

Analysis of User Access Probability and Collision in Device-to-Device Communication for 5G Cellular Network

Amrita J. Itkurkar¹, S.K.Sudhansu²P.G., Department of Digital Communication, M.B.E.S. College of Engineering, Ambajogai, Maharashtra, India¹P.G., Department of Digital Communication, M.B.E.S. College of Engineering, Ambajogai, Maharashtra, India²

ABSTRACT: In the near future, i.e., beyond 4G, to fulfil the increasing demands for higher capacity, improved data rate, decreased latency and better quality of service, the wireless based networks of today will have to advance in various ways. In next generation of wireless networks, Device-to-Device (D2D) communication is considered as an innovative mobile network technology for improving communication performance and network capacity of fifth generation (5G) cellular system. It is introduced to offload the increasing traffic to the user equipment. To achieve better efficiency and improved traffic transmission rate in communication, it is highly important to reduce collision. In this paper, our goal is to design a scheme to minimize collision probability for D2D communication. We first provide performance analysis based on the Markov process model using numerical calculations on Matlab. In addition, we present the relationship between user access probability and collision probability. The results demonstrate the viability of the proposed scheme.

KEYWORDS: D2D communication, 5G, Collision probability, Markov process, User access probability.

I. INTRODUCTION

Mobile communications, which enable anytime and anywhere universal connectivity, is an integrated part of our daily life. A large number of new bandwidth-hungry mobile applications are emerging which leads to rapid increase in wireless communication traffic. Nonetheless, the existing techniques are not satisfying with the users' needs. Therefore, to sustain such a traffic growth and in a meantime to improve quality of service and network capacity, continuous innovations on wireless communication technologies are required. In the coming fifth generation (5G) cellular networks, emerging technologies will lead to architectural and component design changes to please user requirements [1-5]. For instance, various researchers study different aspects/advantages to utilize millimeter wave transmission in 5G wireless communication systems [6,7]. Massive multiple-input multiple-output (MIMO), which has been upgraded from current MIMO technology uses arrays of large number of antennas to increase the system throughput [8]. We know that 2G-3G-4G cellular network architecture design have complete control from infrastructure side. However, in the coming 5G system this base-station-centric architecture of cellular system 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 refers to direct communication between two mobile users allowing local exchange of user plane traffic without going through a network infrastructure [9]. D2D communication is generally non-transparent to the cellular network and it can be categorized into both In-Band (using cellular spectrum) and Out-Band (using unlicensed spectrum). In-Band communication can be further classified into Underlay (same licensed spectrum for cellular and D2D user) and Overlay (dedicated cellular resources for D2D user) modes. Out-Band communication can be divided as Controlled (by base station) and Autonomous (controlled by user) [9-11]. In a traditional cellular network,

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it is implied that all communication must go through the base station. However, mobile users in today's cellular network use high data rate services and are in a range for D2D communication. Thus D2D communication had been proposed to improve performance such as increased data rate, reduced transmission power, enhanced network capacity and extended coverage area [9-11].

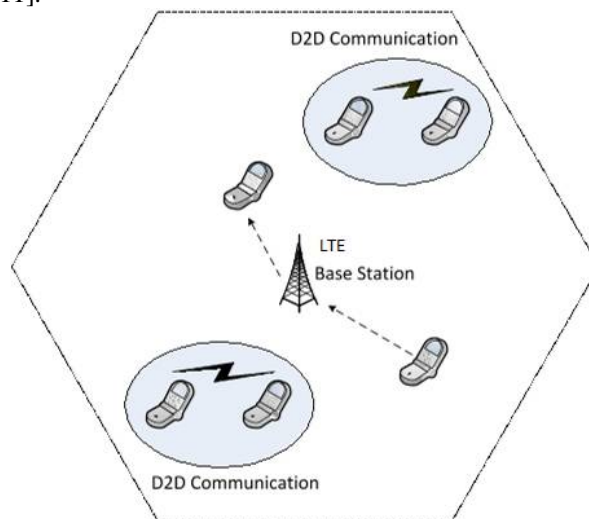


Fig.1.D2D communication in a cellular network. LTE, long-term evolution

Fig. 1 shows a simple example of Device-to-Device communication in a cellular network. It shows that users can communicate directly without traversing the base station.

To date, extensive research has been done on D2D communication in cellular networks. Most of the researches proposed to use the cellular spectrum for both D2D and cellular communication. Most of the work in previous studies had been done on issues such as resource allocation and interference mitigation [12-16]. However, all of the existing works lack the overall performance analysis based on reduction of Collision probability. Collision probability has been extensively studied as it is the most important ingredient for any performance evaluation (such as rate of transmission or delay evaluation).

In this paper, we are considering the system model based on D2D discovery and link setup procedure as proposed in the previous works [1,17]. Here, the performance analysis of the given system model based on the Markov process model is provided to reduce the collision probability. Moreover, the user access probability is also calculated and we obtain the relationship between user access probability and collision probability under different number of maximum collision. The results are obtained by using extensive numerical calculations on Matlab.

The rest of paper is organized as follows: We discuss related work in Section II. The given system model is illustrated in Section III. The mathematical modelling and performance analysis is formally presented in Section IV. The numerical calculations results are presented in Section V and finally we conclude the paper in Section VI.

II. RELATED WORK

In this section we provide the related work on D2D communication. We also review the literatures related to device discovery and access procedure.

In underlay In-Band D2D communication, cellular and D2D users share the same licensed spectrum which will result in interference creation for cellular users. On the contrary, overlay In-Band D2D users use the dedicated spectrum and eliminates the possibility of interference from D2D users to cellular users while reduces the amount of available resources for cellular communication.

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Many of the authors have focused their studies on the In-band D2D communication with the main aspects of interference cancellation, resource allocation, mode selection, power saving. The authors of [10] propose a model to minimize the power consumption while meeting user data rate requirements, they also define an algorithm to jointly determine mode selection, channel allocation and power assignment. In [11], the authors discuss technical challenges and important research aspects that enable D2D communications underlying cellular networks. To enhance the overall capacity of cellular networks and D2D systems, authors of [12] propose a new interference management strategy. In [13], a reverse iterative combinatorial auction scheme is introduced as the resource allocation mechanism in which the packages of the D2D pairs are auctioned off in each round. In [14], problem formulation for resource allocation and an algorithm for interference mitigation in LTE network is proposed. Shaoyi et al. [15] design a new interference cancellation scheme based on the location of users. In [16], to avoid interference, the authors propose the scheme that D2D users read the resource allocation information so that they can avoid the resource block used by the cellular users in the proximity. Lin et al. [17], propose the hybrid architecture that combines ISM 2.4G spectrum/Bluetooth as Out-band mode and Wifi-Direct with the cellular spectrum as In-band mode.

The D2D discovery is categorized into several types, which are summarized in [18] along with the discussion on D2D discovery procedure and long-term evolution (LTE)-based design. The authors of [19] propose a distributed peer discovery protocol for LTE-A networks. Meryem et al. [20] provide an overview of the new agreements in 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) Radio Access Networks (RAN) related to evaluation methodology and channel modelling for D2D discovery and communications. The authors of [21] propose a D2D discovery and link setup procedure and analysed its performance in terms of energy consumption and delay by utilizing the measurement results of real LTE smartphones.

III. D2D SYSTEM MODEL

In this work, we are illustrating the similar system model based on D2D discovery and link setup procedure as proposed in the previous works [1] [17] [21]. Here, one assumption is made that a D2D-enabled mobile User Equipment (UE) of a given user is able to discover and be discoverable by the D2D-enabled UEs of his or her friends. Initially the link setup procedure of D2D communication has to be completed before the D2D traffic transmission. Hence, as a first step the UE initiating the D2D communication has to discover other potential D2D user and establish a link connection. Fig. 2 shows the D2D discovery and link setup model as follows.

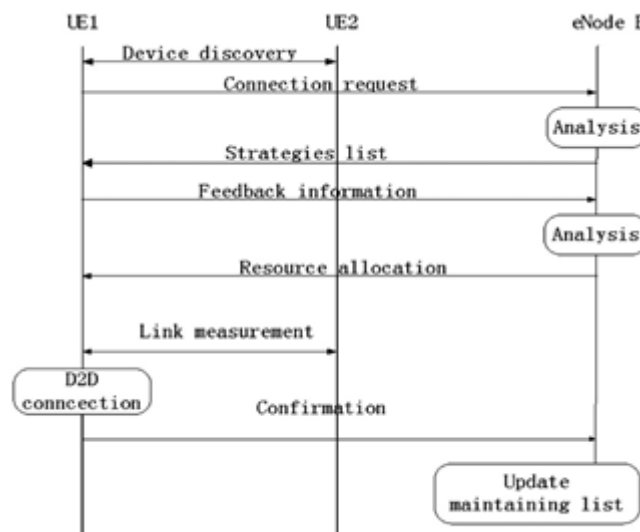


Fig. 2. D2D discovery and link setup model.

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As Fig. 2 illustrates, D2D communication occurs between two UEs. The D2D link setup procedure is composed of three parts: D2D link setup request/response, resource allocation and D2D link establishment

1. D2D link setup request/response: The UE that intends to communicate with others in D2D mode periodically sends the basic device information which 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.
2. Resource allocation: After receiving a connection request from the initiated UE, eNodeB analyses 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.
3. D2D link establishment: After resource allocation to each UE, 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. After that a D2D link is established and the link setup is completed.

IV. MATHEMATICAL MODELLING AND PERFORMANCE ANALYSIS

In LTE-based Device-to-Device communication is a prominent technology that reuses the cellular spectrum effectively and improves the system capacity and quality of service and network throughput significantly; thus, the users planning to initiate D2D communication 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. In spite of that, in this work, the exponential back-off algorithm is adapted. Also, we set the maximum collision times to be smaller than that in the LTE-A specification [22]. In order to simplify the complexity of the design, the exponential back-off algorithm is selected since it just makes a few modifications based on the IEEE 802.11 model.

In this paper, the collision probability for D2D user's access is denoted by p , the maximum number of collisions is denoted by m , and W_0 as the equivalent representation of CW_{min} .

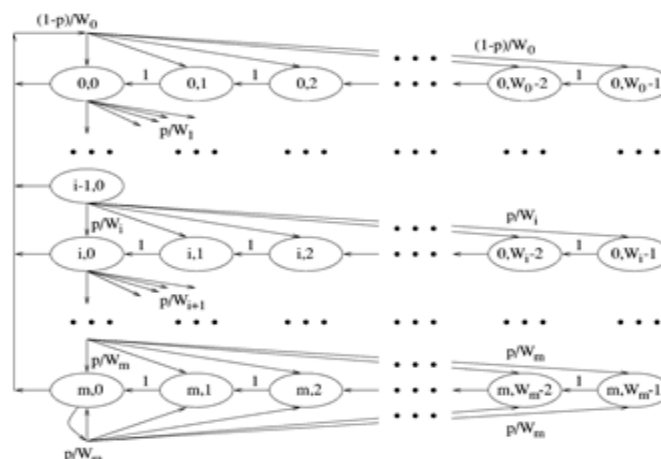


Fig. 3. The Markov process model for exponential back-off procedure of $\{s(t), b(t)\}$.

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As Fig. 3 shows, the Markov process model for exponential back-off procedure can be described as bidimensional process $\{s(t), b(t)\}$ [23], where $s(t) \in [0, m]$, $m \in \mathbb{Z}_0^+$ and $b(t) \in [0, W_i - 1]$, $W_i = 2i$, $i \in [0, m]$. Here, $s(t)$ presents the collision time's counter and $b(t)$ means the back-off times for the UE.

In this Markov chain, the one-step transition probabilities are,

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

$$P\{0, k | i, 0\} = \frac{1-p}{W_0}, k \in [0, W_0 - 1], i \in [0, m] \quad (2)$$

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

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

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

Here, we assume $b_{i,k}$, presented as Equation (5) is the stationary distribution of the Markov process. According to Figure 3, we can have Equations (6) and (7). From Figure 3, 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 $b_{m,0}$.

$$b_{i,k} = \lim_{t \rightarrow \infty} P\{s(t) = i, b(t) = k\}, i \in [0, m], k \in [0, W_i - 1] \quad (5)$$

$$b_{i-1,0} \times p = b_{i,0} \Rightarrow b_{i,0} = p^i \times b_{0,0}, i \in [1, m] \quad (6)$$

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

$$pb_{m-1,0} = (1-p)b_{m,0} = p^m \times b_{0,0} \Rightarrow b_{m,0} = \frac{p^m \times b_{0,0}}{1-p} \quad (7)$$

From the stationary distribution theorem [23], we can obtain $b_{i,k}$ from the following:

$$\begin{aligned} b_{i,k} &= \frac{W_i - k}{W_i} \times \{(1-p) \sum_{j=0}^m b_{j,0} \quad i=0 \\ & p \times b_{i-1,0} \quad 0 < i < m \\ & p \times (b_{m-1,0} + b_{m,0}) \quad i=m \} \end{aligned} \quad (8)$$

Making use of the fact that $\sum_{j=0}^m b_{j,0} = \frac{b_{0,0}}{1-p}$, Equation (8) can be rewritten as

$$b_{i,k} = \frac{W_i - k}{W_i} \times b_{i,0}; i \in [0, m]; k \in [0, W_i - 1] \quad (9)$$

Since, the summation of each stationary distribution is 1. Thus, we have

$$\begin{aligned} 1 &= \sum_{i=0}^m \sum_{k=0}^{W_i-1} b_{i,k} = \sum_{i=0}^m b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i - k}{W_i} = \sum_{i=0}^m b_{i,0} \times \frac{W_i + 1}{2} \\ & \times \frac{b_{0,0}}{2} \left[(\sum_{i=0}^{m-1} (2p)^i + \frac{(2p)^m}{1-p}) + \frac{1}{1-p} \right] \end{aligned} \quad (10)$$

In order to obtain the explicit expression of $b_{0,0}$, equation (10) can be rewritten as

$$b_{0,0} = \frac{2(1-2p)(1-p)}{(1-2p)(CW_{min} + 1) + pCW_{min}(1-(2p)^m)} \quad (11)$$

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Here, we define τ as the transmitting probability, it can be given by

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

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

$$p_k = \frac{(\lambda/N)^k}{k!} e^{-\frac{\lambda}{N}}, \lambda > 0, k = 0, 1, 2 \dots \quad (13)$$

In Equation (13), 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

$$p = p_c = 1 - p_k(0) - p_k(1) = 1 - (1 + (\lambda/N))e^{-\frac{\lambda}{N}} \quad (14)$$

Substituting Equation (14) into (12), we can obtain

$$\tau = \frac{2(1-2p_c)}{(1-2p_c)(CW_{min} + 1) + p_cCW_{min} (1-(2p_c)^m)} \quad (15)$$

V. NUMERICAL CALCULATIONS AND RESULTS

In this work, we have done the extensive numerical calculation on the Matlab platform. Here, we assume that the cell radius is 500 meters, the distribution of UEs follows the Poisson, the transmitting power of D2D and Base Station users is 50mW and 250mW 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.

While performing Matlab coding, we assume the total bandwidth is equal to 1MHz, we denote the same as N and the respective equation is as follows,

$$N = 10^6; \quad (16)$$

For simplicity of calculation, here we consider 2 devices working as Transmitter and 2 devices as Receiver. The channel information denoted as Channel-information related to symbol to noise ratio $E_b N_0$ dB between these devices can be calculated as,

$$\text{Channel_information} = E_b N_0 \text{ dB} + 10 * \log_{10}(\text{sub_carriers}/\text{channel_length}) + 10 * \log_{10}(64/80); \quad (17)$$

Where sub-carriers denotes the number of carriers and channel-length denotes channel length.

At transmitter side, we calculate the matrix for input signal I_p and modulated signal s as,

$$I_p = \text{rand}(1, N) > 0.5;$$

$$s = 2 * I_p - 1; \quad (18)$$

The modulated signal is then reshaped. Later on, we can add noise and channel information to the modulated signal and send it to the receiver. As a next step, the Markov process model based on Fig. 3 is designed such that information should be transmitted between the intended D2D pair and the other unwanted signals get subtracted in order to reduce the collision probability.

At Receiver, we can decode the signal with the help of following equation,

$$I_p \text{Hat} = \text{real}(y \text{Hat}) > 0; \quad (19)$$

$I_p \text{Hat}$ represents the decoded signal and here we consider only real values of received signal $y \text{Hat}$ for simplicity of calculation. Difference between transmitted and received signal which is denoted Total-error is calculated as below.

$$\text{Total-error (ii)} = \text{size}(\text{find}([I_p - I_p \text{Hat}], 2)); \quad (20)$$

As discussed above, total bandwidth is considered as 10^6 or 1 MHz. If there is further increase in bandwidth or number of users which request to access simultaneously, in that case we have increased the range of calculation for checking the user accessing and collision probability of every 10 users and denote it by freqOffsetkHz_v which is calculated using following equation,

$$\text{freqOffsetkHz_v} = [-200:10:200]; \quad (21)$$

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Now, at Transmitter side same process is repeated as mentioned previously, but the transmitted signal is calculated for wide range as given above. Then, after the process of modulation and channel information addition, we finally get signal Y_T at the receiver which is represented as,

$$Y_T = \text{reshape}(Y_T.' 80, n_{\text{Sym}}).' \quad (22)$$

The final calculation of collision probability starts with this signal. In intension of reduction in collision probability, the inverted signal is considered for calculation and only realvalues of received signal are taken into account. It goes further to evaluate the user access probability based on collision. These calculations give desired results and show appreciable reduction in collision probability and correspondent relationship as below.

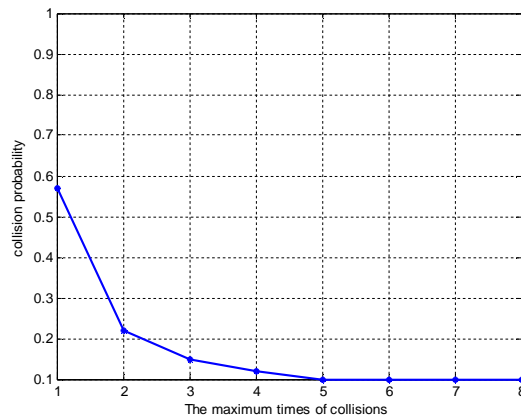


Fig. 4. Collision probability under different maximum number of collisions m .

Fig. 4 shows that, collision probability will reduce if we increase maximum times of collision m and vice versa. This indicates that with suitable selection of maximum times of collision m , we may control the collision probability.

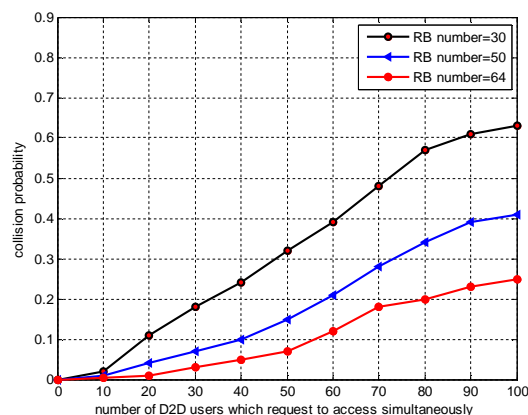


Fig. 5. Collision probability when different number of D2D users accessing simultaneously under the premises of varying Resource Blocks (RB).

From Fig. 5, we can observe that when the number of D2D users requesting for simultaneous access increases, the Collision probability also increases. However, it reduces when we increase the availability of number of Resource Blocks (RB). Also, when RBs have highest value i.e. 64, collision probability is below 0.3 which is quite low.

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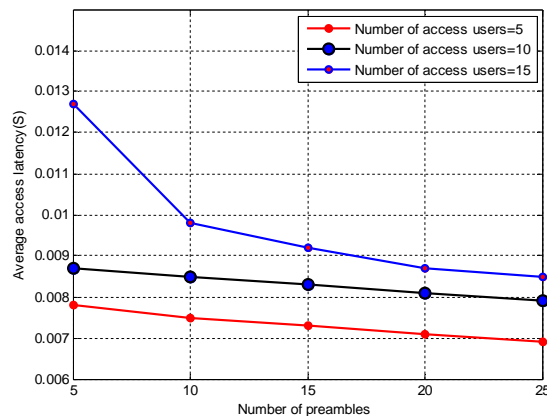


Fig. 6. .The average access delay under the premises of a differing number of preambles.

As Fig. 6 presents, the access delay increases with number of access users. However, to reduce the delay we have to increase number of preambles. Here, preambles indicate resources. With large number of preambles we can accommodate more number of users with minimum access delay.

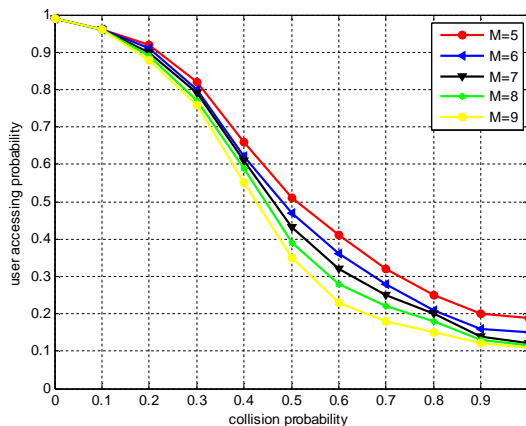


Fig. 7. .The relationship between collision probability and user accessing probability under different maximum number of collisions m.

Fig. 7 gives the relationship between the user's access probability and collision probability under the premise of varying maximum times of collision m. From this relationship, we can conclude that the user access probability increases as the collision probability reduces and vice versa. In addition, the collision probability will decrease if we increase m. We can also observe from Fig. 7 that user access probability is higher than 0.9 with lowest value of collision probability.

VI. CONCLUSION

In this paper, we propose numerical performance analysis based on the Markov process model on Matlab platform. Moreover, this analysis obtains different scenarios to reduce collision probability and shows its effect on user access probability. The results show that with suitable selection of allowable maximum times of collision m and with increase in resource blocks, collision probability is reduced to below 0.3 or almost 0.1. Also, average access delay decreases

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with number of preambles. In addition, we can conclude that, with further increase in resources or bandwidth, maximum number of D2D users can be accommodated for simultaneous access i.e. increase in user access probability with reduced collision.

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