figs. 7 and 9 respectively.

For single request per timeslot, reactive performs better than proactive when there are fewer number of D2D UEs presented within D meters, as shown in Fig. 7. In case of multiple requests per timeslot, proactive is preferable as shown in Fig. 9. Using the proactive protocol, the uplink D2D service request step could be skipped by UEs, resulting in lower overhead when there are large number of D2D requests. Comparing Fig. 7 and Fig. 9, the control overhead is much high in Fig.9, due to the fact that there are many UEs requests and many resource blocks are required for ProSe discovery.

Finally, the curves show that when D is too small, no D2D peer can be found in the vicinity. Correspondingly, the overhead for reactive is zero since D2D is not possible under this situation. However, a small amount of overhead is nevertheless needed for proactive discovery since the BS is still disseminating the ProSe advertisement periodically.

VI. CONCLUSIONS

This paper proposes two protocols for D2D service discovery in cellular network. The reactive protocol works on an on-demand manner and it is initiated by a UE. The proactive protocol employs a multicasts discovery message periodically sent to all UEs by the BS. A general conclusion is that reactive performs better if D2D traffic load is low but proactive is preferable if there are many D2D UEs in the vicinity. Another result shows that the number of potential D2D UEs decreases with shorter transmission range, since the probability of finding another D2D peer is lower.

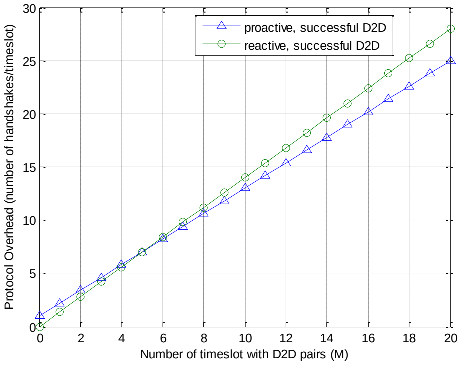

Fig. 8. Case Ib: Protocol overhead for Multiple D2D requests/timeslot with $M = 4$, and $T = 20$.

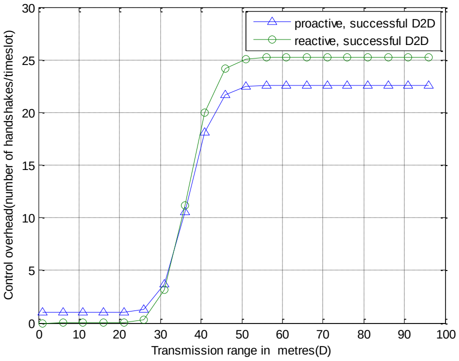

Fig. 9. Case IIb: Protocol overhead for multiple D2D request/timeslot with $n = 100, k = 12, L = 6$ and $T = 20$

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