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Device-to-Device (D2D) Discovery Simulator for 3GPP and Public Safety Network (PSN)

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Abstract

The Public Safety Network (PSN) is important for providing communication after a possible disaster. It provides a communication opportunity between the victims under the wreckage and the rescue team in the case of base stations do not function. Device-to-device (D2D) discovery and communication provides communication services in such difficult situations without the requirement of network infrastructure and by reducing call traffic in cellular communication networks. Therefore, device discovery according to different parameter values in the simulator environment for 3GPP and PSN provides great convenience to users in the application phase. In this study, we presented a device-to-device (D2D) discovery simulator based on the Matlab Graphical User Interface (GUI) for the students and researchers related to the wireless communication area. In this simulator, there are different pathloss models for D2D communication along with the parameters suggested by 3GPP and PSN for educational and research purposes. D2D discovery results are given in visual graphics with the parameter settings in the simulator's interface. Thanks to the D2D discovery simulator, the students and researchers can easily understand how the user mobile devices discover each other which is necessary for D2D communication in the disaster area. They can also compare device discovery algorithms with different parameters and models. Six different scenario examples and an evaluation questionnaire about the D2D discovery simulator were proposed to students and researchers at a University in Turkey. The users (students and researchers) can easily test D2D discovery algorithms with different simulation parameters with a user-friendly interface thanks to the developed simulator.

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1 Introduction

Computers have a supportive role in education as they are used in many fields today. Simulation tools or simulators are preferred to understand difficult and complex structures in the technical field and to learn difficult experiments in the laboratory environment. In addition, it is very important to support theoretical knowledge with practical applications in engineering education [1–3].

Real experiments are nearly impossible to run tests, especially due to the high cost in cellular networks. Simulation tools are essential for obtaining valid predictions about the performance of the scenarios being studied [4]. It is known that it is easier to test the functionality of the network with simulation tools and it also reduces time and cost. The Long-Term Evaluation (LTE) networks are complex; not all network parameters can be considered in mathematical models developed as a research study. Simulation and simulation tools offer the chance to test newly designed algorithms in this complex system [5, 6].

The public safety network (PSN) is a private wireless network used by emergency services such as police, fire rescue, and emergency medical assistance. The effective use of this network enables emergency rescue teams to move faster and speed up disaster response [7–9]. Therefore, the public safety network has importance in providing communication after a possible disaster[10, 11]. The Device-to-device (D2D) communication includes topics related to how smartphones, namely mobile stations or user equipment (UE), which are in the hands of almost everyone and used for many businesses, will discover and how they can communicate after their discovery [12, 13].

Some of the network simulators, such as OPNET-Riverbed Modeler [14] and QualNet [15] are commercial, so users have to pay to get a license to use their software or to order specific packages for their specific use requirements. The advantage of commercial simulators is that they usually have complete and up-to-date documentation and can be constantly maintained by some specialist personnel in the company to correct gaps in the simulators and provide new versions [16]. The open-source network simulators don't often have enough experts working on the documentation. This issue can be serious when different versions come with many new things, and without proper documentation, it will be difficult to follow or understand the previous code. In spite of this, open-source network simulators have the advantage that everything is very clear and anyone or the organization can contribute to it and find errors in it. They can also be very flexible and reflect the latest developments of new technologies faster than commercial network simulators. However, we can see that some of the advantages of commercial network simulators are disadvantages of open-source network simulators. Lack of documentation and version control support in open-source simulators can cause some serious problems and limit the applicability and lifetime of open-source network simulators. NS2 [17], NS3 [18], OMNeT++ [19], SSFNet [20] and J-Sim [21] are typical open-source network simulators.

There are many comparison studies [22–25] about network simulators in the literature. In addition to simulation studies have also been carried out in the literature to facilitate wireless network teaching. Experiments are presented with the platform named RTWiFi-Lab [26] and Labview software [27] that provide the concepts of different wireless and digital communication techniques such as signal detection, data modulation, frequency, phase shift estimation. A web-based user interface was designed by using Matlab software [28], which will facilitate the understanding of modulation techniques in analog and digital communication [29, 30]. In addition, a training tool for spread spectrum expression in communication systems was studied [31] with the open source GNU Octave software [32], similar to Matlab software. There are few studies on PSN and D2D simulators in the literature and these studies are as follows;

LTE based PSN simulation environment Network Simulator (NS-3) [18] has been developed especially by using NS-3 LTE-EPC Network Simulator (LENA) module [33]. The SimuLTE is one of these models that provide a simulation framework for the data plane of OMNeT ++ [19] based LTE-Advanced (LTE-A) networks [34].

The main contributes that the proposed Matlab [28] GUI design different from other simulators and emulators are as follows;

- A customized simulator design for learning and teaching D2D discovery,
- Simulation of two different discovery methods such as PSN and D2D can be done from a single interface,
- Having an educational, easy to understand and user-friendly GUI for students and researchers,
- It can be done separately according to different path loss parameters for PSN and D2D discovery,
- Finding UE pairs matching different search algorithms made in the discovery area and seeing SINR, energy efficiency, capacity and throughput values in a single result screen according to the values calculated in the simulation.

The remainder of this paper is organized as follows: Sect. 2 provides D2D discovery system modelling. Section 3 presents D2D discovery algorithms. Section 4 presents the design of the D2D discovery simulator. Sample scenarios for D2D discovery are provided in Sect. 5. Section 6 presents user survey and results of D2D discovery simulator. In the last section, the conclusions are discussed.

2 D2D Discovery System Model

The successful device discovery enables UEs to communicate directly with each other in D2D communication. The D2D system model for device discovery in a single cell as a scenario example is showed Fig. 1. In this figure, the direct connections between UE pairs are depicted by blue solid lines, while the interference between D2D receivers and D2D transmitters is represented by orange dashed lines.

The D2D discovery system model is succinctly introduced through the utilization of model equations. The calculation for the SINR metric, denoted as γ, is provided below:

$$\gamma = \frac{S}{I + N} \tag{1}$$

where the power of the incoming signal is represented by S, the noise is presented by N and the interference power of the other signals in the network are denoted by I. The incoming signal power (S) is calculated as given in Eq. 2:

$$S^{(i,j)} = P_T^{(i,j)} G_T^{(i,j)} G_R^{(i,j)} PL(d_{i,j})^{-1} |h_i|^2 \tag{2}$$

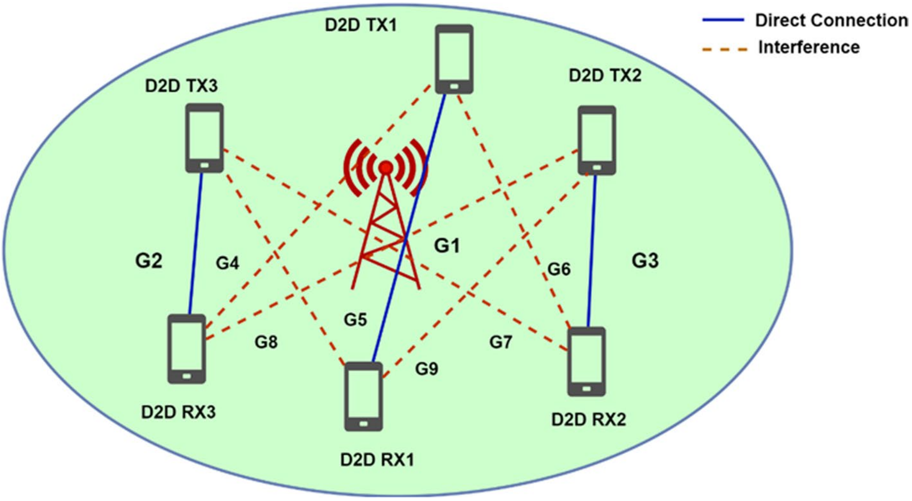


Fig. 1 D2D discovery model for device discovery in a single cell [35, 36]

where the signal power between ith UE and jth UE is denoted by $S^{(i,j)}$, the transmit power is represented by $P_T^{(i,j)}$, the transmitter antenna gain is denoted by $G_T^{(i,j)}$, the receiver antenna gain is represented by $G_R^{(i,j)}$, the path loss is denoted by PL, the distance between ith UE and jth UE is represented by $d_{i,j}$, the fading coefficient is denoted by h_i. The formula is used for interference calculation between ith and jth UEs is given in Eq. 3:

$$I^{(i,j)} = \sum_{k=1,k\neq i,j}^{K} P_T^{(k,j)} G_T^{(k,j)} G_R^{(k,j)} PL(d_{k,j})^{-1} |h_k|^2 \tag{3}$$

where the interference between ith UE (transmitter) and jth UE (receiver) is denoted by $I^{(i,j)}$. The noise is used in the calculation of the SINR metric as Additive White Gaussian Noise (AWGN). According to the D2D system model in Fig. 1, for example, the calculation of SINR (γ_{RX_1}) is presented below for D2D communication between TX_1 and RX_1 UEs.

$$\gamma_{RX1} = \frac{P_{TX_1} G_1}{P_{TX_2} G_9 + P_{TX_3} G_5 + N_0} \tag{4}$$

$$G_1 = \frac{G_T^{(TX_1,RX_1)} G_R^{(TX_1,RX_1)} PL |h_{TX_1}|^2}{d_{TX_1,RX_1}} \tag{5}$$

$$G_9 = \frac{G_T^{(TX_2,RX_1)} G_R^{(TX_2,RX_1)} PL |h_{TX_2}|^2}{d_{TX_2,RX_1}} \tag{6}$$

$$G_5 = \frac{G_T^{(TX_3,RX_1)} G_R^{(TX_3,RX_1)} PL |h_{TX_3}|^2}{d_{TX_3,RX_1}} \tag{7}$$

where the transmit powers of TX_1, TX_2, TX_3 are respectively denoted by P_{TX_1}, P_{TX_2}, P_{TX_3}, the AWGN is represented by N_0, the transmitter antenna gains between RX_1 and other transmitter UEs (TX_{1-3}) are denoted by $G_T^{(TX\_,RX_1)}$, the receiver antenna gains between RX1 and other transmitter UEs (TX_{1-3}) are signified by $G_R^{(TX\_,RX_1)}$, the path loss is represented by PL, the distances between RX_1 and other transmitter UEs (TX_{1-3}) are denoted by $d_{TX\_,RX_1}$, the fading coefficients of the transmitters are signified by $h_{TX\_}$. The path loss models for PSN, constant propagation loss [37] and Log-Normal Shadowing models [38] are given below:

$$PL(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \tag{8}$$

where the path loss exponent is represented by n, the reference distance is denoted by d_0, the random shadowing effect is signified by X_σ. The path loss at the reference distance (d_0) is represented by $\overline{PL}(d_0)$. The 3GPP [39], Cost231-Hata [40, 41], Winner5f [42] and Lee [40, 43] path loss models for D2D are summarized in Table 1.

In the 3GPP path loss model, the transmission frequency (GHz) is denoted by f_c, the distance D2D (km) is denoted by d and the base station antenna height is represented by hBS as default 1.5m in first model. In the Cost231-Hata path loss model, the distance between transmitter and receiver (km) is denoted by d, the receiver antenna height correction factor $a(h_m)$ and the environment correction factor C_m are given in the equations of the model. The frequency (f_c) in (Mhz), h_b and h_m are the transmitter and receiver antenna height in (meter) respectively are given in the last equation of the model. The receiver antenna height correction factor $a(h_m)$ for small to medium cities is given final equation of the model. C_m is 0dB for medium sized city and suburban areas. C_m is 3dB for large city or metropolitan center [40, 41]. The Log-Normal shadowing [44], Winner+B1 [45] and ITU 1411-6 path loss models [46] for PSN are summarized in Table 2. Here, the transmission frequency is represented by f_c.

The Winner5f path loss model support LOS and NLOS [42]. In this model, the distance d in (m) is selected between 30 m and 1.5 km. The frequency f_c in (GHz) is selected between 2 GHz and 6 GHz in equation of the model. In the Lee path loss model, the path loss at reference distance(d_0) in (dB) is denoted by PL_0, the slope (m) in(dB/decade), the transmitter-receiver distance (d) in (km) and the reference distance (d_0) (1.609 km) are given in first equation of

Table 1 Reference Path Loss Models for D2D

Path Loss Model	References
$PL = -44.9 - 6.55\log 10(hBS)\log 10(d) + 5.83\log 10(hBS)$ $+14.78 + 34.97\log 10(f_c)$	3GPP [39]
$PL = A + B\log(d) + C_m - a(h_m)$ $A = 46.3 + 33.9\log(f_c) - 13.82\log(h_b),$ $B = 44.9 - 6.55\log(h_b)$ $a(h_m) = (1.1\log(f_c) - 0.7)h_m - (1.56\log(f_c) - 0.8)$	Cost231-Hata [40, 41]
$PL = 57.5 + 23.5\log(d) + 23\log(\frac{f_c}{5})$	Winner5f [42]
$PL = PL_0 + m\log\left(\frac{d}{d_0}\right) - H_T - H_R$ $H_T = 15\log\left(\frac{h_t}{h_{tref}}\right), H_R = 10\log\left(\frac{h_r}{h_{rref}}\right),$ $PL_0(f) = PL_0(f_0) + 20\log(\frac{f}{f_0})$	Lee [40, 43]

Table 2 Reference Path Loss Models for PSN

Path Loss Model	References
$\overline{PL}(d_0) = 22.7 + 26\log(f_c)$	Log-Normal shadowing [44]
$PL = 35.4 + 22.7\log 10(d)$	Winner+B1 [45]
$PL = -27.5 + 20\log 10(f_c) + 10n\log 10(d) + X_\sigma$	ITU 1411-6 [46]

the model. The transmitter antenna height (h_t) in(m), the reference transmitter antenna height (h_{tref}) (30.48 m) are given in equation of the model. The receiver antenna height(h_r) in(m) and the reference receiver antenna height (h_{rref}) (3.048 m) are given in equation of the model. PL_0 and m values may be selected different values for different environment. In this path loss model, PL_0=107.7(dB) and m=38.4 (dB/decade) used for suburban environment at 900MHz. Whereas m remains the same for frequencies different than f_0, frequency correction factor for the intercept (PL_0) [40, 43] is given in final equation of the model. Table 3 summarizes the path loss exponent (n) for different environment [38] and average values used in simulator.

The Euclidean distance relation is used as below for the distance of two nodes (for each D2D point) in the coordinate plane:

$$d = \sqrt{\left(x_T - x_R\right)^2 + \left(y_T - y_R\right)^2} \tag{9}$$

where x_T,y_T denote the location of the UE transmitter and x_R,y_R represent the location of the UE receiver. The throughput ($R^{(i,j)}$) for each D2D uplink scenario is calculated as given below:

$$R^{(i,j)} = B \cdot \log_2\left(1 + \frac{S^{(i,j)}}{N^{(i,j)}}\right) \tag{10}$$

where the bandwidth is represented by (B), the signal power between ith UE and jth UE is denoted by $S^{(i,j)}$, the noise between ith UE and jth UE is represented by $N^{(i,j)}$.The energy efficiency (EE) is calculated for a single hope (node-to-node) according to the bandwidth and the noise ratio.

$$EE^{(i,j)} = \left(\frac{B}{2 \cdot P_T^{(i,j)}}\right)\left(1 + \frac{1}{\zeta^{(i,j)}}\right)\log_2\left(\zeta^{(i,j)} + 1\right) - \log_2(e) \tag{11}$$

Here, the signal to noise ratio is represented by $\zeta^{(i,j)}$ and $log_2(e)$ shows the natural logarithm.

Table 3 Path loss Exponent (n) values for different environment

Environment	Path-loss Exponent	Values used in Simulator
Free-space	2	2
Urban area cellular radio	2.7-3.5	3
Shadowed urban cellular radio	3-5	4
In building LOS	1.6-1.8	1.7
Obstructed in building	4 to 6	5
Obstructed in factories	2 to 3	2.5

3 D2D Discovery Algorithms

3.1 Throughput based Discovery Algorithm (TDA)

The throughput-based discovery algorithm provides to find the UEs in the network according to the throughput metric. The D2D pairs are determined with two basic rules. The first rule detects those exceeding the minimum threshold of throughput for D2D pairs. The second rule determines the best pair with maximum throughput values. The proposed TDA [35, 36] aims to select pre-communication the best D2D pairs according to SINR-based without distance limit. TDA calculates device pairs according to the equations given below:

$$\max R^{(i,j)} \tag{12}$$

$$R^{(i,j)} > R_{th}, 1 \leq i,j \leq N_{UE}, i \neq j \tag{13}$$

where R_{th} represents the threshold of throughput, N_{UE} denotes the number of UEs. The first constraint ensures that the maximum throughput value between ith UE and jth UE in Eq. 12. The second constraint ensures that greater values than the threshold of throughput and then the selected users can not be out of the range between 1 and N_{UE}. The last constraint provides the selected users different from themselves in Eq. 13.

3.2 Shortest Distance Discovery Algorithm (SDA)

The shortest distance discovery algorithm is based on the shortest distance between UEs. Firstly, the D2D pair with the minimum distance is selected and then, if this pair has the minimum SINR threshold, thus it is determined as the best pair for SDA [47]. The best D2D pair is found as follows:

$$\min d^{(i,j)} \tag{14}$$

$$\gamma^{(i,j)} > \gamma_{th}, \gamma^{(j,i)} > \gamma_{th}, 1 \leq i,j \leq N_{UE}, i \neq j \tag{15}$$

where $d^{(i,j)}$ stands for the distance between ith UE and jth UE, γ_{th} denotes the threshold of SINR. The first limitation denotes the minimum distance values between ith UE and jth UE in Eq. 14.

The second limitation represents that the SINR values as bidirectional between ith UE and jth UE is greater than the threshold of SINR in Eq. 15. The third limitation provides that the selected users different from themselves are in the range between 1 and N_{UE}.

3.3 Maximum SINR with No Limit on the Distance of Discovery Algorithm (MSNA)

The maximum SINR with no limit on the distance of discovery algorithm finds the D2D pairs among the UEs according to the SINR values, and determines the best pair with maximum SINR. The distance among the UEs is not important in this discovery algorithm [47]. The best D2D pair is found by MSNA as given below:

$$\max \gamma^{(i,j)} \tag{16}$$

$$\gamma^{(i,j)} > \gamma_{th}, \gamma^{(j,i)} > \gamma_{th}, 1 \leq i,j \leq N_{UE}, i \neq j \tag{17}$$

where $\gamma^{(i,j)}$ denotes the SINR. The constraints of MSNA are the same as SDA. The first constraint denotes the best D2D pair with maximum SINR values. The second constraint represents UEs with SINR values greater than the threshold level detected in the network.

3.4 Maximum SINR with Limit on the Distance of Discovery Algorithm (MSLA)

The maximum SINR with limit on the distance of discovery algorithm aims to identify the optimal Device-to-Device (D2D) pair within the network by considering a distance constraint between User Equipments (UEs). In contrast to the MSNA [47], which lacks a distance threshold, this method incorporates such a limitation. The process of discovering the best D2D pair using the Maximum SINR with Limit on the distance of discovery algorithm (MSLA) is outlined below:

$$\max \gamma^{(i,j)} \tag{18}$$

$$\gamma^{(i,j)} > \gamma_{th}, \gamma^{(j,i)} > \gamma_{th}, 1 \leq i,j \leq N_{UE}, i \neq j, d^{(i,j)} < d^{th} \tag{19}$$

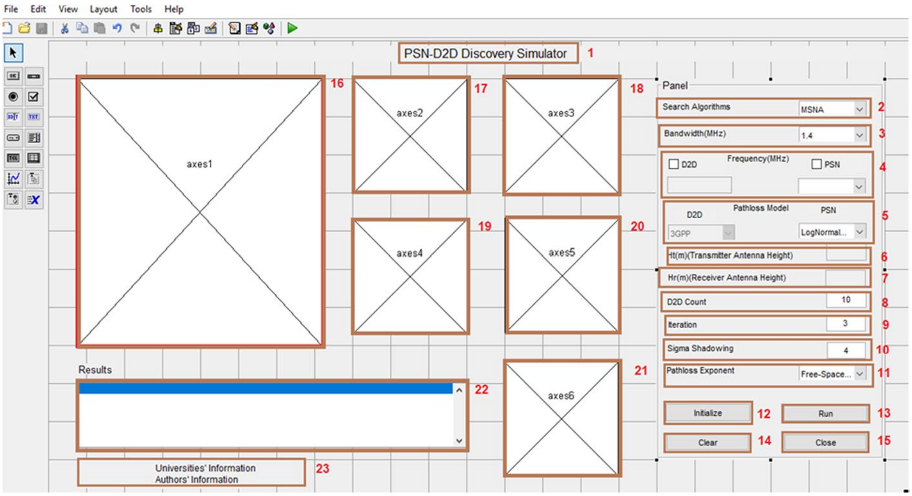
where d_{th} represent the distance threshold. The algorithm incorporates two key limitations to determine the best Device-to-Device (D2D) pair based on these constraints. The first limitation involves identifying the D2D pair with the highest SINR value among all possible pairs. This criterion ensures that the selected pair achieves the maximum signal quality in terms of the SINR metric. The second limitation encompasses a two-step process. Initially, the algorithm detects devices based on their distances from one another, considering only those that exceed the predefined threshold value (d_{th}). Subsequently, from the detected devices, MSLA selects devices that possess SINR values exceeding a specified threshold level. This additional criterion ensures that the chosen devices not only satisfy the distance constraint but also exhibit sufficiently high SINR values. It is worth noting that MSLA supports the utilization of various distance threshold values for D2D discovery, allowing for flexibility and adaptability in the algorithm's operation.

4 D2D Discovery Simulator Design

This section presents the introduction and details of the device-to-device exploration simulator. The GUI design of the PSN-D2D Simulator is shown in Fig. 2. The interface has basically been done to be simple and understandable for all users. Numbered fields in this GUI are respectively expressed as follows:

Field-1 shows the name of the developed simulator. Field-2 is the combo box (drop-down list) where D2D discovery search algorithms are selected. Clicking on the combo box (Fig. 3a), D2D discovery the search algorithms are listed as given below:

- MSNA (Maximum SINR with No limit on the distance of discovery Algorithm),
- SDA (Shortest Distance discovery Algorithm),
- MSLA (Maximum SINR with Limit on the distance of discovery Algorithm for 50, 100, 150, 200, and 250 ms),
- TDA (Throughput based Discovery Algorithm).



Search Algorithms MSNA

Bandwidth(MHz) 1.4

3GPP

LogNormal...

Ht(m)(Transmitter Antenna Height)

Hr(m)(Receiver Antenna Height)

D2D Count 10

Iteration 3

Sigma Shadowing 4

Pathloss Exponent Free-Space...

Fig. 2 PSN-D2D Discovery Simulator GUI Design

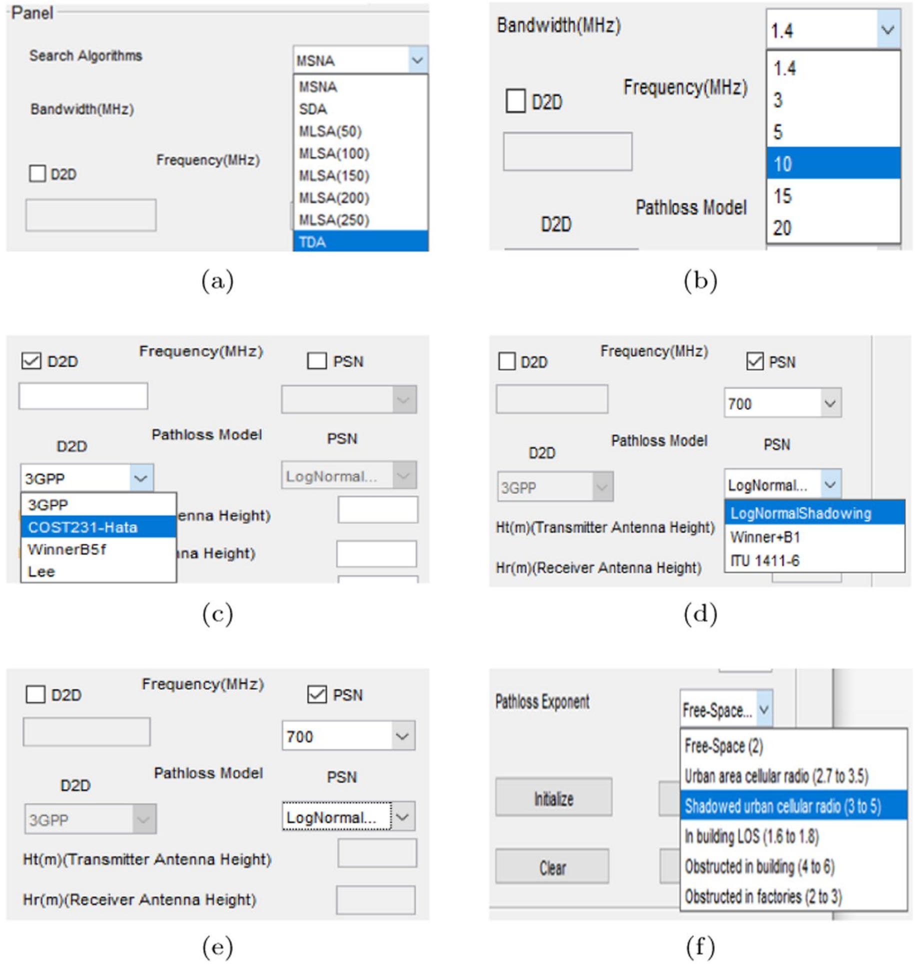
Field-3 refers to the bandwidth. The bandwidth used in LTE for D2D communication can be selected from the combo box menu as shown in Fig. 3b. Field-4 represents the frequency value. The selectable tick boxes are placed on the GUI in order to separate between D2D and PSN frequencies. There is a textbox area where a numerical value for D2D (MHz) is entered as the frequency value. The value used for PSN is a fixed 700 Mhz frequency.

Field-5 is used for the path loss model. The selectable tick boxes are placed in order to choose between D2D and PSN path loss models. 3GPP, Cost231-Hata, WinnerB5f and Lee models can be selected for the option of D2D (Fig. 3c), and Log Normal Shadowing, Winner + B1 and ITU 1411-6 models can be selected for the option of PSN in the GUI (Fig. 3d). The transmitter antenna height (m) is entered from Field-6. The receiver antenna height (m) is entered from Field-7 (Fig. 3e). These are active for D2D option and not active for PSN.

Field-8 represents the number of D2D. In the simulation, this value gives the number of randomly distributed devices (UEs) in the disaster area. Its default value is 10 for D2D discovery simulator. Field-9 is a field where the number of iterations for the simulation period can be entered manually by the user. D2D device discovery is provided according to the number of different iterations.

Field-10 shows the manually entered value in dB for the sigma shadowing parameter. Its default value is 4 for this simulator. When the fields 6-10 on the GUI are left blank/deleted/not entered by the user, an error message is returned to the user. Field-11 shows the value to be selected according to the environment types for the path loss exponent value. The environment types are listed as free-space, urban area cellular radio, shadowed urban cellular radio, In building, obstructed in building and obstructed in factories (Fig. 3f).

In Field-12, has a button to randomly distribute the devices to the area. When this button is pressed as shown in Fig. 4, the points representing randomly distributed D2D-UE mobile devices are shown on the axes area numbered 16 according to the D2D number entered by the user. Each time the button is pressed, a random distribution is provided.



(a) (b)

(c) (d)

(e) (f)

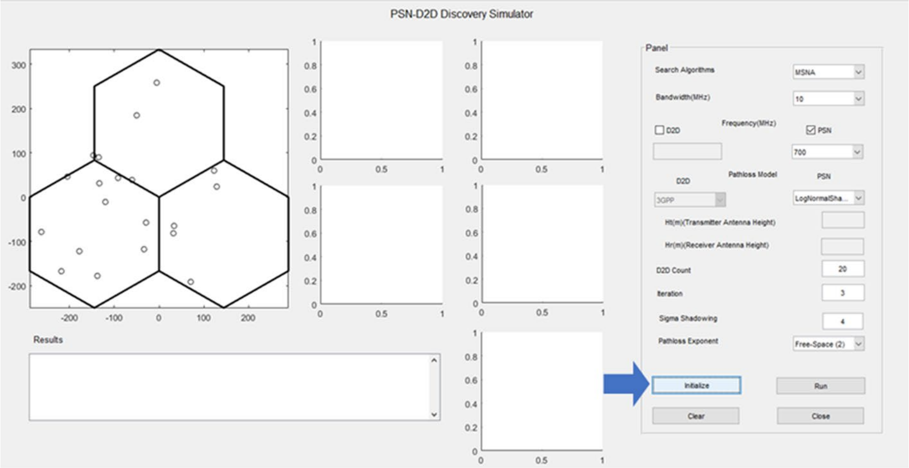
Fig. 3 Some features of PSN-D2D Discovery Simulator GUI

In Field-13 there is a button to start the simulation. After pressing the run button, the graphics of the simulation results and the number of matched D2D pairs can be seen on the result screen for selected D2D search algorithm and simulation parameters presented in the GUI (Fig. 5).

Field-14 includes the clear button. When this button is pressed, all graphics on the GUI are deleted. The close button in Field-15 is used to close the GUI screen. The hexagonal exploration zone in which points representing randomly distributed D2D-UE mobile devices are determined on the axes area in Field-16.

Fields 17-21 are used to show the graphics (SINR of active pairs, average pairs number, energy efficiency (Mbit/Joule), capacity (Mbps), and throughput (Mbps)) obtained from the simulation results of D2D search algorithms.

Field- 22 is a console where the results are displayed. When the simulation is completed, the obtained numerical results are displayed on this console. These results are as follows: A screenshot on the console of an example result taken is given in Fig. 6.



Panel

Search Algorithms: MSNA

Bandwidth(MHz): 10

Frequency(MHz): ☐ D2D ☑ PSN 700

Pathloss Model: D2D 3GPP; PSN LogNormalSha...

Ht(m)(Transmitter Antenna Height)

Hr(m)(Receiver Antenna Height)

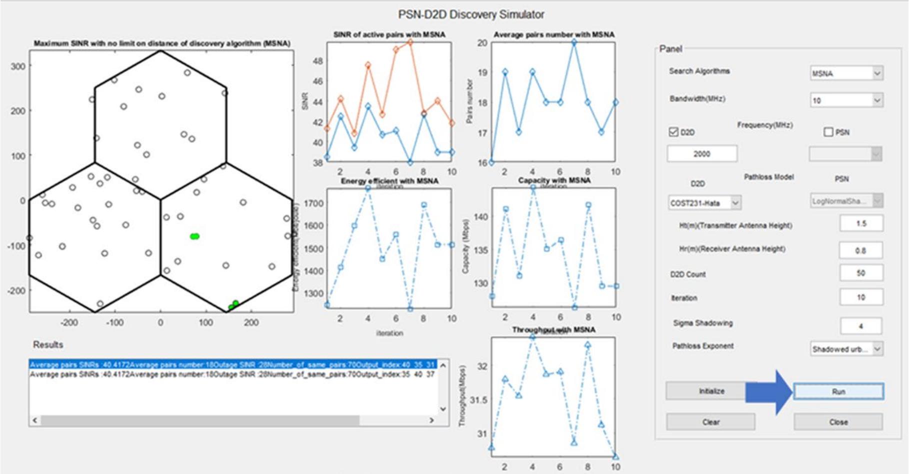
D2D Count: 20

Iteration: 3

Sigma Shadowing: 4

Pathloss Exponent: Free-Space (2)

Fig. 4 UEs distributed randomly by using press initialize button



Average pairs SINRs :40.4172Average pairs number:18Outage SINR :28Number_of_same_pairs:70Output_index:40 35 31

Average pairs SINRs :40.4172Average pairs number:18Outage SINR :28Number_of_same_pairs:70Output_index:35 40 37

Panel

Search Algorithms: MSNA

Bandwidth(MHz): 10

Frequency(MHz): ☑ D2D 2000 ☐ PSN

Pathloss Model: D2D COST231-Hata; PSN LogNormalSha...

Ht(m)(Transmitter Antenna Height): 1.5

Hr(m)(Receiver Antenna Height): 0.8

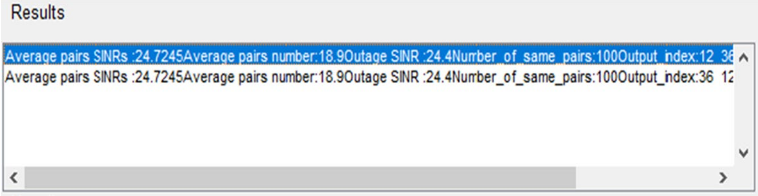
D2D Count: 50

Iteration: 10

Sigma Shadowing: 4

Pathloss Exponent: Shadowed urb...

Fig. 5 GUI screenshot obtained by pressing the run button



Results

Average pairs SINRs :24.7245Average pairs number:18.9Outage SINR :24.4Number_of_same_pairs:100Output_index:12 36

Average pairs SINRs :24.7245Average pairs number:18.9Outage SINR :24.4Number_of_same_pairs:100Output_index:36 12

Fig. 6 Simulator results on the console of the GUI

1. Average SINR of the active pairs: This shows the average of SINRs of the active pairs obtained by the D2D search algorithm selected on the GUI interface.
2. Average pairs number: This shows the number of the active pairs found by the D2D search algorithm selected on the GUI interface.
3. Outage SINR: It includes the outage SINR value of the selected D2D search algorithm during the discovery of the suitable UEs.
4. Number of the same pairs: It gives the value of discovering the same UEs during repetitive operation as a percentage.
5. Output index: This shows the index values of the discovered UE pairs for each runs.

Lastly, Field 23 displays the university and author information for which this graphical user interface (GUI) was developed. The proposed GUI design enables D2D discovery simulations to be conducted across eight distinct options based on the chosen algorithm. During each iteration, the existing UEs are randomly positioned within the sample scenario, considering the specific case that has been selected. For instance, in the case of selecting case-1, the simulations are executed using the MSNA algorithm, and subsequently, key output values such as outage SINR, active pairs, capacity, and energy activity are computed.

In the simulation, hexagonal-shaped structures represent the disaster area to be explored. When the simulation is started, it finds matching D2D user equipment (UE-mobile station-mobile phone) in the discovery area by making a random distribution according to the search algorithm to be selected and the D2D number. The graphs at the end of the simulation are evaluated according to different metrics.

5 Sample Scenarios

In this section, six different scenarios for D2D and PSN are designed on the GUI and the simulation results is presented in the summary tables.

5.1 Scenario-1 for D2D Discovery

The D2D discovery results have been obtained on different algorithm in the simulator for scenario-1. The parameters used in this scenario are summarized in Table 4.

According to the simulation parameters given in Table 4, device discovery results for eight different search algorithms are examined on the simulator. In order to evaluate the

Table 4 The simulation parameters used for D2D Scenario-1

Parameters	Models/Values
Bandwidth (MHz)	1.4
Frequency (MHz)	2100
Path loss Model	Log Normal Shadowing
Transmitter Antenna Height (m)	15
Receiver Antenna Height (m)	1.5
D2D Count	20
Iteration	10
Sigma Shadowing	4
Path loss Exponent (Environment)	Urban area cellular network

results of the discovery algorithms on the simulator, metrics such as average SINR of active pairs, the average number of active pairs, outage SINR, and number of same active pairs are displayed in the GUI visually and textually.

Table 5 summarizes the results of the discovery algorithms according to the first scenario parameters. For the first scenario, the simulation results in Table 5 present the performance metrics of the different discovery algorithms included in the proposed GUI. According to the results in this table, in terms of average SINR of active pairs, MSLA (150 m) has the highest value of 31.83 among eight different discovery algorithms, while the MSLA (100 m) algorithm has the lowest value with 20.43. TDA is the algorithm with the highest average number of pairs discovered within the 20 UEs, while SDA is the last algorithm with the lowest number of pairs. TDA has the outage SINR value with 13%, which provides the best service, thus the least disruption to service, while SDA is the worst algorithm in terms of the outage SINR. Under the first scenario, it appears that MSNA, SDA, MSLA (200 m) and TDA find the same pair of devices at each iteration. On the other hand, the MSLA (250 m) algorithm has the worst performance among the discovery algorithms in terms of finding the same pairs.

5.2 Scenario-2 for D2D Discovery

The D2D discovery results have been obtained on different path loss model in the simulator for scenario-2. Table 6 summarizes the parameters used in this scenario. The results were obtained for four different path loss models using the parameters given in Table 6. The results were obtained by the proposed D2D discovery simulator in terms of average SINR of active pairs, the average number of active pairs, outage SINR, and number of same active pairs. In Table 7, the results of MSNA are shown for the different path loss models.

The WinnerB5f path loss model has the highest value with a value of 37.89 among four different path loss models in terms of average SINR of active pairs, while 3GPP model has the lowest value with a value of 29.17 according to Table 7. While the 3GPP model is the first model with the highest number of pairs out of 25 pairs with 20.65, the Lee path loss model was the last with the lowest number of pairs (18.10 pairs). The 3GPP model is the path loss model with a value of 17.40% that provides the best service, thus the least disruption to service, while the Lee model is the worst path loss model. It shows that MSNA has

Table 5 Results of the discovery algorithms for D2D Scenario-1

Algorithm Name	Average SINR of active pairs	Average number of active pairs	Outage SINR	Number of same active pairs
MSNA	26.25	8.30	17%	100%
SDA	20.80	2.00	90%	100%
MSLA :50m	27.53	4.00	60%	90%
MSLA :100m	20.43	6.50	35%	90%
MSLA :150m	31.83	7.10	29%	80%
MSLA :200m	25.30	7.60	24%	100%
MSLA :250m	22.28	8.40	16%	60%
TDA	26.90	8.70	13%	100%

Table 6 The simulation parameters used for D2D Scenario-2

Parameters	Models/Values
Search Algorithm	MSNA
Bandwidth (MHz)	10
Frequency (MHz)	2100
Transmitter Antenna Height (m)	15
Receiver Antenna Height (m)	1.5
D2D Count	50
Iteration	20
Sigma Shadowing	3
Path loss Exponent (Environment)	Shadowed urban cellular radio

Table 7 Results of MSNA for path loss models in D2D Scenario-2

Path loss Model	Average SINR of active pairs	Average number of active pairs	Outage SINR (%)	Number of same active pairs (%)
3GPP	29.17	20.65	17.40	55
Cost231-Hata	33.10	19.65	21.40	80
WinnerB5f	37.89	19.05	23.80	80
Lee	30.76	18.10	27.60	60

Table 8 The simulation parameters used for D2D Scenario-3

Parameters	Models/Values
Search Algorithm	TDA
Bandwidth (MHz)	10
Frequency (MHz)	2500
Path loss Model	3GPP
Transmitter Antenna Height (m)	15
Receiver Antenna Height (m)	1.5
D2D Count	50
Iteration	10
Sigma Shadowing	4

discovered 80% of the same pairs for the WinnerB5f and Cost231-Hata models. The 3GPP model has the worst result among the path loss models with 55% in terms of discovering the same pairs.

5.3 Scenario-3 for D2D Discovery

The D2D discovery results have been obtained on six different path loss exponent for environment models in the D2D discovery simulator for Scenario-3. Table 8 shows the

Table 9 Results of TDA for path loss exponent for environment models in D2D Scenario-3

Path loss Exponent for Environment	Average SINR of active pairs	Average number of active pairs	Outage SINR (%)	Number of same active pairs (%)
Free-Space	17.79	18.40	26.40	100
Urban Area	33.56	19.10	23.60	100
Shadowed CN	21.28	20.10	19.60	50
In Building Area	18.55	17.10	31.60	100
Obstructed area	33.60	20.40	18.40	100
Obstructed factories	24.73	18.90	24.40	100

parameters utilized in this scenario. As can be seen from this table, we selected TDA as discovery algorithm. Table 9 summarizes the simulation results for the different environment models.

"Obstructed area" model has the highest value with 33.60 among four different environment models in terms of average SINR of active pairs, while "Free-Space" model has the lowest value with 17.79 according to Table 9. While "Obstructed area" environment model is the first model with the highest number of pairs out of 25 pairs with 20.40, "In Building Area" model is the last with the lowest number of pairs (17.10 pairs). "Obstructed area" model is an environment model with a value of 18.40% that provides the best service, thus the least disruption to service, while "In Building Area" model is the worst environment model for the path loss. "Shadowed CN" model (CN: Cellular Network) had the worst result among the path loss environment models with 50% in terms of finding the same pairs.

5.4 Scenario-1 for PSN Device Discovery

In this subsection, the performances of different device discovery algorithms are examined in the first scenario using the proposed D2D discovery simulator. Table 10 shows the simulation parameters determined in this scenario.

The results can be obtained for each discovery algorithms thanks to the D2D discovery simulator We have taken simulation results of all discovery algorithms in the first PSN scenario. Table 11 presents the performance results of the different discovery algorithms in the proposed D2D simulator. Looking at the results in this table, the MSLA (250 m) has

Table 10 The simulation parameters used for PSN Scenario-1

Parameters	Models/Values
Bandwidth (MHz)	1.4
Frequency (MHz)	700
Path loss Model	Log Normal Shadowing
D2D Count	20
Iteration	10
Sigma Shadowing	4
Path loss Exponent (Environment)	Urban area cellular network

Table 11 Results of the discovery algorithms for PSN Scenario-1

Algorithm Name	AverageS-INR of active pairs	Average number of active pairs	Outage SINR	Number of same active pairs
MSNA	25.32	7.50	25%	60%
SDA	22.44	2.00	90%	100%
MSLA :50m	24.22	6.00	40%	60%
MSLA :100m	14.16	6.80	32%	50%
MSLA :150m	31.47	6.70	33%	100%
MSLA :200m	28.11	7.20	28%	50%
MSLA :250m	32.18	7.20	28%	100%
TDA	13.00	8.20	19%	90%

the highest value (32.18) among eight different discovery algorithms in terms of average SINR of active pairs, while TDA has the lowest value with 13.00.

TDA is the algorithm with the most active pair discovery capacity out of 10 pairs with 8.20 average active device pairs, while SDA is the algorithm with the lowest pair discovery capacity with 2 average active device pairs. TDA is the algorithm with a value of 19%, that provides the best service, thus the least disruption to service, while SDA is the worst algorithm. The results about the number of same active pairs shows that SDA, MSLA (150 m) and MSLA (250 m) find the same pair of devices at each iteration.

5.5 Scenario-2 for PSN Device Discovery

The PSN device discovery results have been obtained for three path loss models in PSN Scenario-2. The simulation parameters utilized for this scenario are summarized in Table 12. MSLA (150 m) has been selected as discovery algorithm in PSN Scenario-2 to show the effects of the different path loss models. Users can perform this scenario in the same way for different search algorithms.

The simulation results of MSLA (150 m) were obtained for three path loss models according to the parameters summarized in Table 12. The table results consists of average SINR of active pairs, the average number of active pairs, outage SINR, and number of same active pairs. In Table 13, the simulation results of MSLA (150 m) are shown for the different path loss models.

Table 12 The simulation parameters used for PSN Scenario-2

Parameters	Models/Values
Search Algorithm	MSLA(150 m)
Bandwidth (MHz)	20
Frequency (MHz)	700
D2D Count	50
Iteration	10
Sigma Shadowing	4
Path loss Exponent (Environment)	In Building

Table 13 Results of MSLA (150 m) for path loss models for PSN Scenario-2

Path lossModel	Average SINR of active pairs	Average number of active pairs	Outage SINR (%)	Number of same active pairs (%)
Winner+B1	11.62	13.00	48.00	100
ITU-1411-6	11.35	14.20	43.20	70
Log Normal Shadowing	15.30	11.70	53.20	80

The Log Normal Shadowing path loss model has the highest value (15.30) among three different path loss models in terms of average SINR of active pairs, while the ITU-1411-6 model has the lowest value with 11.35 according to Table 13. While the ITU-1411-6 model is the first model with the highest number of pairs out of 25 pairs with 14.20, the Log Normal Shadowing path loss model is the last with the lowest number of pairs (11.70 pairs). The ITU-1411-6 model is the path loss model with a value of 43.20% that provides the best service, thus the least disruption to service, while the Log Normal Shadowing model is the worst path loss model. It shows that MSLA (150 m) has found the same pairs for the Winner+B1.

5.6 Scenario-3 for PSN Device Discovery

The PSN device discovery results have been obtained on six different environment model using the D2D discovery simulator in PSN-Scenario-3. TDA has been determined as discovery algorithm in PSN Scenario-3 to evaluate the effects of the different environment models. Users of the proposed D2D simulator can perform this scenario in the same way for different discovery algorithms. Table 14 summarizes the simulation parameters of this scenario. Table 15 shows the simulation resuts of TDA for six environment models.

Looking at the results in Table 15, "Obstructed area" model has the highest value (33.77) among different environment models in terms of average SINR of active pairs, while "In building area" model has the lowest value with 6.43. While "Shadowed cellular network" model was the first model with the highest number of pairs out of 25 pairs with 21.20, "In Building Area" model was the last with the lowest number of pairs (17.30 pairs). "Shadowed cellular network" model is environment model with a value of 15.20% that provides the best service, thus the least disruption to service, while "In Building Area" model is the worst environment model for the path loss.

Table 14 The simulation parameters used for PSN Scenario-3

Parameters	Models/Values
Search Algorithm	TDA
Bandwidth (MHz)	10
Frequency (MHz)	700
Path loss Model	Log Normal Shadowing
D2D Count	50
Iteration	10
Sigma Shadowing	4

Table 15 Results of TDA for path loss exponent for environment models in PSN Scenario-3

Path loss Exponent for Environment	Average SINR of active pairs	Average number of active pairs	Outage SINR (%)	Number of same active pairs (%)
Free-Space	17.82	18.50	26.00	100
Urban Area	15.14	19.30	22.80	50
Shadowed CN	27.75	21.20	15.20	100
In Building Area	6.43	17.30	30.80	40
Obstructed area	33.77	20.20	19.20	100
Obstructed factories	23.46	18.90	24.40	100

5.7 Evaluation of D2D and PSN Scenarios

A summary table is presented for six different scenarios for D2D and PSN discovery in Table 16. This table summarizes the scenario results according to the performance metrics. From the table result, it is understood which discovery algorithm, which path loss model, which environmental model is more effective for each metric in different scenarios. Thanks to the proposed D2D discovery simulator, the users can create different scenarios and examine the performance of the discovery algorithms visually and textually on the GUI.

6 D2D Discovery Simulator User Survey and Results

The D2D Discovery simulator developed within the scope of this study was surveyed in terms of design and usability in general among users who taken Basic Computer Science and Programming Languages courses at Bilecik Seyh Edebali University in Turkey, and

Table 16 Summary table for D2D and PSN scenarios

Scenarios	Average SINR of active pairs	Average number of active pairs	Outage SINR (%)	Number of same active pairs (%)
D2D-S1	MSLA (150 m)	TDA	TDA	MSNA, SDA, MSLA (200 m), TDA
D2D-S2	WinnerB5f	3GPP	3GPP	WinnerB5f, Cost231-Hata
D2D-S3	Obstructed area	Obstructed area	Obstructed area	Free-Space, Urban area, In building area Obstructed area, Obstructed factories
PSN-S1	MSLA (250 m)	TDA	TDA	SDA, MSLA (150 m/250 m), TDA
PSN-S2	Log Normal Shadowing	ITU1411-6	ITU1411-6	Winner+B1
PSN-S3	Obstructed area	Shadowed CN	Shadowed CN	Free-Space, Shadowed CN, Obst. area Obstructed factories

the results were evaluated. In the survey, users were asked about gender, age information, education level, occupation, and working year in the institution within the scope of demographic characteristics. A total of 10 questions were asked about the designed interface design, in terms of color harmony, ease of single interface, ease of use of different options, contribution to education, and clarity. In the last question, they were asked to rate the overall design of the interface.

Students who had taken computer and basic programming courses, students of computer department, and users with technical qualifications were selected as the the general framework of the survey. Google Form application was used as the survey program. The number of participants in the survey is 178. Demography characteristics of participants are shown in Table 17. N represents number of participants and % is percentages of participants. Demography characteristics of participants are shown separately in the Table 18.

According to Table 17, 92.70% of the users participating in the survey are between the ages of 20-30. In terms of education, 84.83% of them consist of those who have undergraduate and graduate education. 79.21% of those who participated in the survey are users who study and work in the field of computers (Computer Engineering, Centre of Information Technology, Computer Programming, and Management Information System).

According to Table 18, 90.45% of the users participating in the survey are students. In terms of education, 83.23% of them consist of those who have undergraduate (bachelor) education. 63.98% of those who participated in the survey are students of department of Management Information System. From Table 18, 9.55% of the users participated in this survey are staffs. In terms of education, 64.71% of the participants have master's degree and 11.76% of them have doctorate education. 64.71% of those who participated in the survey are staffs who work at the Centre of Information Technologies.

The evaluation test about the D2D Discovery Simulator graphical interface design consists of ten short-answer conceptual questions. For the D2D exploration simulator evaluation, users were asked the following questions:

Table 17 Demography characteristics of participants

Variables	N	(%)	Variables	N	(%)
Sex			**Occupation**		
Men	132	74.16	Staff	9	5.06
Women	46	25.84	Student	161	90.45
Age Category(years)			Staff and student	8	4.49
20-25	159	89.33	**Working year**		
26-30	6	3.37	1-5 year (158+10)	168	94.38
31-35	7	3.93	6-10 year	4	2.25
36-40	1	0.56	11-15 year	5	2.81
41 +	5	2.81	16-20 year	0	0.00
Level of Education			21 +	1	0.56
High school	7	3.93	**Department**		
Vocational school	20	11.24	Computer Engineering	10	5.62
Undergraduate (Bachelor)	138	77.53	Mechanical Engineering	20	11.24
Graduate	11	6.18	Management Information	103	57.87
Doctorate	2	1.12	Civil Engineering	17	9.55
			Centre of Information Tech	11	6.18
			Computer Programming	17	9.55

Table 18 Demography characteristics of participants (student and staff)

Occupation					
	N	(%)		N	(%)
Student	161	90.45	Staff	17	9.55
Working year					
1-5 year	158	98.14	1-5 year	7	41.18
6-10 year	3	1.86	6-10 year	4	23.53
11-15 year	-	-	11-15 year	5	29.41
16-20 year	-	-	16-20 year	-	-
21 +	-	-	21 +	1	5.88
Level of Education					
High school	7	4.35	High school	-	-
Vocational school	20	12.42	Vocational school	-	-
Undergraduate	134	83.23	Undergraduate	4	23.53
Graduate	-	-	Graduate	11	64.71
Doctorate	-	-	Doctorate	2	11.76
Department					
Computer Engineering	4	2.48	Computer Engineering	6	35.29
Mechanical Engineering	20	12.42	Mechanical Engineering	-	-
Management Information	103	63.98	Management Information	-	-
Civil Engineering	17	10.56	Civil Engineering	-	-
Centre of Information Tech	-	-	Centre of Information Tech	11	64.71
Computer Programming	17	10.56	Computer Programming	-	-

1. The graphical interface design is beautifully designed in terms of color harmony
2. Data entry in a single interface has avoided complexity
3. In the graphical interface, it was appropriate to select the features with different options (selection algorithms, path loss models, environmental effect, etc.) in the form of pop-up windows
4. It is suitable that the interface leaves the user free to perform different tests for data entry
5. It is suitable to distinguish between D2D and PSN and make different path loss selections from the interface
6. Button design and functionality are appropriate in the graphical interface
7. The graphical interface design is designed to be useful for the end-user and the student
8. It has a positive contribution to education in special and technical subjects such as device discovery with graphical interface design
9. The explanations made in the graphical interface are sufficient to understand the features
10. Please rate the D2D discovery simulator

The users (students and staff) were asked to rate D2D discovery simulator for ten items given above, on a five-point scale (excellent=5, very good=4, good=3, fair=2, very poor=1). The evaluation test results of D2D discovery simulator are shown in Table 19.

Table 19 D2D Discovery Simulator User Survey Results

	5		4		3		2		1		
No	N	%	N	%	N	%	N	%	N	%	μ
1	39	21.91	66	37.08	43	24.16	20	11.24	10	5.62	3.58
2	59	33.15	70	39.33	31	17.42	7	3.93	11	6.18	3.89
3	50	28.09	77	43.26	32	17.98	7	3.93	12	6.74	3.82
4	55	30.90	74	41.57	29	16.29	10	5.62	10	5.62	3.87
5	50	28.09	67	37.64	43	24.16	8	4.49	10	5.62	3.78
6	58	32.58	66	37.08	27	15.17	16	8.99	11	6.18	3.81
7	51	28.65	61	34.27	45	25.28	9	5.06	12	6.74	3.73
8	56	31.46	68	38.20	35	19.66	10	5.62	9	5.06	3.85
9	47	26.40	68	38.20	40	22.47	12	6.74	11	6.18	3.72
10	53	29.78	74	41.57	33	18.54	10	5.62	8	4.49	3.87

These questions about the designed interface design consist of parts such as color harmony, ease of single interface, ease of use of different options, contribution to education, and clarity. In the last question, users were asked to rate the overall design of the interface. μ represents questions' weighted average values in Table 19. The survey results of the D2D discovery simulator are shown in Fig. 7.

Within the scope of D2D discovery simulator graphical interface design according to Table 19, 3.58 in terms of color compatibility (Q1), 3.89 in point of ease of single interface (Q2), 3.82 and 3.78 in terms of ease of use of different options (Q3 and Q5), ease of data entry (Q4) 3.87, 3.81 with regard to button design and functionality (Q6), 3.73 and 3.85 in terms of the contribution of single interface use to education (Q7 and Q8), 3.72 in point of explanations (Q9), and the rating of the simulator (Q10) was found to be successful at a rate 3.87 out of 5. According to the answers given in the questionnaire, it is seen that

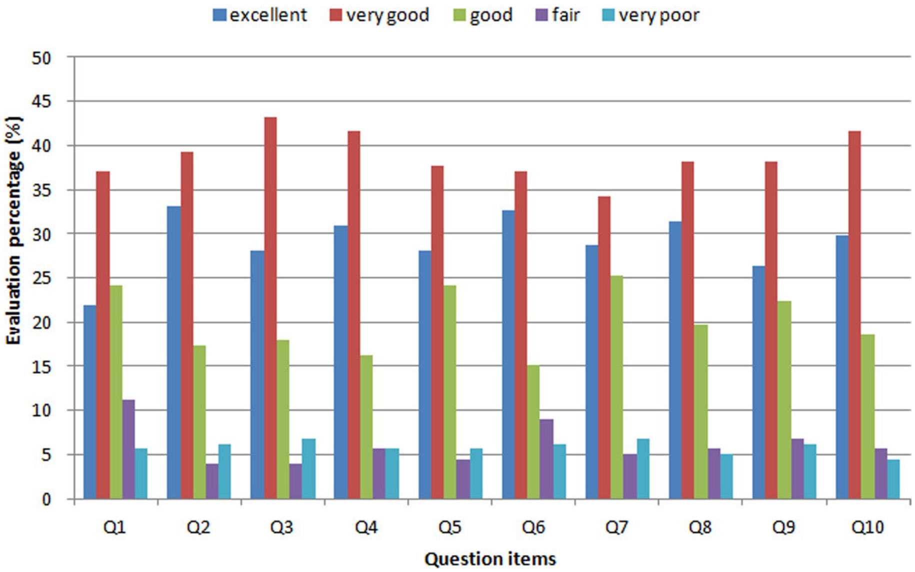


Fig. 7 D2D discovery simulator evaluation results

the study gives good results in terms of using a single interface, ease of data entry and contribution to education.

In survey, apart from the questions about the D2D discovery simulator, general opinion about the GUI were optionally asked. From this general evaluation, 89.90% of positive opinions were expressed. Negative opinions were generally about choosing more vivid colors in color harmony (Q1).

7 Conclusion

The Simulation tools or simulators are very important to support theoretical knowledge with practical applications in especially engineering education. In this study, an interface (GUI) named D2D discovery simulator has been developed so that different parameters can be entered with the help of a single interface and the results can be viewed from a single interface.

The simulation can be run by making selections on the interface according to the path loss environmental impact models (free space, urban cellular radio area, shadowed urban cellular radio area, etc.). The outputs can be seen on the result screen. In this study, as an example, the effects and results of D2D discovery algorithms which have different scenarios and parameters such as different path loss, environmental impact values on device discovery, were evaluated using the D2D discovery simulator.

The D2D discovery simulator was surveyed in terms of design and usability in general among users who had taken Basic Computer Science and Programming Languages courses at Bilecik Seyh Edebali University in Turkey, and their results were evaluated. According to the answers given in the questionnaire, it is seen that the study gives good results in terms of using a single interface, ease of data entry and contribution to education.

The developed simulator provides a user-friendly interface that enables users, including students and researchers, to conveniently evaluate various D2D discovery algorithms under different simulation parameters. This allows for easy testing and analysis within a user-friendly environment. For the simulation parameters selected on the simulator, the SINR, energy efficiency, capacity and throughput values of the matched UE pairs after D2D discovery are plotted on the relevant graphs according to the number of iterations. Also, the calculated metrics are given on the result screen. D2D discovery simulator is important as it is a simulator to be used for academics, technical staff and students who want to learn D2D and PSN subjects. This simulator can be developed according to different needs depending on usage.

Availability of data and materials The authors declare that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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