

Analysis of Discovery and Access Procedure for D2D Communication in 5G Cellular Network

Zhijian Lin¹, Liang Du¹, Zhibin Gao¹, Lianfen Huang^{1*}, Xiaojiang Du^{1,2}, Mohsen Guizani³

¹Department of Communication Engineering, Xiamen University, Xiamen, Fujian, China, 361005

²Department of Computer and Information Sciences, Temple University, Philadelphia PA 19122 USA

³Qatar University, Qatar

E-mail: linzhijian1234@126.com, gaozhibin@xmu.edu.cn, dxj@ieee.org, mguizani@ieee.org

Corresponding author: Lianfen Huang, lfhuang@xmu.edu.cn.

Abstract—Device-to-device (D2D) communication, which is defined as a direct communication between two mobile users without traversing the Base Station (BS) or the core network to offload the increasing traffic to the user equipments, is one of the key technologies in the fifth generation (5G) of wireless communication systems. Discovery and communication are the basic two features to fulfill the need for the D2D communication. However, Most of existing D2D studies focused on the communication issues always assume that the discovery is completed. In this paper, we propose two strategies of device discovery and access scheme for the 5G cellular networks. Then the performance analysis based on two dimensional discrete time Markov process model is provided. In addition, we present numerical simulation on the Matlab platform. The simulation results demonstrate the viability of the proposed scheme.

Index Terms—D2D communication, device discovery, access procedure, Markov process.

I. INTRODUCTION

With the explosive increase in mobile service and user demands, such ever increasing data traffic has put significant pressure on the infrastructure of state-of-the-art cellular networks. Nonetheless, the existing techniques are not satisfying the users' needs in terms of mobile TV and voice, streaming music and video downloads due to the limited spectrum and bandwidth. Therefore, in order to deal with this significant pressure and provide a solution toward meeting new and evermore stringent end-user requirement, the next generation networks which is collectively referred to as 5G is expected to be deployed by 2020 by the mobile stakeholders.

To take a step toward this solution, one-key enabler toward a more disruptive and cost effective communication paradigm which is refer to as Device-to-Device (D2D) is adapted in the 5G technology. It is worth mentioning that a key motivation for D2D connectivity is the potential for operators to offload traffic from the core network and the frame work for a new communication paradigm to support social networking through localization. The concept of D2D communication is to allow the direct communications between two mobile users without traversing the BS or the core network. Thus, D2D communication can benefit from extremely high bit rate, low power consumption and shorter latency.

To the best of our knowledge, D2D communication which is proposed as a promising technology in the 5G system is

one of the highlights of 3GPP Release 12. As early as the 3GPP meeting held in June 2011, Qualcomm submitted a study item description on radio aspects of D2D discovery and communication. After that, so many companies and research institutions focus on the standardization of D2D communication, such as ZTE, Huawei, Intel and so on. And therefore many technology reports appear. [1] started a study on LTE Proximity Services (ProSe) which is the same concept of D2D communication in the Radio Access Network, and the D2D use cases and potential requirements are captured in [2]. In addition, [3] provided needed architectural enhancements to support ProSe and the security architecture is defined in [4]. Moreover, there are a large number of papers concerning on the D2D communication research in the aspect of interference management, resource allocation, power control and so on.

In this paper, we propose a sound model for analyzing discovery and access in D2D networks. The main contributions of this paper are summarized as follows:

(1) we propose two strategies of D2D device discovery and access procedure in the 5G cellular networks which initiated by the serving gate-way and the UEs, respectively. Moreover, we elaborate on the detail of the procedure and provide the visual flow diagram.

(2) we provide a mathematical model for analyzing the access and discovery in the first step before the D2D traffic transmission. The model utilizes a Markov process to make the performance analysis which distinguish interrelationship between access and congestion/collision probabilities.

(3) we present the evaluation by setting up the Matlab platform which validate the correctness of our analysis.

The remainder of this paper is organized as follows. After scanning the main related works in Section II, the mathematical model is presented in Section III. After that, we elaborate on the access procedure model and performance analysis in Section IV. In Section V, the numerical simulation is provided. Finally, conclusions and future work are presented in Section VI.

II. RELATED WORK

There is a large number of recent papers addressing D2D communication which concern about many applications such as mobile data offloading [5], cell coverage extension [6]

and file sharing [7], and also various of research issues such as interference management [8], resource allocation [9] and mode selection [10]. However, to the best of our knowledge, there are few existing researches investigating the device discovery and access procedure. In order to distinguish my work from the existing studies, we review all the literatures related to device discovery and access procedure. In TR 22.803 [11], several types of D2D discovery is categorized such as restricted ProSe discovery, open ProSe discovery and so on. In [12], the authors introduce scenarios, use cases and requirements for discovery of D2D and discuss the D2D discovery procedure, D2D discovery signal and LTE-based design. In [13], Yang and Huang propose a distributed peer discovery protocol for LTE-A networks, a mathematical model is also developed to evaluate the resource consumption while achieving the target discovery probability. In [14], the paper provides the evaluation methodology and channel modeling for D2D discovery and communication and also present a simulation environment based on 3GPP assumptions. Hong et al. Propose a D2D discovery and link setup procedure and analyze the interrelationship between the energy consumption and delay [15]. The main difference from the cited works compared to our proposal is the mathematical model and the performance metric analysis. In our work, we provide the mathematical model for analyzing device discovery and access procedure in D2D networks, the model utilizes a Markov process to distinguish the interrelationship between access and congestion/collision probabilities. Finally, evaluations are performed in the Matlab platform.

III. PROPOSED DISCOVERY AND ACCESS STRATEGIES

Discovery and Communication are basic two enabling features to fulfill the need for the D2D communication. However, Most of the existing D2D studies focused on the D2D communication issues assume that the discovery and access procedure is completed. As a result, few have investigated on this aspect. Although so many D2D communication issues have been widely discussed in the 3GPP meeting, there is still lack of a common procedure. In this session, we assume that a D2D-enabled UE is able to discover other D2D-enabled UEs in the proximity or be discoverable by the other D2D-enabled UEs of his/her proximity. Then we propose two strategies of device discovery and access procedure for the D2D network.

A. Initiated by the UEs

Intuitively, when a person starts to communicate with his/her friend, he/she do hope to set up the D2D communication due to the high data rate, low energy consumption and especially the shorter latency if they are gaming. Therefore, the first step to initiate the D2D connectivity should be done by the UEs themselves. As Fig. 1 displays, the access procedure is presented as follows:

1: One person/UE who hopes to make the D2D connectivity with others will send the basic device information periodically in the physical random access channel (PRACH) including a traffic type, denoted by the binary coding such as 00, 01,

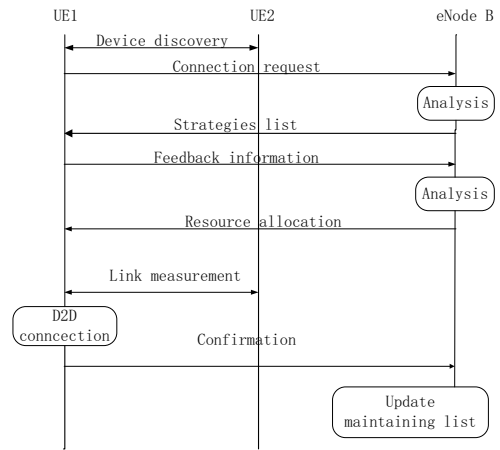


Fig. 1. An access procedure initiated by the UEs.

10 and 11, which correspond to file, video, voice and other types respectively; a device status, denoted by 0 and 1, which indicate close and open respectively; and a device identity, which is the international mobile subscriber identification number (IMSI) expressed by 48 bits. At the meantime, this UE detects the receiving information from others.

2: After matching the targeted UE, the initiated UE starts to send the D2D connectivity request to the eNodeB.

3: The eNodeB analyzes the connectivity request and selects the suitable communication pattern for the D2D pair according to the channel conditions and cell resource utilization.

4: When the normal cellular communication mode is adapted, it means that the D2D connectivity request is failed and the communication between the UEs returns to the conventional cellular mode.

5: Conversely, if the D2D mode request including orthogonal or reused pattern is permitted, the eNodeB will establish a strategy list including communication patterns, power indicator, scan spectrum and scan time and send it to UE1.

6: UE1 provides the feedback information to the eNodeB after completing the channel measurements which include the normalized interference interval denoted by T_{interf} and the normalized interference strength denoted by S_{interf} . We denote the weighted factor by α to T_{interf} , β to S_{interf} and define Opt_{chan} to present the channel interference level as

$$Opt_{chan} = \alpha T_{interf} + \beta S_{interf}. \quad (1)$$

7: The eNodeB allocates the spectrum resource with the lowest Opt_{chan} to UE1 and informs UE2 to sense at the same channel. Then UE1 sends a training sequence at the allocated channel in order to help UE2 to obtain the link quality. After that, UE2 will send the the confirmation back to UE1 if the link quality is satisfied, then UE1 confirms to eNodeB.

B. Initiated by the serving gateway (S-GW)

Beside the first scenario initiated by the UEs, the D2D connectivity can be also initiated by the S-GW even if the UEs do not aware of the proximity. When data packets reach

the S-GW, the IP head inside the data packets can be analyzed under the core network and whether the link can be considered as a D2D link or not will be observed. Fig. 2 shows the details which are described as follows:

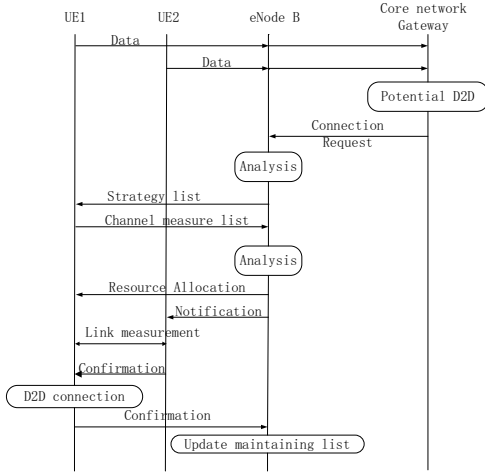


Fig. 2. An access procedure initiated by the S-GW.

1: After analyzing the IP head of the received data packets, the S-GW will initiate the D2D connectivity request to the eNodeB when the S-GW judge that the transmitter and receiver are at the same cell and the channel condition between them supports the D2D communication. The request messages include a device identity and a traffic type which are mentioned above.

2: The eNodeB establishes a strategy list, which includes the communication patters, power indicator, scan spectrum and scan time, after analyzing the request messages from S-GW and sends it to UE1.

The following steps are the same as the first scenario that D2D connectivity is initiated by the UEs.

IV. MATHEMATICAL MODELING AND PERFORMANCE ANALYSIS

Considering the total performance of the whole system, we do hope the system can obtain as much more throughput, less energy consumption, and shorter delay as possible. Thus the users whom intend to initiate the D2D connectivity would have higher priority than cellular users due to the advantage of D2D communication. In cellular communication mode, the cellular users utilize the fixed maximum back-off time. Nonetheless, in our work, the binary exponential back-off algorithm is adapted and we defined the minimum contending window (CW_{min}) as 1. Moreover, we set the maximum collision times to be smaller than that in the LTE-A specification [16]. In order to simplify the complexity of the design, it is benefited from the binary back-off algorithm since it just makes a few modifications based on the 802.11 model, and this will save the time to implement it into the hardware. In this paper, the collision probability for the D2D users access is denoted by p , the maximum number of collisions is denoted by m , and W_0 is

the equivalent representation of CW_{min} . As Fig. 3 shows, the state transition diagram of the binary back-off procedure can be described as the two dimensional discrete time Markov process $\{s(t), b(t)\}$ [17], where $s(t) \in [0, m]$, $m \in Z_0^+$ and $b(t) \in [0, W_i - 1]$, $W_i = 2^i$, $i \in [0, m]$. $s(t)$ presents the collision times counter and $b(t)$ means the back-off times for the UE.

As indicated in Fig. 3, the transition probability for one step can be expressed as

$$P\{i, k - 1 | i, k\} = 1, k \in [0, W_i - 1], i \in [0, m], \quad (2)$$

$$P\{0, k | i, 0\} = \frac{1-p}{W_0}, k \in [0, W_0 - 1], i \in [0, m], \quad (3)$$

$$P\{i, k | i - 1, 0\} = \frac{p}{W_i}, k \in [0, W_i - 1], i \in [1, m], \quad (4)$$

$$P\{m, k | m, 0\} = \frac{p}{W_m}, k \in [0, W_m - 1]. \quad (5)$$

In equation (6), $b_{i,k}$ is the stationary distribution of the Markov process, then (7) and (8) can be obtained according to Fig. 3. In addition, we can observe that $b_{m,0}$ consists of two parts, the first transition probability is from $b_{m-1,0}$ to $b_{m,0}$, and the other one is from $b_{m,0}$ to $b_{m,0}$.

$$b_{i,k} = \lim_{t \rightarrow \infty} P\{s(t) = i, b(t) = k\}, \quad (6)$$

$$i \in [0, m], k \in [0, W_i - 1]$$

$$b_{i-1,0} \times p = b_{i,0} \Rightarrow b_{i,0} = p^i \times b_{0,0}, i \in [1, m] \quad (7)$$

$$pb_{m-1,0} + pb_{m,0} = b_{m,0} \Rightarrow$$

$$pb_{m-1,0} = (1-p)b_{m,0} = p^m \times b_{0,0} \Rightarrow \quad (8)$$

$$b_{m,0} = \frac{p^m \times b_{0,0}}{1-p}$$

According to the stationary distribution theorem [17], $b_{i,k}$ can be obtained as following:

$$b_{i,k} = \frac{W_i - k}{W_i}$$

$$\times \begin{cases} (1-p) \sum_{j=0}^m b_{j,0} & i = 0 \\ p \times b_{i-1,0} & 0 < i < m \\ p \times (b_{m-1,0} + b_{m,0}) & i = m. \end{cases} \quad (9)$$

Since $\sum_{j=0}^m b_{j,0} = \frac{b_{0,0}}{1-p}$, (9) can be rewritten as

$$b_{i,k} = \frac{W_i - k}{W_i} \times b_{i,0}; i \in [0, m]; k \in [0, W_i - 1]. \quad (10)$$

Since the summation of each stationary distribution equals to 1, thus we have

$$1 = \sum_{i=0}^m \sum_{k=0}^{W_i-1} b_{i,k}$$

$$= \sum_{i=0}^m b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i - k}{W_i} = \sum_{i=0}^m b_{i,0} \times \frac{W_i + 1}{2} \quad (11)$$

$$\times \frac{b_{0,0}}{2} \left[\left(\sum_{i=0}^{m-1} (2p)^i + \frac{(2p)^m}{1-p} \right) + \frac{1}{1-p} \right].$$

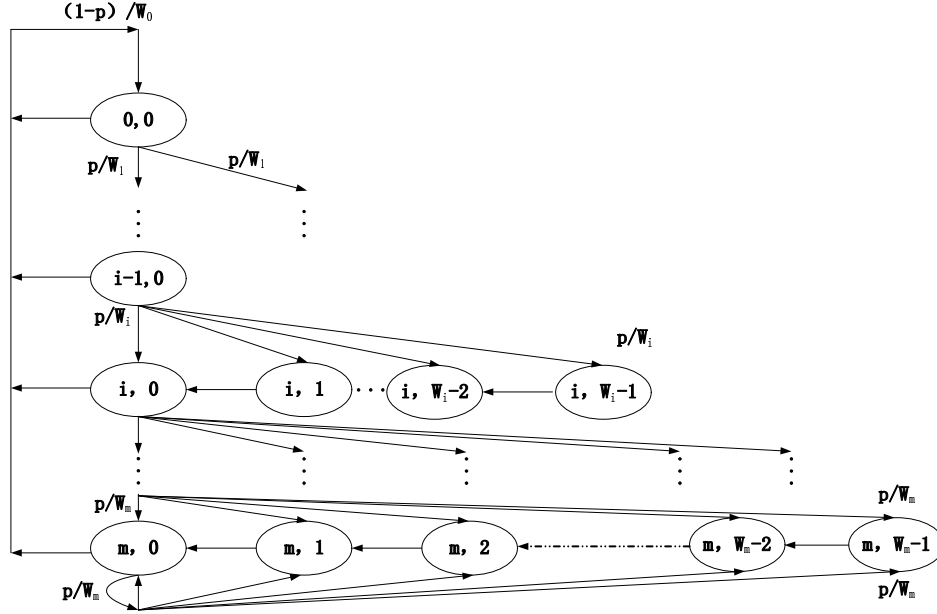


Fig. 3. A state transition diagram of two dimensional discrete time Markov process $\{s(t), b(t)\}$.

In order to obtain the explicit expression of $b_{0,0}$, equation (11) can be rewritten as

$$b_{0,0} = \frac{2(1-2p)(1-p)}{(1-2p)(CW_{min} + 1) + pCW_{min}(1-(2p)^m)}. \quad (12)$$

we denote by τ as the transmitting probability, then it can be given by

$$\begin{aligned} \tau &= \sum_{i=0}^m b_{i,0} = \frac{b_{0,0}}{1-p} \\ &= \frac{2(1-2p)}{(1-2p)(CW_{min} + 1) + pCW_{min}(1-(2p)^m)}. \end{aligned} \quad (13)$$

It is reasonable that the number of D2D users' access requests occurred at the same slot satisfies the Poisson distribution, thus the probability of k D2D UEs simultaneously initiating access requests at every access slot can be expressed as

$$p_k = \frac{(\lambda/N)^k}{k!} e^{-(\lambda/N)}, \lambda > 0, k = 0, 1, 2, \dots \quad (14)$$

In (14), λ is the intensity of users asking for simultaneous access, N is the number of preambles. The access collision probability can be given as

$$\begin{aligned} p &= p_c = 1 - p_k(0) - p_k(1) \\ &= 1 - (1 + (\lambda/N))e^{-(\lambda/N)}. \end{aligned} \quad (15)$$

Substituting (15) into (13), we can obtain

$$\tau = \frac{2(1-2p_c)}{(1-2p_c)(CW_{min} + 1) + p_c CW_{min}(1-(2p_c)^m)}. \quad (16)$$

V. SIMULATION RESULTS AND EVALUATIONS

In our work, we set up the simulation on the Matlab platform. We assume that the cell radius is 500 meters, the distribution of UEs follows the Poisson, the transmitting power of BS and D2D users is 250mW and 50mW respectively, the maximum distance between D2D pair equals to 25m and the total number of preamble resource is 64, the intensity of random access equals to 1.

In the simulation, as Fig. 4 shows, we can obtain the relationship between three parameters including the user's access probability, collision probability and the allowable maximum number of collisions m . From the three dimensional (3D) figure, we can conclude that the user's access probability decreases as the collision probability increases under the fixed number of allowable maximum collisions m , and vice versa. In addition, the collision probability will decrease if we increase m when we control the access probability to be stable. Therefore, this paper can be the guidelines for people to select the suitable m according to the real D2D users access probability and the requirement of collision probability.

In addition, from Fig. 5, we can also observe that when the number of D2D users that request to access simultaneously increases, the collision probability also increases. However, it reduces when we increase the available number of RBs. It is worth mentioning that when the number of D2D users that simultaneously request to access is less than 10, the collision probability is below 0.1. Comparing with Fig. 4, we can observe that the user's access probability is higher than 0.9. This result will meet the requirement of a practical system performance. Moreover, when the number of RBs is few and the number of D2D users that request to access simultaneously is large enough, the collision probability is almost equal to 1.

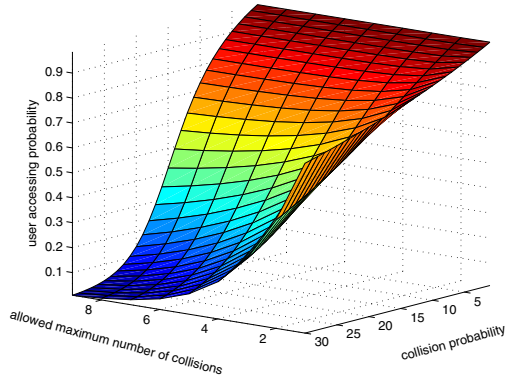


Fig. 4. The relationship between user's accessing probability, collision probability and the allowable maximum number of collisions.

In our work, we also present the average access latency which is one of the most important performance metrics in our strategies. From Fig. 6 we observe that the average access latency increase as the growing number of access users or as the decreasing number of preambles.

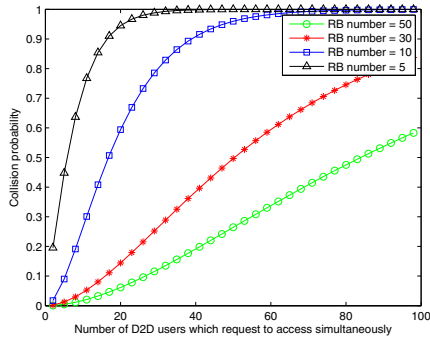


Fig. 5. The relationship between the collision probability and the number of D2D users which request access simultaneously under the premise of a different number of RBs.

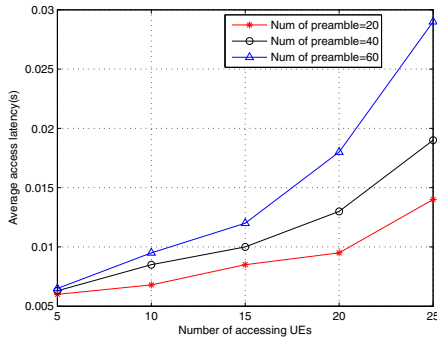


Fig. 6. The relationship between the average accessing latency and the number of D2D users which request access simultaneously under the premise of a different number of preambles.

VI. CONCLUSION

In this paper, two strategies of D2D device discovery and access procedure for the 5G cellular network are proposed with the mathematical model based on two dimensional discrete time Markov process. In addition, we provide the performance analysis. Furthermore, we conduct extensive simulations using the Matlab platform. In our analysis, we obtain the relationship between the accessing probability, collision probability and the maximum number of collisions. A reasonable trade-off between the allowable maximum number of collisions and the collision probability is discussed and the simulation results show that the average accessing latency increases as the growing number of preambles or the decreasing number of accessing users .

ACKNOWLEDGMENT

This work was supported in part by the 2012 National Natural Science Foundation of China (Grant number 61172097), the 2014 National Natural Science Foundation of China (Grant number 61371081), the 2013 Science Technology Key Project of Fujian (Grant number 2013H0048), the 2013 Science Technology Project of Xiamen (Grant number 3502Z20131155), the 2015 National Natural Science Foundation of China (Grant number 61401381), the National High-Tech R&D Program (863 Program 2015AA01A705), as well as the United States National Science Foundation under grant CNS-1065444.

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