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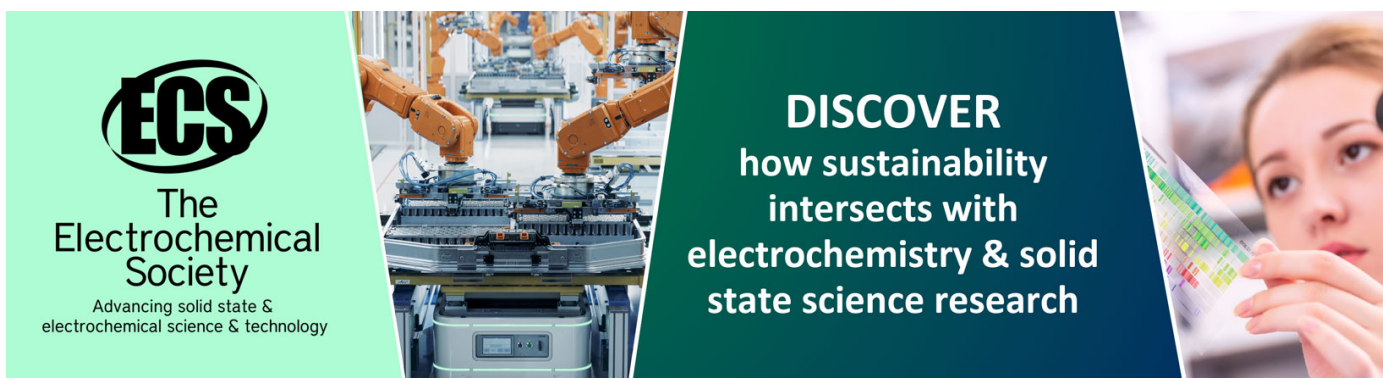
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Utilizing Device to Device Communication in Cellular Networks with the distance-based model selection method

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Abstract. The recent advances in the technology of smart devices caused a tremendous increase in wireless traffic in conventional cellular networks, thus leading to overloading the base station, and hence delaying the response to users' requests. To overcome this, Device to Device (D2D) communication has been proposed recently to alleviate the traffic congestion at the base station (BS) by establishing a direct link between users. However, deciding whether a communication should be performed directly via D2D mode or via the base station is considered one of the challenges of applying such a method. Therefore, a mode selection based model was presented in this paper. The method depends on the probability of a user's proximity close to 1.0. Furthermore, the proposed method also takes into account the interference with both; other cellular communication and D2D communication. The simulation results showed that a significant reduction in the delay can be achieved when responding to user requests after using the proposed model selection method. The increase in frequency reuse within the cell is considered as the main reason behind this behavior. Also, for a more simplified and less complex model selection method, it is more appropriate to apply the proposed model selection method to only the cell edges.

1. Introduction

During the past decade, the wireless traffic has grown exponentially, due to the advancements in smart device's technology. This has caused a massive increase in traffic load on the Base Station (BS), which made the present conventional communication methods struggle to cope with this high demand [1][2][3]. Therefore, new methods and techniques are being studied currently were researchers around the world. One of these methods is Device to Device (D2D) communication, which is considered very promising, giving the fact that it reduces the load on the BS [4][5]

Generally, Device to Device communication is based on establishing direct links between any two devices that are close to each other to exchange their traffic directly without the base station (BS). D2D communication exists in two forms: out-of-band communication which deploys unlicensed spectrum and intra-band communication which deploys licensed spectrum [3][4]. Also, there are many advantages to utilizing D2D communication such as proximity, reuse and path.

The selection of communication mode is considered as a major challenge when combining conventional cellular networks with D2D communication. The mode selection is the technique that determines whether the traffic between two devices is established via the base station or D2D mode. Furthermore, the method of spectrum allocation is also determined by the mode selection method [6].



Generally, there are three D2D modes available. In the first one, a dedicated spectrum is used to establish a direct link between the users. This mode is known as the Device to Device (D2D) mode. While in the second mode, the communication is performed via the base station as in conventional cellular networks. This mode is called the Cellular Mode (CM). This mode requires more resources than the D2D mode due to the long communication range. On the other hand, the third mode utilizes the spectrum resources shared with cellular users to establish communication between the D2D users. This mode is known as Reuse Mode (RM). And upon good interference management, this mode can enhance the spectrum efficiency considerably [7][8].

The mode selection has been studied by a number of researchers. This has led to the development of a number of methods for mode selection, such as those based on users' locations and distance, interference intensity and path loss. Wang et al. [9] proposed a model selection method that relies on the distance between users, where it is applicable to both; the RM and DM modes. While Cho et al. [10] used the degree of interference between D2D users as a mode selection criterion. Furthermore, the distance to the base station and that among D2D users was also utilized by ElSawy et al. [11] as a mode selection criterion. It's also worth noting that there many other mode selection methods that have been proposed by other researchers [12][13][14]

As shown when examining the literature, most of the previous distance-based model selection methods were derived based on an empirically obtained threshold value. On the other hand, and in this paper, a probability of proximity-based mode selection method is presented herein. The method depends on both; the probability of proximity and users' density when determining the covenant distance for the D2D mode. The appropriate mode is decided by the base station based on the possible interferences within the cell and the range of communication.

2. Probability of users' proximity

Herein, the convenient range of transmission for D2D communication depends on the probability of users' proximity, which is also the determining factor for whether a CM or an RM mode is used. Fig.1 shows a base station with a coverage radius (r). The users are randomly located within the coverage radius with a uniform distribution. The number of users within the coverage radius is referred to as (n). The figure illustrates that if the transmission range (D) of a user is equal or greater than the distance to the targeted user (d), a D2D pair can be established between these users. The probability (P) that a distance between two users (d) is less than or equal to a target distance (D) is given in the following expression [15].

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

Where λ denotes for the users' density within the cell.

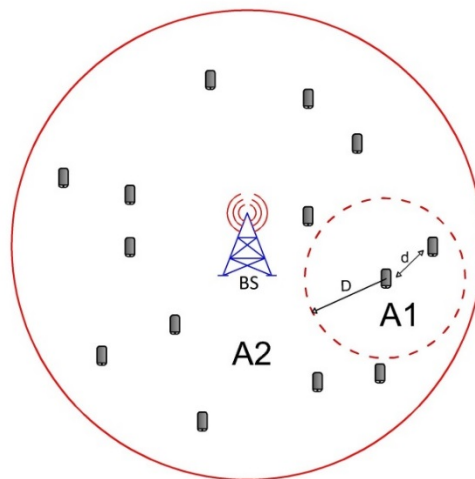


Figure 1 A communication cell

Fig.2 shows the relationship between the transmission range (D) and the proximity probability of two users with different users' densities. As expected, the figure illustrates that as the users' density increases, the proximity probability of two users establishing D2D mode increases and vice versa. Furthermore, and for a specific users' density, the proximity probability of two users establishing D2D mode also increases. To illustrate this, consider a cell with 10 users and a transmission range of 60 meters, the proximity probability of two users establishing D2D link is about 60%. However, when the number of users within the cell is increased to 20 users, the value could reach up to 95%

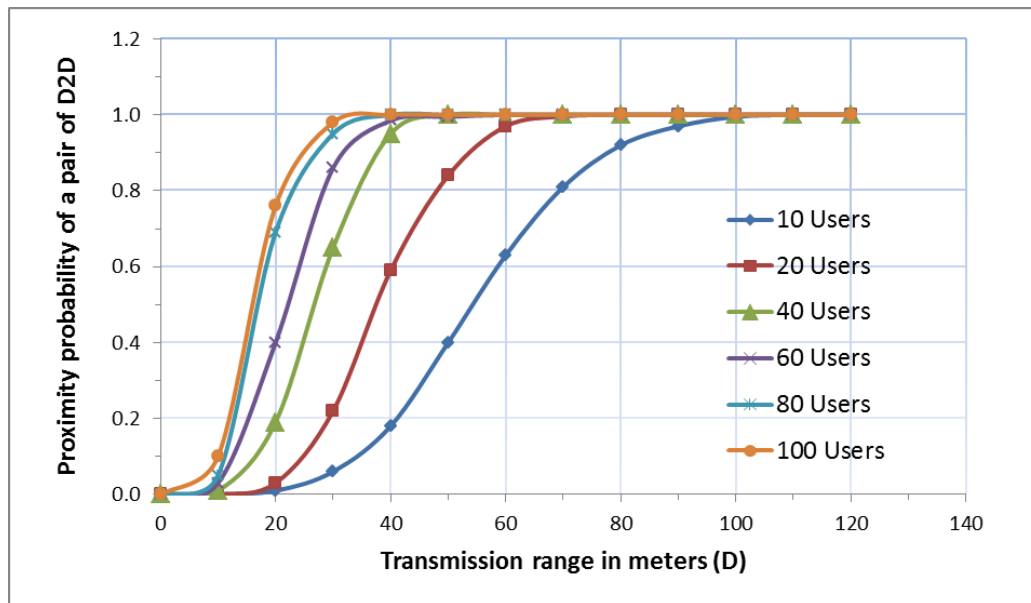


Figure 2 Proximity probability of two users

3. Proposed method

As shown in fig.1, any user who wants to send information has its own transmission area which is referred to as A1 with a transmission diameter of radius (D), while the area of the whole communication cell is referred to as A2. Both cells shall not have interaction with each other. When the destination user happens to be within the first cell (A1) while the base station is out, an RM mode can be established between these users. If there is any other ongoing communication that may cause interference, Frequency reuse is not recommended in this case. Therefore, regular cellular mode (CM) is preferable in this case. It's worth noting that in a frequency reuse mode, both the conventional cellular communication and D2D communication are allowed to take place simultaneously using the same time slot

To explain the proposed selection method in more detail, an example is illustrated below. Here, and in order to respond to users' requests, the proposed mode selection method is combined with a scheduling scheme. As shown in fig. 3, an eight-time slot frame is used here, four of which are located for the downlink, while the remaining four are for the uplink.

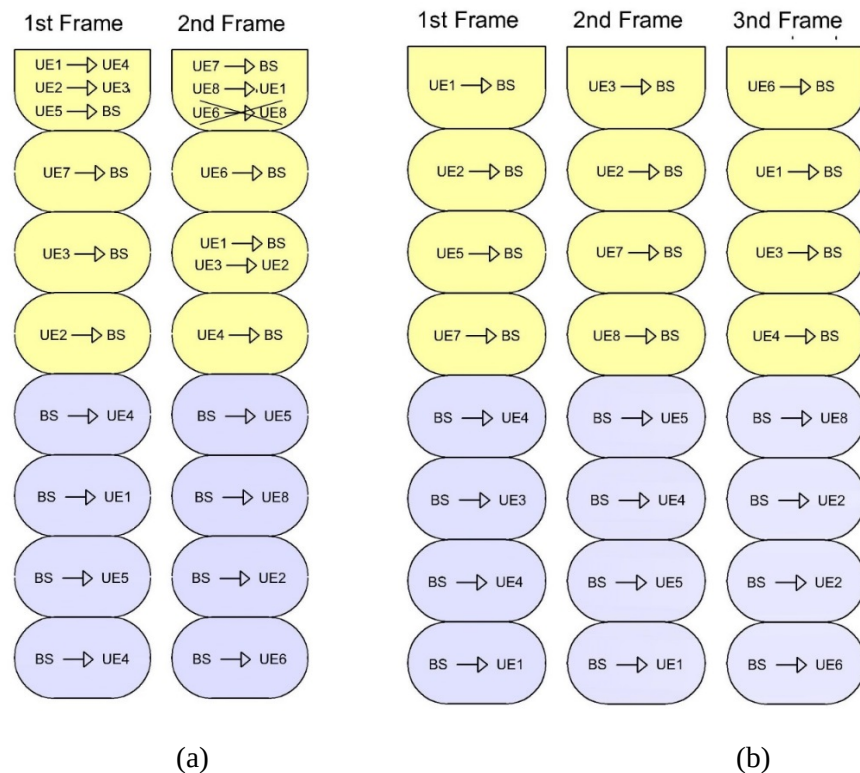


Figure 3 An illustration of responding to requests using the proposed model selection method for both: a) RM, b) CM modes

It is well known that when using the conventional cellular mode, a tow time slots are required, one between the sender and the base station and the other is between the base station and the receiver. On the other hand, an only one-time slot is required for the uplink when using D2D mode. Fig. 4 shows the example cell which supports both; CM and RM modes. As shown in the figure, the cell contains eight users (UE1 to UE8). Table 1 illustrates the communication requests between the different users. The mode selection is determined by the base station (BS). At first, the proposed method determines the transmission radius (D) at which the probability of proximity of two users is close to 1.0, see fig.4.

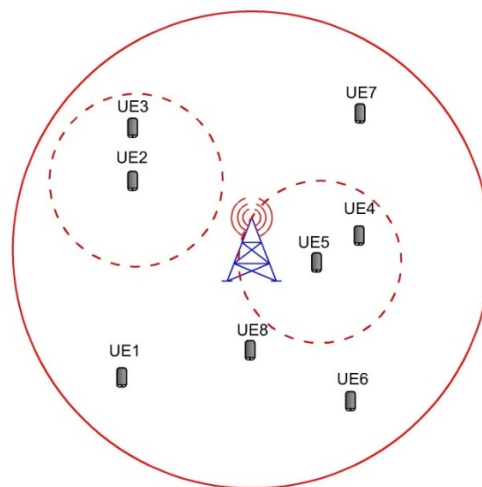


Figure 4 An illustration of responding to requests using the proposed model selection method

Table 1 An illustration of users' requests in a cell

Sender	UE1	UE2	UE5	UE7	UE3	UE2	UE7	UE8	UE6	UE1	UE3	UE4
Receiver	UE4	UE3	UE4	UE1	UE5	UE4	UE5	UE1	UE8	UE2	UE2	UE6

The method is designed to make a one by the examination of one request. In the beginning, the base station checks whether it is within the transmission range of the sender or not. And if so, the communication will be established via the base station. Otherwise, D2D mode is possible. A D2D mode between the transmitting and the receiving user can be established, only if the receiving user is inside the transmission distance (D) of the transmitting user. Still, a thorough examination regarding the interference between the D2D pair and the other D2D users must be performed. However, the communication between the D2D users must be performed via the CM, if the receiving user is out of the transmission distance of the sending user.

As shown in table 1, and since the first two receiving users are within the transmitting distance of the sending users and there is no interference with the base station, a D2D mode was established for both requests. Also, both requests don't interfere with each other, since their transmission distance don't overlap. Furthermore, a CM mode was established in the third request (UE5 and UE4). Also, and as shown in fig. 3a, the 6th, 5th, and 4th requests were performed in cellular mode (CM) because they don't satisfy D2D requirements. Also, the second frame shall only start when all the time slots of the first frame are used.

4. Results of simulation

To simulate the proposed method of mode selection, a communication, cell of a radius of 1000 m was assumed. All users were randomly distributed within the cell in a uniform manner. The total number of requests generated and scheduled was 10 000. Furthermore, and depending on the user's density, the distance at which the probability of proximity is equal to 1.0 was determined, see table 2.

Table 2 Range of proximity

Proximity range (m)	36	38	40	50	70	100
Number of users	100	80	60	40	20	10

Furthermore, two types of RM were simulated. The first type is denoted as RM1, see fig. 5a. This mode allows all users within the cell to communicate in both modes; RM and CM. While in the second type which is denoted as RM2, only the users at the cell edges are allowed to communicate in RM and CM modes, while all users within the center of the cell must communicate strictly through the CM model, see fig. 5b.

The number of frames required to respond to each user in both modes; CM and RM1 are shown in fig. 6. According to the figure, and when using RM1 mode, a significant reduction in the delay was achieved when responding to user requests. The figure also shows that for RM1 mode; as the number of users increases, the rate at which the number of frames is reduced decreases. The reason behind this is the decrease in the number of D2Ds, which is a result of the growing interference with other D2Ds and cellular communications at any time slot.

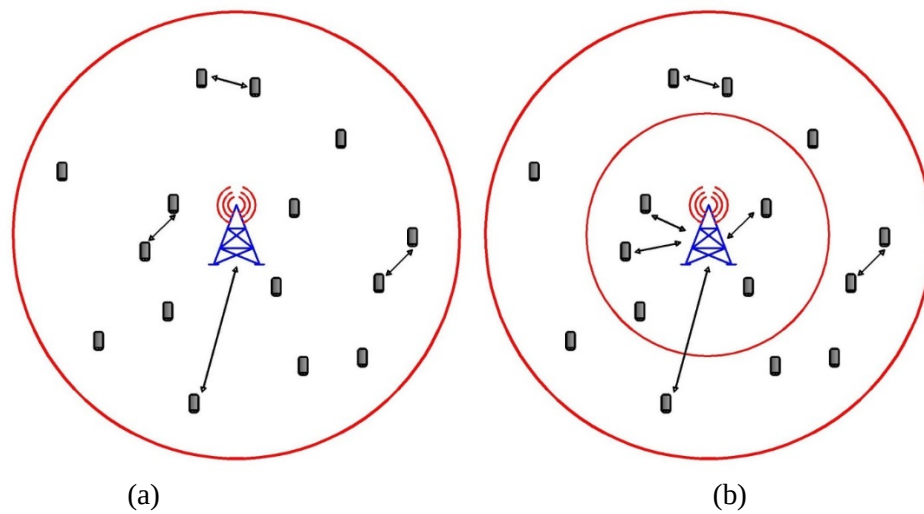


Figure 5 Reuse modes; a) RM1, b) RM2

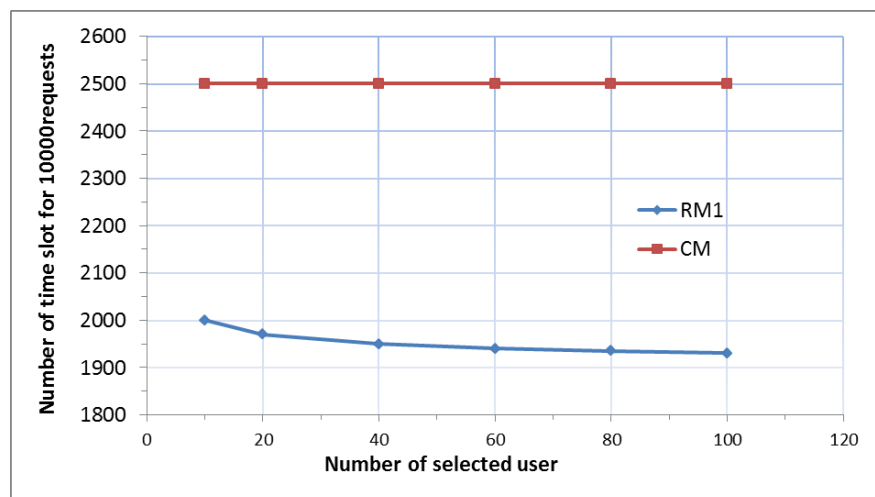


Figure 6 The relationship between users' requests and the number of required frames

Fig 7. shows a comparison between RM1, RM2, and CM in terms of the number of required frames. Based on the figure, and although RM2 mode has no advantage over RM1 in terms of reducing the delay, it can be noted that as the radius of the RM2 mode around the base station becomes smaller, the rate of time slot reduction increases. This is because as the radius decreases, the range for a D2D mode becomes larger and vice versa. This shows that RM2 mode is also useful, as it can be used to reduce congestion within the cell.

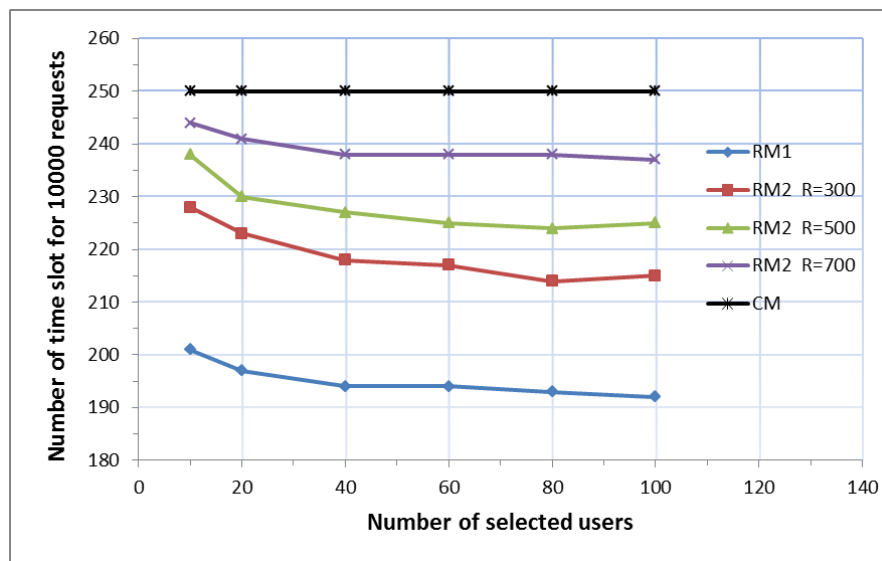


Figure 7 Compression between RM1, RM2, and CM in terms of the number of required frames

5. Conclusions

This paper proposes a model selection method that is based on the probability of users' proximity. The range of transmission in RM mode was obtained for different densities of users. The transmission range is based on a probability of users' proximity close to 1.0. Afterward, and by considering both; the interference with cellular users and proximity range, the possibility of D2D mode was established. The simulation results showed that a significant reduction in the delay can be achieved when responding to user requests after using the proposed model selection method. The increase in frequency reuse within the cell is considered as the main reason behind this behavior. Also, for a more simplified and less complex mode selection method, it is more appropriate to apply the proposed model selection method to only the cell edges.

Conflict of interests

There is no conflict of interests to disclose

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