On the Performance of Network-Assisted Indoor Device-to-Device Communication Using Location Awareness and Realistic Path Loss Models

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***Abstract*—This paper proposes a framework to analyze the viability of network-assisted Device-to-Device (D2D) communication in an indoor propagation environment using location awareness. Based on the past location information of the users a probability model is developed. The model helps to evaluate the probability of a user's location on a specific indoor site at a given time of the day. Further, leveraging this location information, a heterogeneous framework is considered where user devices are capable of supporting cellular, as well as D2D communication. In order to quantify the performance, the proposed D2D+cellular framework is compared with the conventional cellular framework, and the gains are measured in terms of spectral efficiency and amount of energy saved. It is shown, on opting D2D over cellular for indoor communication it is possible to achieve an average spectral efficiency gain of 10.45 bits/s/Hz as well as an average energy saving of 59%. Further, it is also observed that there exists a critical point beyond which D2D ceases to be beneficial over conventional cellular communication.**

I. Introduction

As per recent statistics [1] by the year 2019, the number of cellular users worldwide will surpass the 5 billion mark. With such large number of devices in use the load on cellular network is bound to increase. As a consequence, there is a need to strengthen the existing cellular network, enabling it to undertake this extended load. In the 3rd Generation Partnership Project (3GPP) release 12 and 13, Long Term Evolution - Device-to-Device communication (LTE-D2D) [2]–[4] appears to be a promising feature to combat the congestion in the cellular network through offloading cellular data. This proximity-based network-assisted D2D communication (a.k.a Proximity Services based D2D) [3] underlying the conventional cellular network is envisioned to substantially bring down the network load as the information is not routed through the core network. However, the core network still carries the control and signaling information. D2D communication is expected not only to increase the reliability of communication but also increase the energy and spectral efficiency of the network.

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Recently, a number of approaches have been proposed in the literature to analyze a D2D communication underlying a cellular network. For instance, in [5], [6] an outage analysis of these networks has been performed whereas in [7] spectral efficiency has been evaluated. In all of the above, it has been assumed that the users follow a spatial Poisson Point Process (PPP) with distance dependent path loss. Although distance dependent path loss models can characterize an outdoor propagation environment, however, they are fairly inaccurate when considering the indoor propagation environment [8].

In [9], [10] indoor D2D scenarios have been investigated with the aim of channel measurement and modeling. The authors have performed measurements in different experimental set-ups over a wide range of frequency. They have derived the channel parameters that better characterize an indoor D2D channel. Specifically, [9] has compared the measurement results with the existing standard indoor channel models and [10] demonstrated the susceptibility of D2D communication channel to shadowing caused by human body. Nevertheless, the above cited works lack in providing an insight into the performance of D2D underlying a cellular network. The work in [11] proposes an indoor D2D scenario where D2D links share uplink resources with a cellular network. However, the D2D pairs are generated and restricted to be present within a single room. In this paper, unlike above, we investigate the performance of D2D communication in an indoor environment while leveraging the location information of the users.

In the proposed work, Wi-Fi signals have been used as location beacons to identify the location of the user [12]. The users in this work are students from our institute and the location information has been gathered over the period of one semester through the database of Wi-

Fi access points spread over the entire campus. Using this database a probability model has been developed. The developed model has been applied to evaluate the performance metrics such as spectral efficiency and energy consumption for the proposed and conventional frameworks. The relevance of utilizing location information can be justified as follows. First, the analysis involves real world user location that assesses better the probability of D2D communication and second, the proposed method of using probability model enables us to incorporate the decisions made by the base station, given it has the flexibility to select D2D mode of transmission.

The main contributions of the proposed work are summarized as follows:

- The viability of D2D communication within the indoor environments has been explored. For indoor propagation, impact of additional factors such as floor and wall attenuation have also been considered.
- Instead of randomly generating the user location information, we leverage the Wi-Fi access point database to gather the location information of a user. Later, this location information is utilized to develop a probability model and to analyze the trade-offs of D2D communication vis-a-vis cellular communication.
- Through the probability model, it has been observed that mobility pattern of the users is different on weekdays and weekends. Hence, two separate set of results for D2D communication have been obtained.
- The proposed work demonstrates that when D2D framework is chosen significant amount of energy saving, as well as spectral efficiency gain, is possible.
- It has also been observed that number of floors in the indoor propagation environment has a significant impact on the performance of D2D communication. Hence, there would be a critical number of floors beyond which the performance gains obtained through D2D vis-a-vis cellular cease to exist.

To the best of our knowledge this is the first publicly available work that utilizes the location information to weigh the benefits of D2D communication in indoor propagation environment. The rest of the paper is organized as follows. Section II presents the proposed model for analysis, section III discusses the two frameworks studied in this work, section IV demonstrates the simulation results obtained and section V concludes the paper.

II. Proposed Model for Analysis

In the proposed analysis two users, denoted as User 1 and User 2, are considered. The users can opt for either cellular or D2D communication to communicate with each other. It has been assumed that users are allocated orthogonal resource blocks[1] for communication. So, a specific resource block will be accessed by the cellular transmitter or by D2D pair.

The mobility pattern of the users was studied every day from 9:00 a.m. till 7:00 p.m. for a period of one semester. During this specific time frame the campus is vibrant with students present in one building or another. The location data of the users is extracted from the Wi-Fi access points that are distributed all over the campus. Fig. 1 shows the building locations within the campus. On a typical weekday, the users can be present in the hostel building (Building **H**), academic building (Building **A**) or student center (Building **S**), whereas on the weekends, the users can be present in any of the three buildings or can be outside the campus (**O**). Using the past data we have generated a probability model for the two users of interest as discussed in next subsection.

A. Generation of Probability Model

The fact that human mobility generally follows a regular pattern encouraged us to use the past data for generating a probability model for determining the probability with which a user can be found in a building in a given time slot. The time from 9:00 a.m. to 7:00 p.m. was divided into 20 time slots of 30 minutes each and the location of the users for each slot was recorded. In the analysis, it is assumed that on an average a user tends to stay in a building for a minimum of 30 minutes, which is good enough considering the low mobility of the user across the buildings. The location of users can be in buildings **H**, **A** or **S** on weekdays or buildings **H**, **A**, **S** or **O** on weekends. Consequently, based on the readings for each slot a probability term associated with each building for each user is determined as shown in Table I.

B. Propagation Channel Modeling

We have adopted Winner II channel models for modeling the D2D and cellular links [8]. Winner II specifies path loss models for different propagation environments. Out of the path loss models specified in [8], models that describe the indoor to outdoor scenario and indoor office scenario are of interest to us[2]. The path loss models for these scenarios are given below:

Indoor to Outdoor (urban macro cell)

$$PL(\text{in dB}) = [44.9 - 6.55\log_{10}(h_{BS})]\log_{10}(d) + 34.46 + 5.83\log_{10}(h_{BS}) + 23\log_{10}(f_c/5) + 17.4 + 0.5d_{in} - 0.8h_{MS}, \quad (1)$$

where base station height, h_{BS} = 25 m, mobile device height, h_{MS} = $3n_{Fl}$ + 1.5 m and n_{Fl} is the floor index

[1]The orthogonal resource blocks can be time, frequency, codes or a combination of two.

[2]Indoor to outdoor scenario to be same as outdoor to indoor (urban macro cell) scenario due to the principle of channel reciprocity.

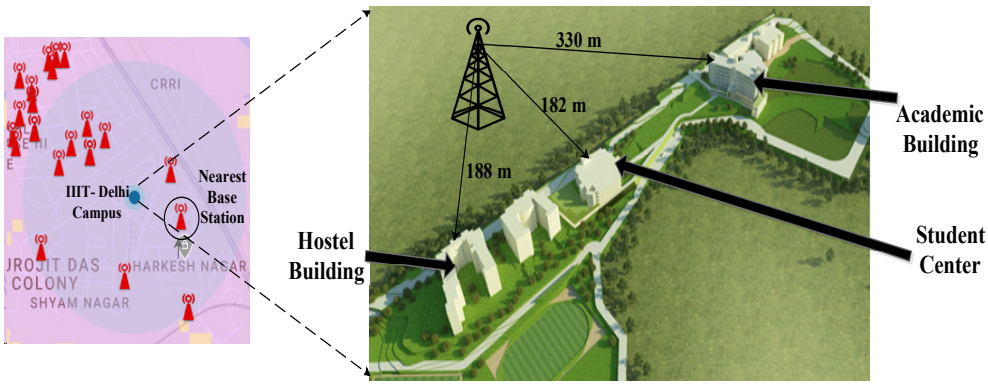

Figure 1: Layout of IIIT-Delhi Campus.

Slot Number	Time of the Day	Weekdays						Weekends							
		User 1			User 2			User 1				User 2			
		$P^{tx}_{\mathbf{H}}$	$P^{tx}_{\mathbf{A}}$	$P^{tx}_{\mathbf{S}}$	$P^{rx}_{\mathbf{H}}$	$P^{rx}_{\mathbf{A}}$	$P^{rx}_{\mathbf{S}}$	$P^{tx}_{\mathbf{H}}$	$P^{tx}_{\mathbf{A}}$	$P^{tx}_{\mathbf{S}}$	$P^{tx}_{\mathbf{O}}$	$P^{rx}_{\mathbf{H}}$	$P^{rx}_{\mathbf{A}}$	$P^{tx}_{\mathbf{S}}$	$P^{rx}_{\mathbf{O}}$
1	9-9:30	1	0	0	1	0	0	0.7	0	0	0.3	0.7	0	0	0.3
2	9:30-10	0.59	0	0.4	1	0	0	0.6	0	0.1	0.3	0.7	0	0	0.3
3	10-10:30	0.9	0.09	0	0.82	0	0.176	0.4	0	0.3	0.3	0.6	0	0.1	0.3
4	10:30-11	0.72	0.23	0.045	0.88	0.058	0.058	0.5	0.2	0	0.3	0.6	0	0.1	0.3
5	11-11:30	0.59	0.4	0	0.94	0.058	0	0.5	0.2	0	0.3	0.7	0	0	0.3
6	11:30-12	0.545	0.454	0	0.88	0.12	0	0.4	0.2	0	0.4	0.7	0	0	0.3
7	12-12:30	0.454	0.545	0	0.88	0.12	0	0.3	0.2	0	0.5	0.7	0	0	0.3
8	12:30-13	0.318	0.636	0.045	0.88	0.12	0	0.2	0.3	0	0.5	0.7	0	0	0.3
9	13-13:30	0.227	0.636	0.136	0.76	0.176	0.058	0.2	0.3	0	0.5	0.6	0.1	0	0.3
10	13:30-14	0.183	0.454	0.363	0.47	0.294	0.235	0.2	0.2	0.1	0.5	0.5	0.1	0.1	0.3
11	14-14:30	0.227	0.545	0.227	0.35	0.35	0.294	0.2	0.2	0.1	0.5	0.3	0.1	0.2	0.4
12	14:30-15	0.409	0.59	0	0.12	0.7	0.176	0.2	0.3	0	0.5	0.2	0.2	0.2	0.4
13	15-15:30	0.272	0.727	0	0.176	0.7	0.12	0.1	0.4	0	0.5	0.3	0.2	0	0.5
14	15:30-16	0.363	0.636	0	0	1	0	0.2	0.4	0	0.4	0.2	0.2	0	0.6
15	16-16:30	0.136	0.86	0	0.058	0.88	0.058	0.1	0.5	0	0.4	0.2	0.2	0	0.6
16	16:30-17	0.09	0.9	0	0.058	0.88	0.058	0.1	0.5	0	0.4	0.2	0.2	0	0.6
17	17-17:30	0.09	0.86	0.045	0	0.94	0.058	0.1	0.5	0	0.4	0.1	0.2	0.1	0.6
18	17:30-18	0.045	0.95	0	0.058	0.76	0.176	0.1	0.5	0	0.4	0.2	0.2	0	0.6
19	18-18:30	0.18	0.77	0.045	0.058	0.7	0.235	0.1	0.5	0	0.4	0.2	0.2	0	0.6
20	18:30-19	0.18	0.818	0	0.12	0.88	0	0.1	0.5	0	0.4;	0.2	0.2	0	0.6

Table I: Probability Model for Weekdays and Weekends

(for ground floor n_{Fl} = 1). d_{in} is the distance from the indoor transmitter to the wall, d_{out} is the distance between the point on the wall that is nearest to the indoor transmitter and base station, and $d = d_{out} + d_{in}$.

Indoor Office

$$PL = 20\log_{10}(d) + 46.4 + 20\log_{10}(f_c/5) + WL + FL, \quad (2)$$

where d is the distance between the D2D transmitter and receiver in meters, f_c is the frequency[3] of operation in GHz, WL = $5n_w$ (for soft walls) or $12n_w$ (for hard walls) and n_w are the number of walls penetrated by the signal. The campus buildings in our case have hard wall partitions thus WL = $12n_w$ has been considered. $FL = 17+4(n_{fl}-1)$ and n_{fl} is the number of floors penetrated by the signal. In this work, (1) and (2) have been applied for modeling the cellular and D2D links respectively.

[3]Winner II model can be applied to all LTE carrier frequencies falling in the range of 2-6 GHz and in our case we have f_c = 2.3 GHz.

The antenna gains at the base station and user devices are assumed to be 10 dBd and 0 dBd respectively.

Fig. 2, 3 and 4 show the floor layouts for the buildings **H**, **A** and **S**. All the floors of a building have the similar floor layout. In our analysis, a user in any given building at any point of time will most likely be present on a specific floor and room. This is because User 1 has a hostel Room-1 assigned in 1st floor and User 2 has a Room-2 assigned in 3rd floor. Similarly, in building **A**, User 1 has a cubicle in PhD Lab-1 on 2nd floor and User 2 has a cubicle in PhD Lab-2 on 4th floor. Hence, in case of D2D communication when both users are present in building **H** or **A** the floor separation is two. When in building **S** the users typically are in the ground floor and 1st floor dining areas and therefore a maximum separation of one floor. So, $n_{fl} = 2$ for buildings **H** and **A** where as $n_{fl} = 1$ for building **S**. Further, as evident from the floor layout, the horizontal separation between the users is limited to a single wall, i.e., n_w = 1.

The ceiling height in building **H** and **A** is 3 m. Hence,

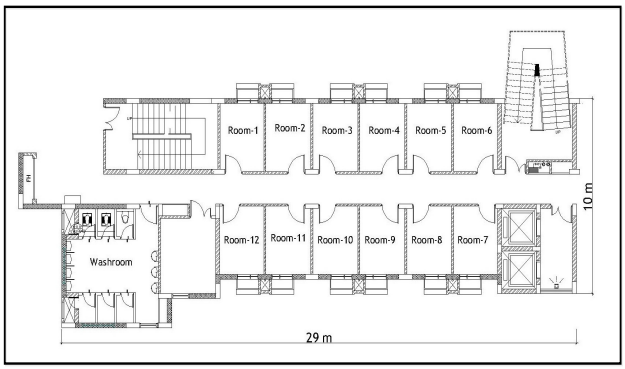

Figure 2: Floor layout of hostel building (building **H**).

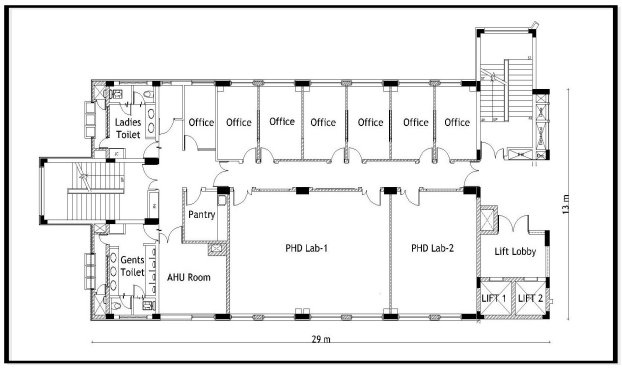

Figure 3: Floor layout of academic building (building **A**).

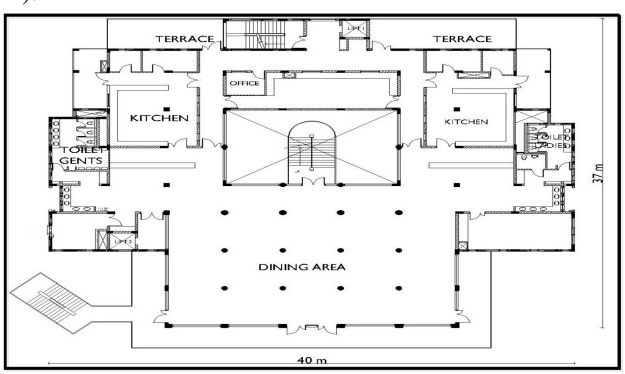

Figure 4: Floor layout of student center building (building **S**).

the maximum transmission distance[4] between the two users present in building **H** and **A** will be 6 m. Further, the ceiling height of building **S** is 7 m, and hence maximum transmission distance will be 7 m for the users located in this building. When User 1 or (and) User 2 are outside campus D2D communication may not be possible, hence, not considered in the proposed work. Thus, in such a scenario an average cellular transmission distance of 250 m is assumed[5].

[4]Restricting the transmission distance to be equal to ceiling height times number of floors penetrated.

[5]Urban scenario with high density of cellular towers and cellular range of 500 m [13].

III. Cellular V/s D2D+Cellular Framework

For the performance analysis, two transmission modes are considered:

1) Cellular: In this scenario, the two users always use conventional cellular mode of communication to communicate with each other.
2) D2D+Cellular: In this scenario, if the two users are in the same building, they will use D2D mode of communication, otherwise, they would communicate via cellular mode.

A. Probability of D2D Communication

First, we calculate the probability with which D2D can occur in the D2D+cellular scenario. The probability of D2D communication in n^{th} time slot for both weekdays and weekends can be given by:

$$P^{n}_{D2D} = P^{tx}_{\mathbf{H}} P^{rx}_{\mathbf{H}} + P^{tx}_{\mathbf{A}} P^{rx}_{\mathbf{A}} + P^{tx}_{\mathbf{S}} P^{rx}_{\mathbf{S}}, \qquad (3)$$

where $P^{tx}_{\mathbf{H}}$, $P^{tx}_{\mathbf{A}}$ and $P^{tx}_{\mathbf{S}}$ are the probabilities of the D2D transmitter (User 1) being in buildings **H**, **A** and **S** in a given time slot respectively. Similarly, $P^{rx}_{\mathbf{H}}$, $P^{rx}_{\mathbf{A}}$ and $P^{rx}_{\mathbf{S}}$ are the probabilities of the D2D receiver (User 2) being in buildings **H**, **A** and **S** in a given time slot respectively. Table II shows the per time slot probability of D2D communication for weekdays and weekend as given in (3). The higher D2D probability in a slot corresponds to a higher chance of User 1 and User 2 being in the same building in a given time slot. For example, in the 1st slot i.e. 9:00 a.m. to 9:30 a.m. both the users are present in hostel with probability 1. This gives rise to a D2D probability of 1 in Table II. Similarly, in the evening hours there is higher probability that both the users are present in building **A**. Hence, in those time slots D2D probability will be higher.

B. Performance Metrics

The performance comparison of the cellular and D2D+cellular modes using the spectral efficiency per slot is performed for both weekdays and weekends. Further, the amount of energy saving that can be achieved in D2D+cellular mode for a predefined quality of service (QoS) has been evaluated.

1) Spectral efficiency: The spectral efficiency achievable corresponding to average signal-to-noise ratio (SNR) values of each slot is given by:

$$S = \log_2 (1 + \delta_{avg}) \text{ bits/s/Hz}, \qquad (4)$$

where δ_{avg} is the average signal-to-noise ratio of each slot. δ_{avg} = δ^{C}_{avg} for cellular mode and δ_{avg} = δ^{D}_{avg} for D2D+cellular mode. We will have different SNR values depending on the location of the cellular transmitter in case of cellular communication and location of the D2D pair in the case of D2D communication. $\delta^{C}_{\mathbf{B}}$, $\delta^{D}_{\mathbf{B}}$ are the SNR values for the cellular and D2D communication respectively and here $\mathbf{B} \in \{\mathbf{H}, \mathbf{A}, \mathbf{S}\}$. δ_O is the SNR

Slot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Weekdays	1	0.59	0.73	0.64	0.57	0.53	0.46	0.35	0.29	0.30	0.33	0.46	0.55	0.63	0.76	0.79	0.81	0.72	0.56	0.74
Weekend	0.49	0.42	0.27	0.30	0.35	0.28	0.21	0.14	0.15	0.13	0.10	0.10	0.11	0.12	0.12	0.12	0.11	0.12	0.12	0.12

Table II: Probability of D2D communication on Weekdays and Weekends

value when the cellular transmitter is outside campus. In general, SNR (dB) is given by :

$$\delta = P_r(\text{dBm}) - \sigma^2(\text{dBm}), \tag{5}$$

where P_r is the received power, which is given by $P_r = P_t - PL$. P_t is the transmitted power in dBm and σ^2 is the noise variance at receiver.

In the cellular mode, the average SNR values per slot are evaluated as a weighted sum of the SNR values corresponding to **H, A, S** and **O**. These weights are the transmitter's probability of being present in each building per slot.

$$\delta^C_{avg_1} = P^{tx}_{\mathbf{H}}\delta^C_{\mathbf{H}} + P^{tx}_{\mathbf{A}}\delta^C_{\mathbf{A}} + P^{tx}_{\mathbf{S}}\delta^C_{\mathbf{S}}, \tag{6}$$

$$\delta^C_{avg_2} = P^{tx}_{\mathbf{H}}\delta^C_{\mathbf{H}} + P^{tx}_{\mathbf{A}}\delta^C_{\mathbf{A}} + P^{tx}_{\mathbf{S}}\delta^C_{\mathbf{S}} + P^{tx}_{\mathbf{O}}\delta_{\mathbf{O}}, \tag{7}$$

where $P^{tx}_{\mathbf{O}}$ is the probability of user being outside campus in a given time slot on weekends. (6) and (7) show the average SNR values for cellular mode on weekdays and weekends respectively.

Similarly, the average SNR per slot in D2D+cellular mode will be a weighted sum of SNR values corresponding to D2D and cellular communication in each building. For D2D communication SNR values are weighted by the joint probability of D2D pair in each building and for cellular communication the weights consider the probability when D2D is not feasible.

$$\begin{aligned}\delta^D_{avg_1} &= P^{tx}_{\mathbf{H}}P^{rx}_{\mathbf{H}}\delta^D_{\mathbf{H}} + P^{tx}_{\mathbf{A}}P^{rx}_{\mathbf{A}}\delta^D_{\mathbf{A}} + P^{tx}_{\mathbf{S}}P^{rx}_{\mathbf{S}}\delta^D_{\mathbf{S}} \\ &+ P^{tx}_{\mathbf{H}}(1-P^{rx}_{\mathbf{H}})\delta^C_{\mathbf{H}} + P^{tx}_{\mathbf{A}}(1-P^{rx}_{\mathbf{A}})\delta^C_{\mathbf{A}} \\ &+ P^{tx}_{\mathbf{S}}(1-P^{rx}_{\mathbf{S}})\delta^C_{\mathbf{S}},\end{aligned} \tag{8}$$

$$\begin{aligned}\delta^D_{avg_2} &= P^{tx}_{\mathbf{H}}P^{rx}_{\mathbf{H}}\delta^D_{\mathbf{H}} + P^{tx}_{\mathbf{A}}P^{rx}_{\mathbf{A}}\delta^D_{\mathbf{A}} + P^{tx}_{\mathbf{S}}P^{rx}_{\mathbf{S}}\delta^D_{\mathbf{S}} \\ &+ P^{tx}_{\mathbf{H}}(1-P^{rx}_{\mathbf{H}})\delta^C_{\mathbf{H}} + P^{tx}_{\mathbf{A}}(1-P^{rx}_{\mathbf{A}})\delta^C_{\mathbf{A}} \\ &+ P^{tx}_{\mathbf{S}}(1-P^{rx}_{\mathbf{S}})\delta^C_{\mathbf{S}} + P^{tx}_{\mathbf{O}}\delta_{\mathbf{O}}.\end{aligned} \tag{9}$$

The above equations (8) and (9) represent the average SNR values for D2D+cellular mode for weekdays and weekends respectively.

2) Energy Saving: For a cellular network, there is always a a trade-off between the transmission power and the achievable QoS. The achievable QoS can be measured in terms of received SNR, bit error rate (BER), throughput etc. In order to achieve a better QoS, more transmission power is required hence more energy is consumed. In the following we show that opting for D2D+cellular mode can lead to considerable energy saving compared to conventional cellular mode of transmission. The amount of energy saved depends on the time slot under consideration and also on the fact that whether it is a weekday or weekend. Let us consider a scenario where a fixed QoS needs to be maintained in cellular and D2D+cellular mode. This implies same average SNR is to be achieved in the two modes. Hence, on equating (6) and (8), the reduced transmitted power, $P^{'}$ corresponding to the D2D link within the D2D+cellular mode[6], per slot for weekdays, will be:

$$P^{'} = \frac{\delta^C_{avg} - \tau}{\alpha + \beta + \eta}, \tag{10}$$

where $\alpha = \frac{P^{tx}_{\mathbf{H}}P^{rx}_{\mathbf{H}}}{PL^D_{\mathbf{H}}N}$, $\beta = \frac{P^{tx}_{\mathbf{A}}P^{rx}_{\mathbf{A}}}{PL^D_{\mathbf{A}}N}$, $\eta = \frac{P^{tx}_{\mathbf{S}}P^{rx}_{\mathbf{S}}}{PL^D_{\mathbf{S}}N}$,

$\tau = P^{tx}_{\mathbf{H}}(1-P^{rx}_{\mathbf{H}})\delta^C_{\mathbf{H}} + P^{tx}_{\mathbf{A}}(1-P^{rx}_{\mathbf{A}})\delta^C_{\mathbf{A}} + P^{tx}_{\mathbf{S}}(1-P^{rx}_{\mathbf{S}})\delta^C_{\mathbf{S}}$,

and $PL^D_{\mathbf{B}}$ is the path loss in case of D2D. Similarly, the reduced transmitted power for weekend can be calculated. In this paper, the two users are assumed to be communicating with each other for a duration of 60, 90 or 120 minutes from 9 a.m. to 7 p.m. on a weekday or weekend. This means a mobile usage of k = 3, 4.5 or 6 minutes in each slot. However, the usage time can be fixed to any value. The energy saved in each slot can be determined in the following manner:

$$\text{Energy saving} = [P^{'}P^n_{D2D} + P_t(1-P^n_{D2D})] \times k \times 60. \tag{11}$$

IV. Results and Discussion

This section presents the results for spectral efficiency for the cellular and D2D+cellular transmission modes, and the amount of energy saving that can be obtained in D2D+cellular mode due to reduced transmitted power over the D2D link. In the following simulations P_t = 23 dBm and σ^2 = -100 dBm has been considered.

Fig. 5 shows the spectral efficiency achievable in cellular and D2D+cellular modes. It can be observed that slots with higher D2D probability (D2D probability can be seen in Table II) have higher spectral efficiency. This is due to the fact that when D2D probability is high, there are more chances of D2D communication; hence average SNR improves. As a consequence, higher spectral efficiency is obtained.

It can also be observed that the spectral efficiency for D2D+cellular on weekdays is more than that on weekends because the D2D communication probability is significantly less on weekends. For instance, if we

[6]Only the transmitted power for D2D gets reduced, cellular transmitted power will be the same in both modes.

compare the 10th time slot for User 1 and User 2 we observe that the spectral efficiency values for weekday and weekend are 11.68 bits/s/Hz and 10.3 bits/s/Hz respectively. It can be explained as follows. Using (5), (8) and (9) δ_{avg} comes out to be 35 dB for weekdays and 31 dB for weekends. Hence, we have S = 11.68 bits/s/Hz for weekdays and S = 10.3 bits/s/Hz for weekends. Using (5), (6), (7) and (4) spectral efficiency for cellular mode is obtained as 1.97 bits/s/Hz and 1.74 bits/s/Hz on weekdays and weekends respectively. This implies a spectral efficiency gain of 9.71 bits/s/Hz and 8.56 bits/s/Hz on weekdays and weekends respectively in the 10th slot. After similar evaluation for the other time slots, the result is an average spectral efficiency gain of 10.45 bits/s/Hz and 8.93 bits/s/Hz on any given weekday and weekend respectively.

It can be seen from Fig. 6, as the mobile usage increases from 60 minutes to 120 minutes the amount of energy saved also increases. This is because the time over which transmitter is operating in the D2D mode increases. Also, while using D2D communication the transmitted power can be reduced to achieve the fixed QoS. Higher the D2D probability, higher are the chances of D2D communication. Hence, there will be an increase in the amount of energy saved. Due to this combined effect of mobile usage duration and probability of D2D communication the energy saving pattern varies over different time slots of weekdays and weekends. Let us illustrate through an example. In the 10th slot, using (10) and (11), the amount of energy saved is 21.72 J and 9.3 J on weekdays and weekends respectively for $k = 6$. Similarly, on determining the energy saved for each of the time slots, on an average 42.60 J and 13.88 J of energy is saved on weekdays and weekends. This accounts for 59.64 % and 19.34 % average energy savings on weekdays and weekends respectively.

A. *Effect of Floors*

In this section we investigate the impact of number of floors on the performance of D2D communication vis-a-vis cellular communication. Specifically, we have restricted our analysis to two users present in the same building **A**. The receiver's location is fixed at the ground floor and the transmitter's location is varied from floor 1 to floor 8. In line with the previous D2D framework, we assume that if the two users are in the same building they will establish a D2D communication link. We measured the spectral efficiency and compared it with the conventional cellular scenario. Fig. 7 shows the spectral efficiency for the D2D and cellular scenarios. It is evident that after a critical point (corresponding to a separation of 6 floors) even D2D communication link starts performing worse than the cellular link. Beyond the critical point, with a link distance ranging from 18-24 m (building **A**) D2D communication is unable to match up to the performance of cellular communication having a link distance of 330 m. Thus, validating the point that D2D communication can not be opted solely on the basis of proximity as the impact of number of floors in an indoor environment should also be considered.

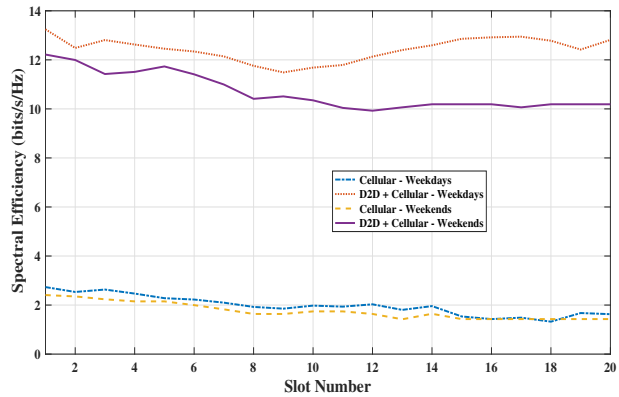

Figure 5: Spectral efficiency on weekdays and weekends.

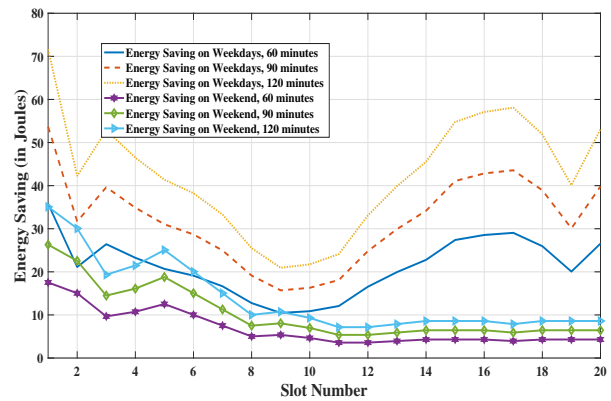

Figure 6: Energy saving on weekdays and weekend.

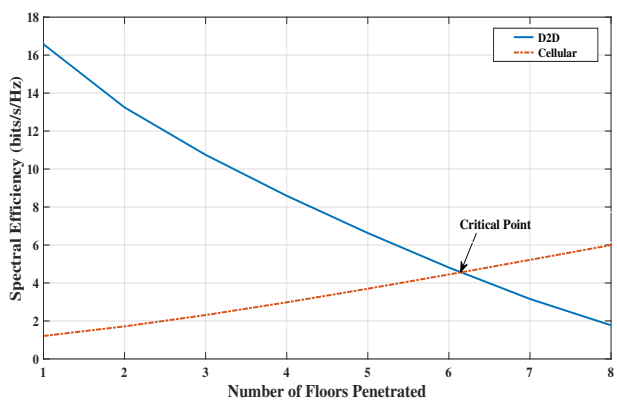

Figure 7: Impact of n_{fl} on spectral efficiency of D2D and cellular communication.

V. Conclusion

This work analyzed the D2D+cellular framework for an indoor propagation environment by making use of real world user location data. The performance of the proposed framework was evaluated in terms of spectral efficiency and amount of energy saving. The results

showed an average spectral efficiency gain of 10.45 bits/s/Hz as well as average energy saving of 59% over conventional cellular framework. Further, we concluded that for an indoor scenario proximity can not be a sole discriminator for D2D and cellular mode because beyond the critical point even with a link distance ranging from 18-24 m D2D performed worse than the cellular case having a link distance of 330 m. As a consequence, the impact of floor and wall attenuation can be overlooked while evaluating the performance of indoor D2D communication.

Further, we are working on a possible extension of this study to higher number of users for a more practical performance analysis.

REFERENCES

[1] Number of mobile phone users worldwide from 2013 to 2019. [Online]. Available: https://www.statista.com/statistics/274774/forecast-of-mobile-phone-users-worldwide/

[2] S. Y. Lien, C. C. Chien, G. S. T. Liu, H. L. Tsai, R. Li, and Y. J. Wang, "Enhanced lte device-to-device proximity services," *IEEE Communications Magazine*, vol. 54, no. 12, pp. 174–182, Dec 2016.

[3] Lte-advanced evolution in releases 12 - 14. [Online]. Available: http://resources.alcatel-lucent.com/asset/200175

[4] N. Gupta and V. A. Bohara, "Rate and outage trade-offs for ofdma based device to device communication frameworks," *IEEE Access*, vol. 5, pp. 14 095–14 106, 2017.

[5] K. M. S. Huq, S. Mumtaz, and J. Rodriguez, "Outage probability analysis for device-to-device system," in *IEEE International Conference on Communications (ICC)*, May 2016, pp. 1–5.

[6] J. Guo, S. Durrani, X. Zhou, and H. Yanikomeroglu, "Device-to-device communication underlaying a finite cellular network region," *IEEE Transactions on Wireless Communications*, vol. 16, no. 1, pp. 332–347, Jan 2017.

[7] G. George, R. K. Mungara, and A. Lozano, "An analytical framework for device-to-device communication in cellular networks," *IEEE Transactions on Wireless Communications*, vol. 14, no. 11, pp. 6297–6310, Nov 2015.

[8] Winner ii channel models. [Online]. Available: https://www.researchgate.net/publication/234055761 _WINNER_II_channel_models

[9] X. Zhao, S. Li, X. Liang, Q. Wang, L. Hentilä, and J. Meinilä, "Measurements and modelling for d2d indoor wideband mimo radio channels at 5 ghz," *IET Communications*, vol. 10, no. 14, pp. 1839–1845, 2016.

[10] S. L. Cotton, "A statistical characterization of shadowed device-to-device communications in an indoor environment," in *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*, April 2014, pp. 3362–3365.

[11] P. Janis, C. Yu, K. Doppler, C. Ribeiro, C. Wijting, K. Hugl, O. Tirkkonen, and V. Koivunen, "Device-to-device communication underlaying cellular communications systems," *International Journal of Communications, Network and System Sciences*, 2009.

[12] P. Sapiezynski, A. Stopczynski, R. Gatej, and S. Lehmann, "Tracking human mobility using wifi signals," *PLOS ONE*, vol. 10, no. 7, pp. 1–11, 07 2015.

[13] Etsi tr 136 942 v9.1.0. [Online]. Available: http://www.etsi.org/deliver/etsi_tr/136900_136999/136942/09.01.00_60/tr_136942v090100p.pdf