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RESEARCH ARTICLE

Efficient device-to-device discovery and access procedure for 5G cellular network

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ABSTRACT

A large number of new data-consuming applications are emerging, and many of them involve mobile users. In the next generation of wireless communication systems, device-to-device (D2D) communication is introduced as a new paradigm to offload the increasing traffic to the user equipment. Before the traffic transmission, D2D discovery and access procedure is the first important step which needs to be completed. In this paper, our goal is to design a device discovery and access scheme for the fifth generation cellular networks. We first present two types of device discovery and access procedures. Then we provide performance analysis based on the Markov process model. In addition, we present numerical simulation on the Vienna Matlab platform. The simulation results demonstrate the viability of the proposed scheme. Copyright © 2015 John Wiley & Sons, Ltd.

KEYWORDS
D2D communication; device discovery; access procedure; Markov process

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1. INTRODUCTION

Wireless data traffic had been dramatically increasing over the past few years. Nonetheless, the existing techniques are not satisfying with the users' needs in terms of the emergence of applications for daily routines (e.g., proximity-aware services). Therefore, there is a wave of popular interest to seek for new paradigms to deal with this problem. In the coming fifth generation (5G) cellular networks, emerging technologies will lead to both disruptive architectural and component design changes [1–5]. For instance, in 5G wireless communication systems, diverse researchers study different aspects of millimeter wave transmission, which are plentiful because spectrums have become scarce at microwave frequencies [6,7]. Massive multiple-input multiple-output, which could increase the system throughput is proposed to utilize a very high number of antennas [8]. We know that 2G–3G–4G cellular networks were built under the design premise of having complete control from the infrastructure side. However, this assumption should be dropped in the 5G systems. The base-station-centric architecture of cellular systems may change, and intelligence at the device side, within different layers of protocol stack, should be exploited, for example, by allowing device-to-device (D2D) connectivity.

Device-to-device communication defined as a direct communication between two mobile users without traversing the base station or the core network is considered to be a promising technique [8–10], which also offloads the increasing data traffic into user equipments (UEs). In a traditional cellular network, it is implicitly implied that two parties willing to establish the same call will not be in close proximity to each other. Therefore, all communications must go through the base station. However, in the age of data, mobile users in today's cellular networks are potentially in range for direct communications using high data rate services. Thus, D2D communication, which can decrease latency [11,12] and increase resource utilization [13,14] had been proposed as a means of taking advantage of the physical proximity of communicating devices. Figure 1 shows a simple example of D2D communication.

The majority of the literatures in D2D communication proposed to use the cellular spectrum for both D2D and cellular communication. Most of these previous studies have focused on issues such as resource allocation and interference mitigation [15,16]. Although, few existing studies have investigated the D2D access procedure. Here we review the literatures related to device discovery and access procedure. In TR 22.803 [17], the D2D discovery is categorized into several types, which are sum-

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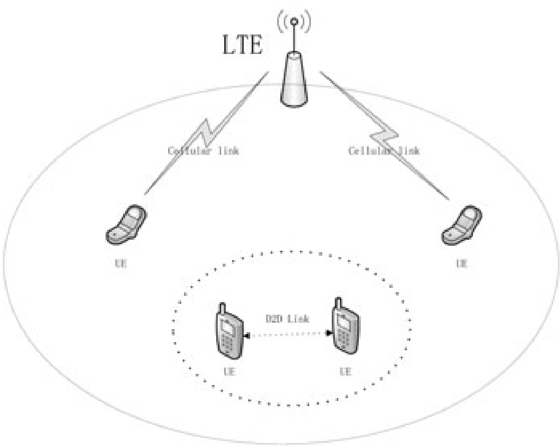

Figure 1. An example of device-to-device communication in a cellular network. LTE, long-term evolution.

marized in [18]. In addition, the D2D discovery procedure and long-term evolution (LTE)-based design are also discussed in [18]. Yang *et al.* proposed a distributed peer discovery protocol for LTE-A networks [19]. In [20], they provided an overview of the new agreements in third generation partnership project LTE radio access networks related to evaluation methodology and channel modeling for D2D discovery and communications. Hong *et al.* proposed a D2D discovery and link setup procedure and analyzed its performance in terms of energy consumption and delay by utilizing the measurement results of real LTE smartphones [21]. However, all of the existing works lack the overall performance analysis based on the Markov process model. In this work, we will provide the system model based on the Markov process and present the performance analysis. Moreover, we give our proposal on the Vienna Matlab platform, which is a system level Matlab simulator developed by Vienna University of Technology [22] and obtain the simulation results.

The rest of this paper is organized as follows: In Section 2, we will describe the system model. After that, we will present the access procedure model and performance analysis in Section 3. In Section 4, the numerical simulation will be provided. Finally, we conclude the paper in Section 5.

2. SYSTEM MODEL

In this work, we assume a D2D-enabled UE of a given user is able to discover and be discoverable by the D2D-enabled UEs of his or her friends. The first step for D2D communication is that the UE that intends to initiate the D2D communication has to discover other potential D2D users and establishes the link connection. In this paper, we propose in detail two main occasions about the device discovery and link setup procedure as follows.

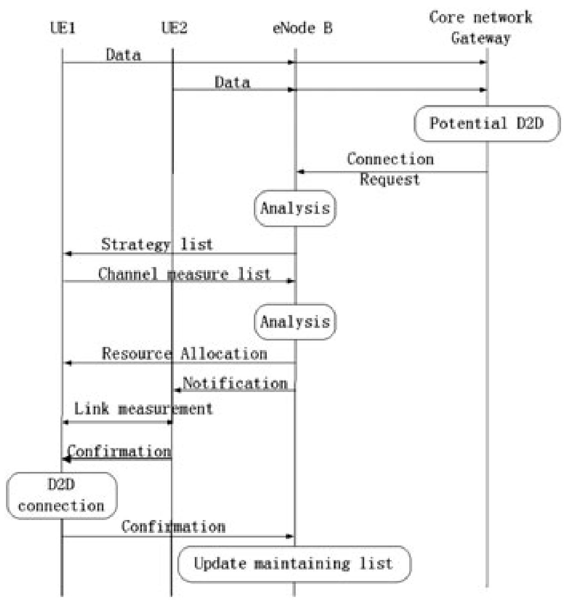

Figure 2. An access procedure initiated by the serving gateway. D2D, device-to-device.

2.1. Initiated by the serving gateway

One occasion for device discovery and access procedure is based on the serving gateway (S-GW), which considers the traffic as a potential D2D link by analyzing the internet protocol head in the data packets under the 5G core network. The following steps are illustrated in Fig. 2.

Step 1: The S-GW initiates the request of a D2D connection to the evolved node B (eNodeB) when the transmitter and receiver are at the same cell, and the distance between them supports the D2D communication. The request messages include a device identity and a traffic type.

Step 2: After analyzing the request messages, the eNodeB establishes a strategy list presented in Table I, which includes communication patterns, power indicator, scan spectrum, and scan time and then sends it to UE1.

Step 3: After receiving the strategy list, UE1 starts to scan the channel and provides feedback information presented in Table II to the eNodeB. The feedback information includes the normalized interference interval denoted as T_{interf} and the normalized interference strength denoted as S_{interf}. We denote the weighted factor by α to T_{interf}, β to S_{interf} and define Opt_{chan} to present the channel interfered level as

$$Opt_{\text{chan}} = \alpha T_{\text{interf}} + \beta S_{\text{interf}} \tag{1}$$

Step 4: According to Equation (1), eNodeB allocates the spectrum resources with the lowest Opt_{chan} to UE1 and informs UE2 to sense in the same chan-

Table I. Device-to-device strategy list.

Parameters	Length/bit	Value	
Communication patterns	2	00	Orthogonal
		01	Reused
		10	Cellular
Power indicator	1	0	High
		1	Low
Spectrum	8	0	Whole spectrum
		[7:4]	Starting
		[3:0]	Ending
Scan time	8	Unit: ms	

Table II. Feedback information.

Parameters	Channel 1	Channel 2	...
T_{interf}(ms)	3	5	...
S_{interf}(dBm)	−99	−91	...

nel. After that, UE1 sends a training sequence to UE2 in order to measure the link quality. Then UE2 sends the confirmation back to UE1 if the link quality is satisfied and UE1 confirms to eNodeB.

2.2. Initiated by the user equipments

The second occasion is initiated by the UE itself other than the S-GW. As Figure 3 illustrates, D2D communication occurs between two UEs, and the access procedure is provided in the following steps:

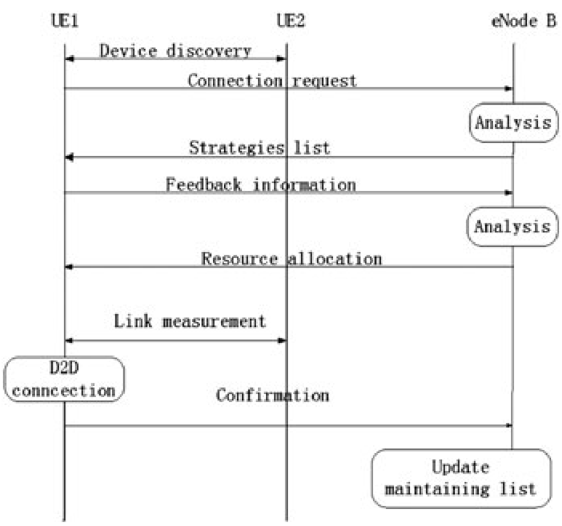

Figure 3. An access procedure initiated by the user equipments (UEs).

Table III. A request list of a device-to-device connection.

Parameters	Length/bit	Value	
Identity	48	IMSI	
D2D status	1	0 : close	
		1 : open	
Traffic type	2	00	Voice
		01	Video
		10	File
		11	Others

IMSI, international mobile subscriber identification number; D2D, device-to-device.

Step 1: The UE that intends to communicate with others in D2D mode periodically sends the basic device information illustrated in Table III. This includes a device identity, a device status, and a traffic type in the physical random access channel. Meanwhile, it detects the same information from others. The device identity could be the international mobile subscriber identification number expressed by 48 bits. The device status is divided into two cases. For instance, 0 indicates close and 1 indicates open. The traffic type has four options including 00, 01, 10, and 11, which correspond to voice, video, file, and other types, respectively.

After discovering the targeted UE, the initiated UE selects the targeted UE as the D2D pair and then sends the connection request to the eNodeB.

Step 2: After receiving a connection request from the initiated UE, eNodeB analyzes it and makes the corresponding operations as follows:

Firstly, the eNodeB selects the suitable communication pattern for the initiated UE according to the cell resource utilization. If a cellular pattern is selected, the initiated UE drops the D2D connected request and returns to the cellular pattern. Otherwise, if the selection is an orthogonal or reused spectrum pattern, the eNodeB sends the messages to the initiated UE including power and spectrum information. After that, the initiated UE generates feedback information to the eNodeB, according to the allocated resource.

These are the same operations within the steps as the first occasion that D2D communication is initiated by the S-GW.

3. ACCESS PROCEDURE MODELING AND PERFORMANCE ANALYSIS

Device-to-device communication is a promising technology that reuses the cellular spectrum effectively and improves network throughput significantly; thus, the users whom intend to initiate D2D communication would have higher priority than cellular users. In cellular networks, the core networks set the fixed maximum back-off time for the cellular users. However, in our proposal, we utilized the binary exponential back-off algorithm for the D2D users and defined the minimum contending window (CW_{min}) as 1. In order to ensure the priority of the D2D UE, we assumed that the allowable maximum collision times is smaller than that defined in the LTE-Advance specification [23]. Moreover, the selection of the binary back-off algorithm simplified the design of the device because it just made few modifications based on the 801.11 model.

In this paper, we denote p as the collision probability for the D2D users' access, m as the maximum number of collisions, and W_0 as the equivalent representation of CW_{min}. The binary back-off procedure can be considered as the two dimensional discrete time Markov process $\{s(t), b(t)\}$ [24]. $s(t)$ is the collision times counter and $s(t) \in [0, m], m \in Z_0^+$. $b(t)$ is the back-off times for the UE, $b(t) \in [0, W_i - 1], W_i = 2^i$, and $i \in [0, m]$. The state transition diagram is illustrated in Figure 4.

As Figure 4 indicates, the one step of transition probability could be written as

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

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

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

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

Equation (2) indicates that the probability of reducing k to $k-1$ is 1, at the beginning of every time slot. Equation (3) calculated the probability that, after transmitting a frame successfully, the UE's status is transferred from $(i, 0)$ to $(0, k)$. Similarly, Equation (4) is the probability of UE's status transferring from $(i-1, 0)$ to (i, k) after failing to transmit a frame. The probability of UE's status from $(m, 0)$ to (m, k) is expressed in Equation (5) when the allowable collision times reached the maximum value m.

We assume $b_{i,k}$, presented as Equation (6) is the stationary distribution of the Markov process. According to Figure 4, we can have Equations (7) and (8). From Figure 4, we can observe that $b_{m,0}$ contains two parts of transition probability, one is from $b_{m-1,0}$ to $b_{m,0}$ and the other is from $b_{m,0}$ to $b_{m,0}$.

$$\begin{aligned} b_{i,k} &= \lim_{t \to \infty} P\{s(t) = i, b(t) = k\}, \\ & i \in [0, m], k \in [0, W_i - 1] \end{aligned} \quad (6)$$

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

$$\begin{aligned} & pb_{m-1,0} + pb_{m,0} = b_{m,0} \Rightarrow \\ & \quad pb_{m-1,0} = (1-p)b_{m,0} = p^m \times b_{0,0} \Rightarrow \\ & \quad b_{m,0} = \frac{p^m \times b_{0,0}}{1-p} \end{aligned} \quad (8)$$

According to the stationary distribution theorem [24], we can obtain $b_{i,k}$ from the following:

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

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

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

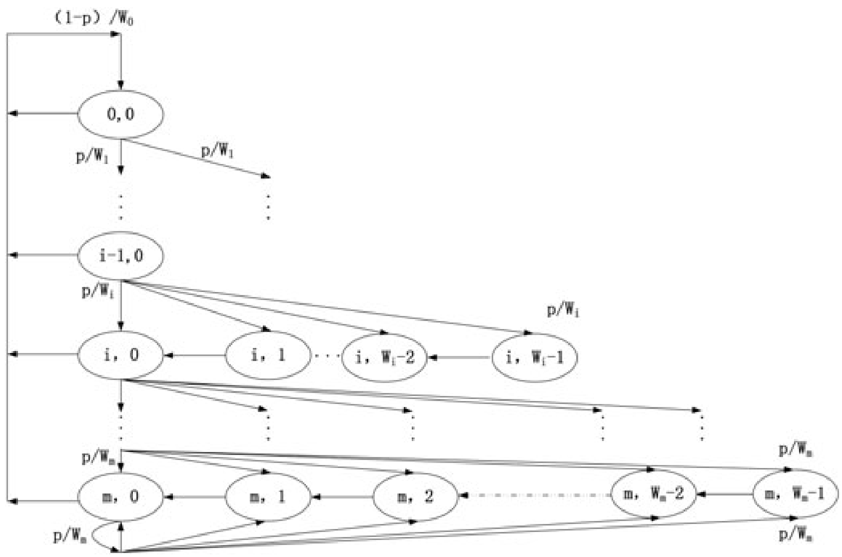

Figure 4. A state transition diagram of Markov process $\{s(t), b(t)\}$.

In addition, the summation of each stationary distribution is 1; thus, we can have

$$\begin{aligned}1 &= \sum_{i=0}^{m}\sum_{k=0}^{W_i-1} b_{i,k} \\ &= \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i-k}{W_i} = \sum_{i=0}^{m} b_{i,0} \times \frac{W_i+1}{2} \\ &\times \frac{b_{0,0}}{2}\left[\left(\sum_{i=0}^{m-1}(2p)^i + \frac{(2p)^m}{1-p}\right) + \frac{1}{1-p}\right]\end{aligned} \tag{11}$$

Transforming Equation (11) to another expression form, we can obtain $b_{0,0}$ as

$$b_{0,0} = \frac{2(1-2p)(1-p)}{(1-2p)(\mathrm{CW}_{\min}+1) + \mathrm{pCW}_{\min}(1-(2p)^m)} \tag{12}$$

Here, we define τ as the transmitting probability, which results in

$$\begin{aligned}\tau &= \sum_{i=0}^{m} b_{i,0} = \frac{b_{0,0}}{1-p} \\ &= \frac{2(1-2p)(1-p)}{(1-2p)(\mathrm{CW}_{\min}+1) + \mathrm{pCW}_{\min}(1-(2p)^m)}\end{aligned} \tag{13}$$

We assume that the procedure of D2D users' access satisfies Poisson distribution; thus, the probability of k D2D UEs simultaneously initiating access requests at every access slot is expressed as

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

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

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

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

$$\tau = \frac{2(1-2p_c)}{(1-2p_c)(\mathrm{CW}_{\min}+1) + \mathrm{p_c CW}_{\min}(1-(2p_c)^m)} \tag{16}$$

Thus, we have

$$p_c\tau(2p_c)^m - 4p_c + 3p_c\tau - 2\tau + 2 = 0 \tag{17}$$

When a large number of UEs start to access simultaneously, we know that frequent collision will occur. In this paper, we propose the control scheme to ensure the acceptable access probability , which is expressed as

$$\alpha\tau(t) + (1-\alpha)\tau(1-t) \geq \rho \tag{18}$$

where α is the weighted factor, $\tau(t)$, and $\tau(t-1)$ is the user's access probability at t and $t-1$ time slot and ρ is the access threshold. Based on this constraint, we could obtain the controllable access probability denoted by P_{ctrl}, as expressed in Equation (19), which can adjust the user's access probability in the next time slot if Equation (18) is not satisfied. Otherwise, $P_{\mathrm{ctrl}} = 1$.

$$P_{\mathrm{ctrl}} = \frac{\alpha\tau(t) + (1-\alpha)\tau(t-1)}{\rho} \tag{19}$$

4. SIMULATION RESULTS AND ANALYSIS

In this section, we put our proposal into the Vienna Matlab platform and receive the simulation results. Here, we assume that D2D communication reuses the downlink resource for transmission. The main simulation parameters are presented in Table IV.

According to Equation (17), the relationship between the user's access probability and collision probability under the premise of different maximum number of collisions m is presented in Figure 5. As Figure 5 displays, we conclude that users' access probability increases as the maximum number of collisions m reduce under the same collision probability. Otherwise, the collision probability reduces as m increases. Therefore, we need to choose a suitable m that considers both the collision probability and the access probability.

At this point, we assume that the arrival of the D2D UE's access request follows the Poisson process. Figure 6 shows the relationship between the maximum times of collisions and the collision probability.

As Figure 7 indicates, when the number of D2D users that simultaneously request access is less than 10, the collision probability is below 0.1. Compared with Figure 5, it appears that the user's access probability is higher than 0.9. This result will satisfy the need of a practical system performance.

Through numerical simulation on the Vienna Matlab platform, we can obtain the average access delay under the premise of a differing number of preambles. As Figure 8 presents, the access delay increases as the number of D2D users, which are simultaneously starting to access, increase. Otherwise, the access delay decreases as the number of preambles reduce.

5. CONCLUSION

In this paper, we proposed two types of D2D device discovery and access procedure for the 5G cellular network, presented the system model based on the Markov process, designed an access control algorithm, and provided the performance analysis. Moreover, we conducted extensive simulations using the Vienna Matlab platform. In our analysis, we obtained the relationship between the access probability and the collision probability for different maximum number of collisions. A reasonable trade-off between

Table IV. Simulation parameters.

Cell type	Hexagon
Cell radius	500 m
Distribution of UEs	Possion
Total Bandwidth	1.4 MHz
Total number of RBs	6
BS Transmitting power	250 mW
D2D Transmitting power	50 mW
Maximum distance between D2D pair	25 m
Total number of Preamble resource	64
The density of random access	1 (config 1 PRACH per 10 ms)
Wireless channel type	Pathloss $d^{-\alpha}$ (d is the distance between D2D pair, $\alpha = 4$)

UEs, user equipments; RBs, resource blocks; D2D, device-to-device; BS, base station; PRACH, physical random access channel.

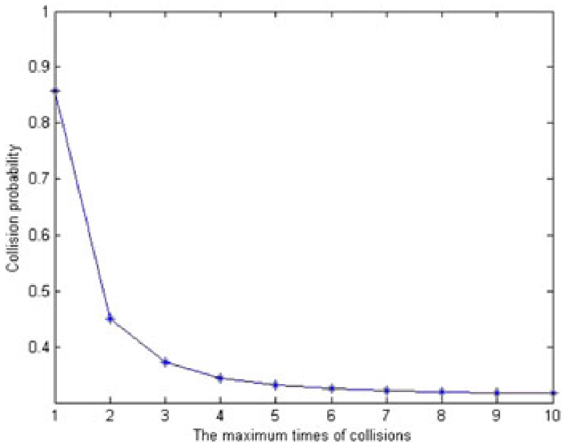

Figure 5. The relationship between the maximum number of collisions and the collision probability.

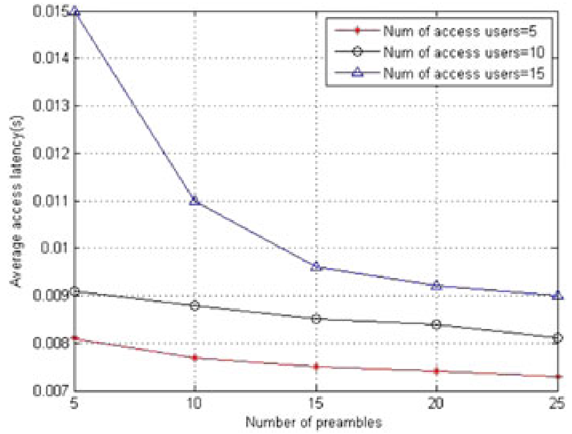

Figure 7. The average access delay under the premise of a differing number of preambles.

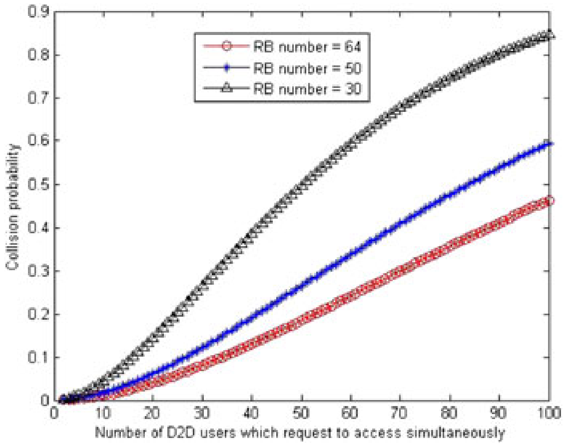

Figure 6. The relationship between the collision probability and the number of device-to-device users, which request access under the premise of a differing number of RBs.

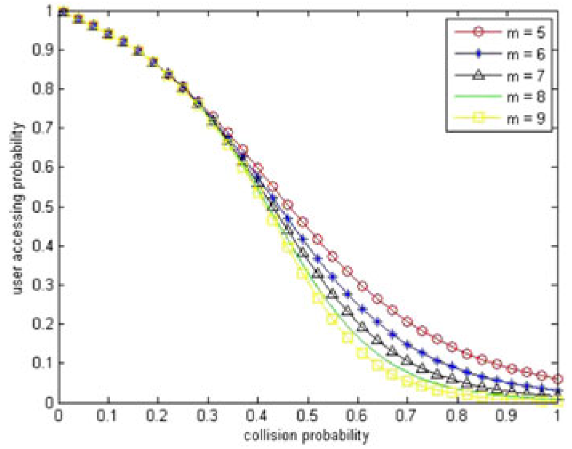

Figure 8. The relationship between user's access probability and collision probability under the premise of a differing maximum number of collisions.

the allowable maximum number of collisions and the collision probability was discussed, and the simulation results showed that the average access latency increased as the number of either preambles or users increase.

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