Performance analysis of D2D network in heterogeneous multi-tier interference scenarios

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ABSTRACT

The trade-off between boosting network throughput and minimizing interference is a critical issue in fifth generation (5G) networks. Diverting the data traffic around the network access point in device-to-device (D2D) communication is an important step in realizing the vision of 5G. Though the D2D network improves the network performance, they complicate the interference management process. Interference is an invisible physical phenomenon occurring in wireless communication which happens when multiple transmissions happen simultaneously over a general wireless medium. Enormous growth in usage of mobile phone and other wireless gadgets in recent years has paved the way for significant role in Interference analysis over multi-tier network. Interference could affect communication systems performance and it might even prevent systems functioning properly. 3G and 4G wireless devices coexisted with reverse compatibility in a coverage area. Also, after their widespread adoption, 5G devices have become prevalent across the globe and this reaffirms interference coexistence as a significant field of research. Multiple systems operating in a region will cause severe interference and ultimately reduce the quality of received signal. A simulation environment for cellular standards coexistence considering real-time parameters is created and experimented. Various research works earlier addresses the interference mitigation techniques in multi-tier networks but none of them present the analysis of scenarios and interfering signal power levels in the respective contexts. In this paper various scenarios with different network interference coexistence were studied, simulated, and analyzed quantitatively.

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1. INTRODUCTION

According to the CISCO internet report, over 70 percent of the global population has mobile connectivity after 2023. Out of 13.1 billion global mobile devices 1.4 billion 5G devices are in usage [1]. There was a humongous proliferation in devices connected to internet which leads to elevated interference conditions. Interference in device-to-device (D2D) communication involves analysis of interference between a D2D users and a conventional cellular communication system [2], [3]. There are different possibilities of interference [4] in the multi-tier networks such as co-tier interference, cross-tier interference. Interference also depends on the power control whether it is centralized, distributed or semi-distributed power control. For analyzing the interference, different scenarios are considered which includes second generation (2G), third generation (3G), fourth generation (4G), and beyond fifth cellular systems as per the standards and specifications defined by ITU, ETSI, and 3GPP [5]–[7]. The D2D system being a victim system got interfered with all other networks and respective interfering received signal strengths are evaluated. Interference and other parameters are described based on the radio interface guidelines and IEEE standards release.

2. RELATED RESEARCH

From the surveys it is evident that the D2D communication underlay cellular networks have experienced improvement in capacity, throughput, end to end latency and coverage [8]. In heterogeneous (HetNets) multitier networks the system undergoes co-tier interference, cross-tier interference and hybrid interference. Power allocation strategies, spectrum allocation strategies and hybrid strategies are used for interference reduction [5]. Interference in HetNets is caused due to random deployment of base stations, non-deterministic variations in channels, spectrum sharing and intracell and inter cell interferences [6]. Though the interference is the prime disadvantage, the HetNets provides improvement in capacity as the devices co-exist with varying levels of distributed power resulting in reduced path loss and latency [7]. For highly denser fifth generation (5G) networks, a stochastic geometrical approach can be used for interference cancellation model [9]. Considering the D2D heterogeneous network as beyond fifth generation network (B5G) the interference management schemes vary into intra-mode inter-cell interference management, inter-cell inter-beam interference management, cross-link interference management, remote interference management, self-interference management, intra-cell multi-user interference management and inter numerology interference management [10].

Number of approaches a design engineer can investigate the interference mitigation. The interference caused due to mutual interference among different tiers of users and the limited spectrum can be overwhelmed by resource allocation algorithms [11]. Few promising methods include distributed resource allocation [12]–[14], dynamic power allocation [15], [16], precoding [17]. Analytically the interference problem can be approached using game theory [18], graph theory [19], and beamforming [20]. Interference mitigation is also a highly complex operation like interference analysis in wireless reception. Distributed power allocation with rapid shifting model is proposed for interference management in [21]. User association-resource-power allocation was employed to eliminate cross-tier and co-tier interference in [22]. The high-power consumption in small cell HetNets can induce more adverse effects of interference and a dynamic offloading adjustments (DLA) algorithms based on Q-learning [23] and a new soft frequency scheme was proposed in [16] to mitigate interference and improve network throughput. Future cellular networks would require immense computation and trade-off for interference mitigation. Feedback between cells for resource allocation, game theory, and antenna allocation algorithms are employed to mitigate interference in 5G heterogeneous networks [24]. The existing interference management methodologies are clearly described by Trabelsi *et al.* [10] and Lopez-Perez *et al.* [25].

3. METHODOLOGY OF INTERFERENCE CALCULATION

The criteria considered for interference calculation are C/I carrier to interference ratio, C/(I+N) carrier to interference plus noise ratio, (N+I)/N desensitization, I/N interference to noise ratio. Sensitivity is the lowest power level at which a receiver can receive a signal. Receiver sensitivity is the minimum input signal level required to produce an output signal with specific signal-to-noise ratio (SNR). It is defined as in (1).

$$Sensitivity(dB) = NoiseFloor + \left(\frac{C}{N+I}\right) \tag{1}$$

These interference criteria can be related by the following relationship given in (2).

$$\left[\frac{C}{N+I}\right]_{dB} = \left[\frac{C}{I}\right]_{dB} - \left[\frac{N+I}{I}\right]_{dB} \tag{2}$$

If the C/I criterion is considered, then the probability of non-interference P_{NI} in receiver can be expressed as in (3).

$$P_{NI} = P\left(\frac{dRSS}{iRSS} > \frac{C}{N} | dRSS > sens\right) \tag{3}$$

Where $dRSS$ is desired signal strength and $iRSS$ is interfering signal strength. By axioms of probability (8) can be given as in (4).

$$P_{NI} = \frac{P\left(\frac{dRSS}{iRSS} > \frac{C}{N} | dRSS > sens\right)}{P(dRSS > sens)} \quad (4)$$

Where $sens$ is the sensitivity of the receiver. Monte Carlo method is individually applied to numerator and denominator as in (5).

$$p'_{NI} = \frac{\frac{1}{M}\sum_{i=1}^{M} \frac{dRSS}{iRSS} > \frac{C}{N} | dRSS > sens}{\frac{1}{M}\sum_{i=1}^{M} \{dRSS > sens\}} \quad (5)$$

Where M is the number of events. If the C/(N+I) criteria is considered, probability of non-interference P_{NI} in receiver can be expressed as in (6).

$$P_{NI} = P\left(\frac{dRSS}{iRSS} > \frac{C}{I+N} | dRSS > sens\right) \quad (6)$$

4. SYSTEM MODELING FOR INTERFERENCE ANALYSIS IN VARIOUS SCENARIOS

4.1. D2D vs LTE uplink system

The interference scenario shown in Figure 1 depicts the victim receiver unintentionally receives the signal from the nearby transmission. In D2D heterogenous communication scenarios various signals interfere with each other. Consider the long-term evolution (LTE) uplink system interferes with the D2D system receiver. The scenario infers the interference impact on system with coexistence of two different communication networks. The LTE network parameters are used as defined in 3GPP standard [5]. In LTE system each eNBs (generally termed as base station) is assigned with several resource blocks (RBs), the RBs are divided from the total bandwidth allocated. From the available total RBs certain number of RBs are allotted to each of the user equipment user equipment's (UEs) (generally termed as mobile station) in the coverage. The emission mask is defined for LTE uplink system in accordance to the system bandwidth.

Figure 2 shows scenario outline for D2D users as victims and LTE transmitters and receivers as interferers. Using Monte Carlo simulation, the system simulated for 200 events. The interfering received signal strength at D2D receiver is -48.19 dBm as shown in Figure 3. The cumulative distribution function (CDF) of the interference criteria C/I and C/(N+I) are shown in Figure 4.

The probability of interference at D2D receiver is obtained as 0.795 for C/I criteria and 0.745 for C/(N+I). Similar modeling is organized for the scenario of interference at D2D receiver with the LTE downlink systems and the iRSS and probability of interference is obtained as -55.03 dBm and 0.675. The two results show that the uplink system causes more interference than the downlink LTE orthogonal frequency division multiple access (OFDMA) system.

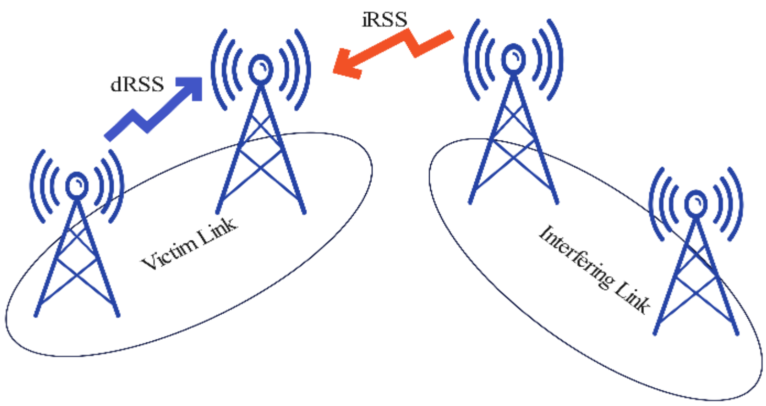

Figure 1. Interference scenarios

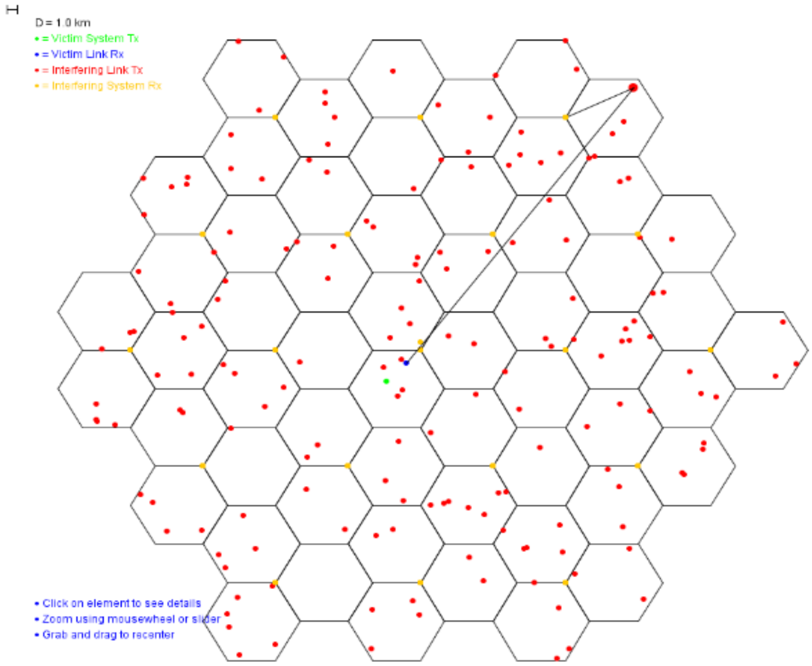

Figure 2. System layout for D2D vs LTE UL

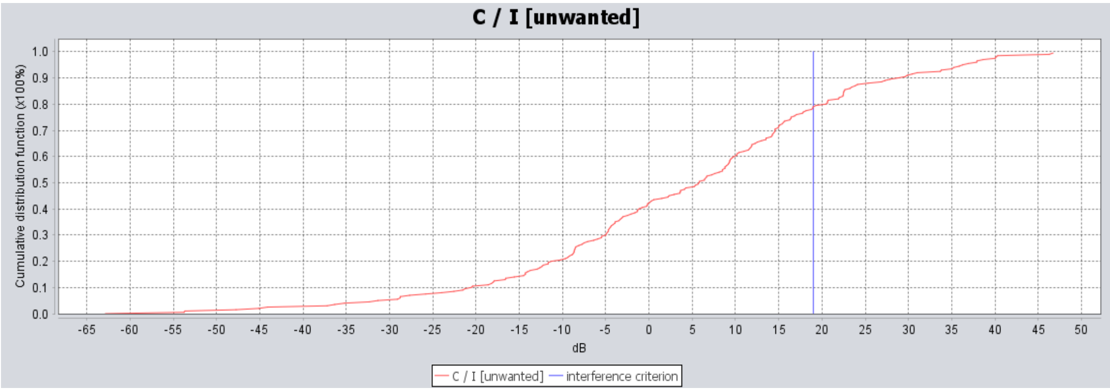

Figure 3. IRSS (dBm) from LTE

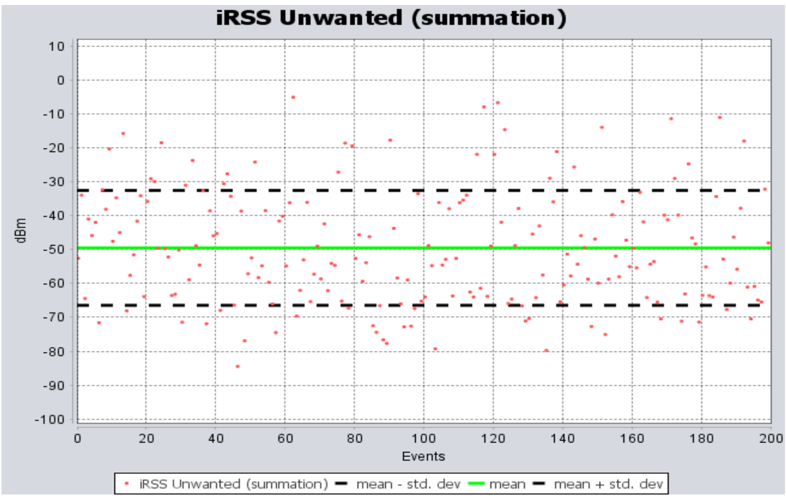

Figure 4. CDF of C/I for LTE vs D2D

4.2. D2D vs 3G vs LTE uplink system

Consider the scenario of multiple system interference to the D2D receiver. The OFDMA LTE system, code division multiple access (CDMA) third generation cellular system and D2D systems coexists in a scenario. That is case possible with future communication systems with reverse compatibility such as cognitive radios and internet of things.

The same parameters are considered for LTE uplink system and the parameters considered for 3G systems are same as given in Table 1 except for the difference in emission mask. Interfering uplink LTE parameters are chosen as in Table 2. Figure 5 shows the estimation of number of users who can operate to full extent without interference and it is 37. Figures 6 and 7 shows the outline of the scenario with D2D devices coexisted with 3G and 4G devices. Similarly, when the network is filled up gradually with the UEs the average noise raise is measured for defined SNR. The average noise value increases as the number of users in the coverage increases.

Table 1. Simulation parameters

Parameters	Transmitter	Receiver
Noise floor and sensitivity		-110 dB and -98 dBm
Power	33 dB	
Operating frequency	900 MHz	900 MHz
Antenna	Trisector Antenna	Trisector antenna
Antenna gain	15 dBi	15 dBi
Antenna height	30 m	
Emission/reception BW		200 KHz
Interference criteria	C/I 19 dB; C/(N+I) 16 dB; (N+I)/N 3 dB; I/N 0 dB	
Positioning	Correlated positioning w.r. to D2D receiver	

Table 2. Interfering LTE UL parameters

Parameter	Value
Max RBs per BS	51
RBs per MS	17
Handover margin	3.1 dB
MCL	70 dB
System BW	10 MHz
Rx noise fig	4 dB
RB BW	180 kHz

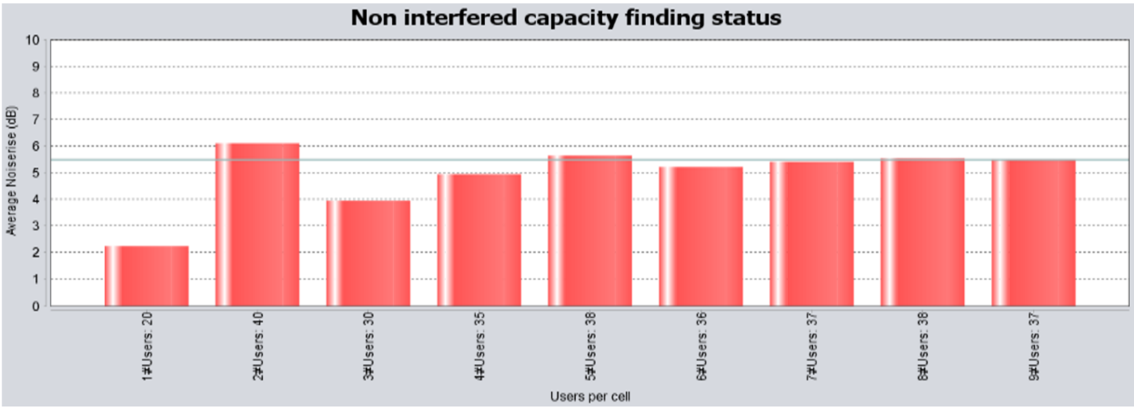

Figure 5. Non-interfered system capacity D2D vs 3G vs LTE UL

4.3. D2D vs 3G vs LTE downlink system

Now, consider the multiple interference to a D2D receiver occurring from 3G and LTE downlink system. The Figures 8 and 9 show the downlink scenario outline and iRss PDF distribution. The effect of interference from the emissions of interferers are calculated. It is evident from Figure 10 that on correlated positioning, the downlink interference results show that the number of users should be less than 10 for non-interference scenario.

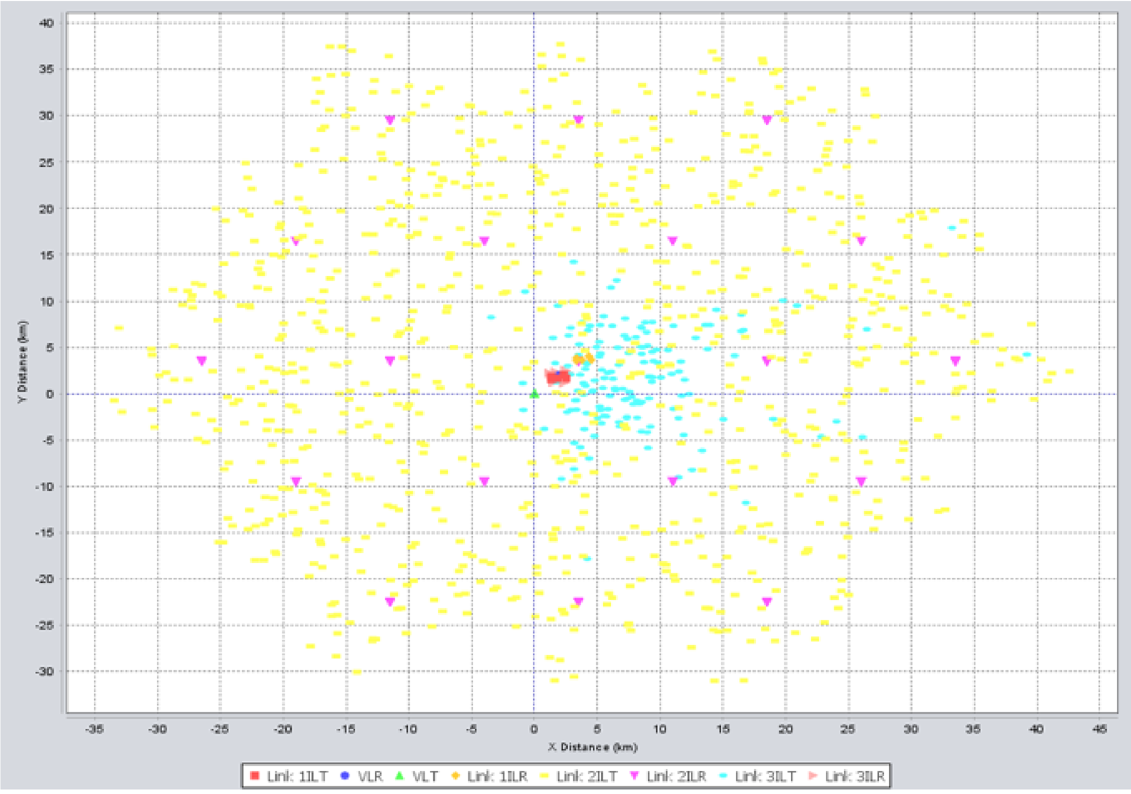

Figure 6. System layout for D2D vs 3G vs LTE UL

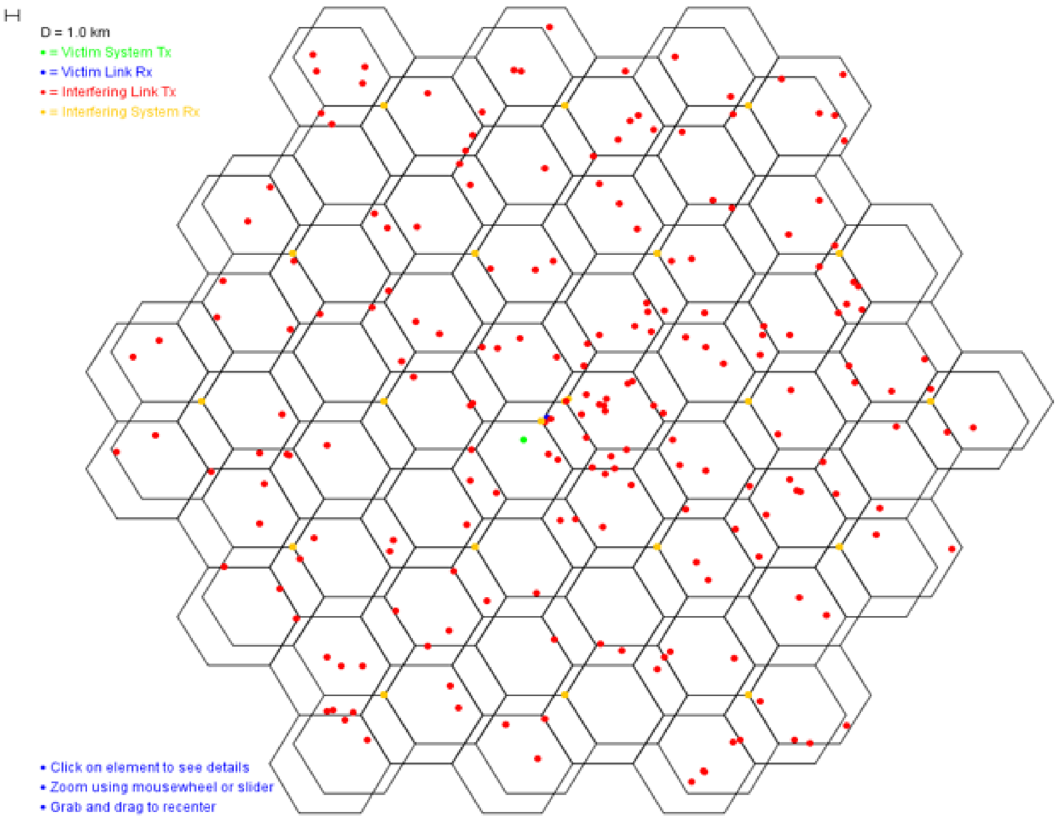

Figure 7. Multiple interfering system layout

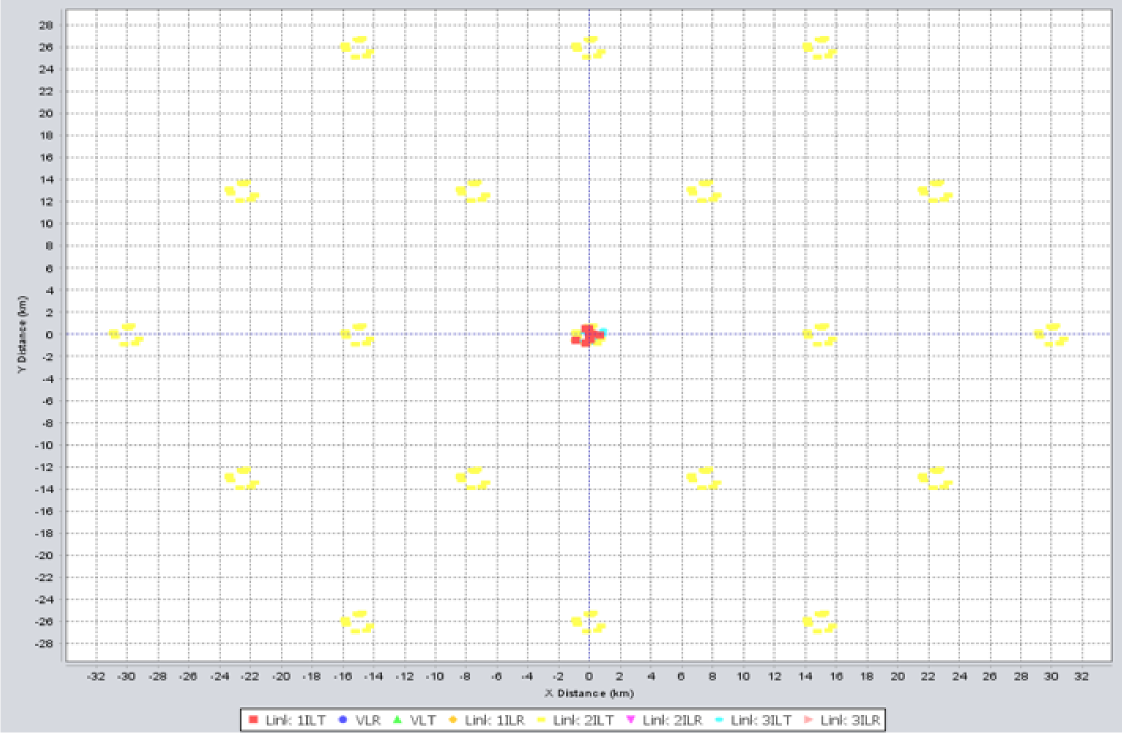

Figure 8. System layout for D2D vs 3G vs LTE DL

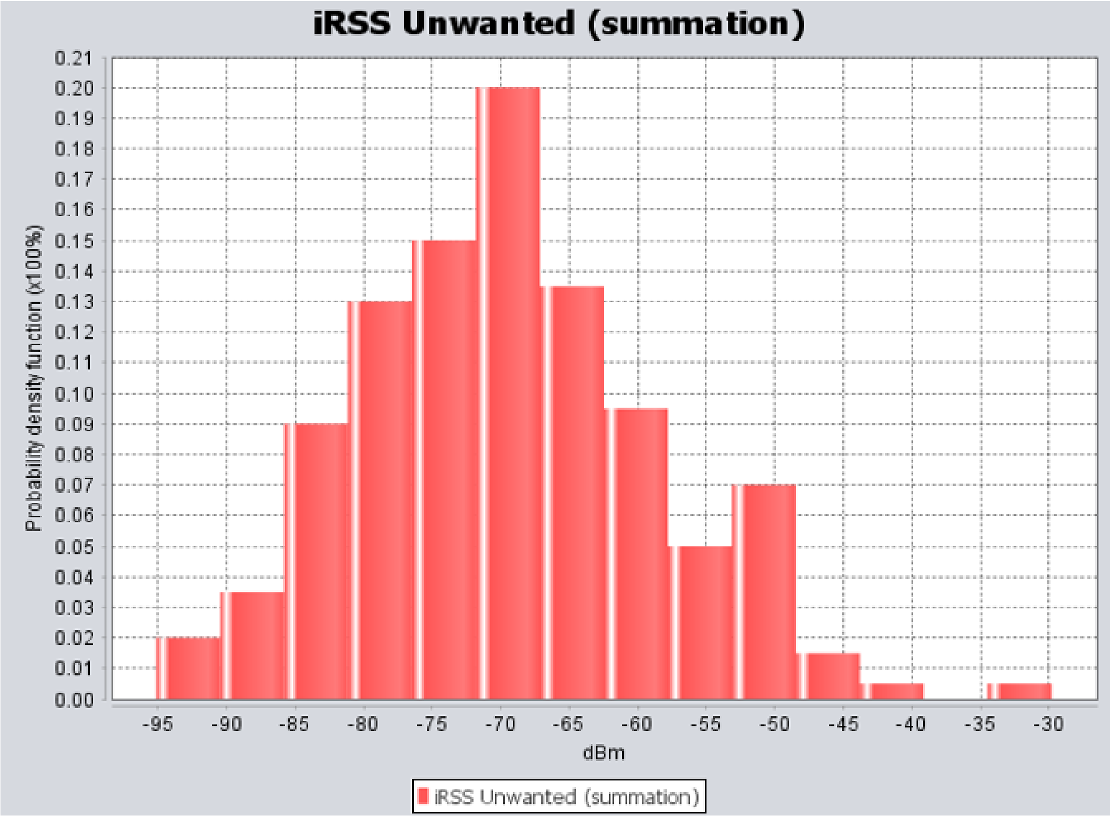

Figure 9. IRSS PDF for D2D vs 3G vs LTE DL

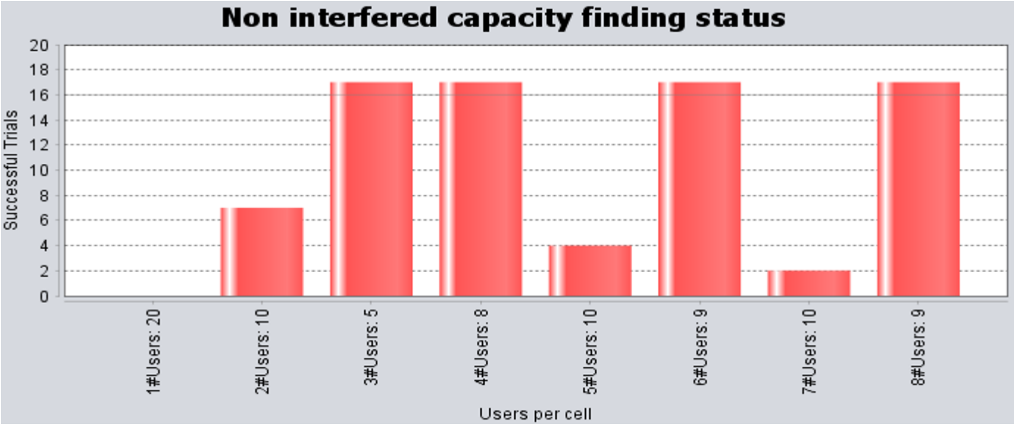

Figure 10. Non-interfered system capacity D2D vs 3G vs LTE DL

5. RESULTS AND DISCUSSIONS

The calculated parameter values are listed in Tables 3 and 4 for all four-interference uplink and downlink scenarios. The values are plotted for comparison in Figures 11 and 12. The interference signal strength is low in D2D and LTE coexisted network than the D2D coexisted with CDMA and LTE network because of position distribution of the devices in a region.

Table 3. IRSS and probability of interference (D2D vs LTE)

Scenario	IRSS (dBm)	Probability of interference C/I	Probability of interference C/(C+I)
D2D vs LTE uplink system	-48.19	0.795	0.745
D2D vs LTE downlink system	-55.03	0.675	0.55

Table 4. IRSS and probability of interference (D2D vs 3G vs LTE)

Scenarios	IRSS (dBm)	Probability of interference C/I	Probability of interference C/(C+I)	Number of users for non-interfering capacity
D2D vs 3G vs LTE uplink system	-51.41	0.835	0.775	37 users
D2D vs 3G vs LTE downlink system	-67.49	0.669	0.554	10 users

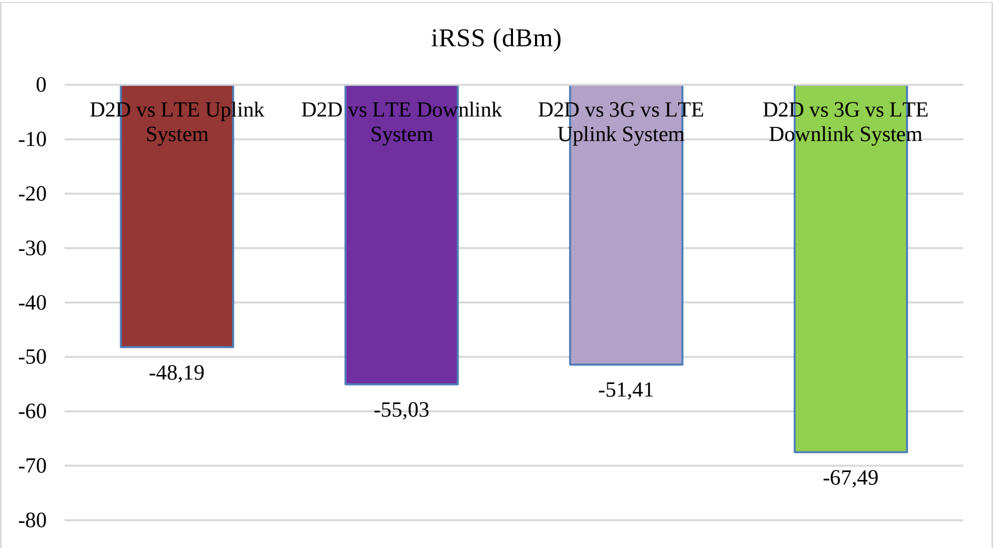

Figure 11. Interference signal strength comparison

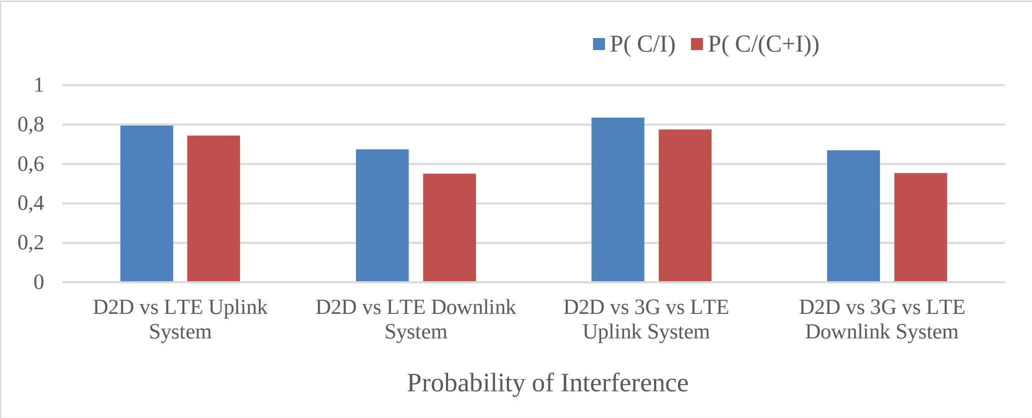

Figure 12. Probability of interference for various scenarios

6. CONCLUSION

D2D communication is known for its ubiquitous approach and is recognized for notable advantages such as reuse gain, proximity awareness, enhanced capacity and improved reliability. D2D has already become part of future 5G networks and offloading local area services. The experiments explore the potential for interference in D2D communication and examines various multi-cell interference scenarios, such as uplink and downlink interference in CDMA and OFDMA cellular networks. The results observed enables the feasible design of effective signal processing and channel utilization techniques for interference free transmissions for the multi-tier coexistence scenarios.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Chellaperumal Arunachalaperumal		✓		✓	✓	✓			✓	✓	✓	✓	✓	
Jenifer Suriya Lazer Jessie		✓	✓	✓			✓	✓		✓	✓			
Jerlin Arulpragasam			✓				✓	✓			✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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