Assessing Coverage and Throughput for D2D Communication

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***Abstract*—In this paper, we access the performance of a Device-to-Device (D2D) communication link. Particularly, we design a framework to evaluate performance with respect to coverage probability and average throughput. Our modeling framework considers a variety of D2D deployment scenarios (i.e., Outdoor-to-Outdoor, Outdoor-to-Indoor, and Indoor-to-Indoor), channel effects (i.e., path loss, shadowing, and small-scale fading), and system parameters (i.e., resource block size, fixed Modulation and Coding Scheme (MCS) versus adaptive MCS, and transmit power). For the defined scenarios, we derive mathematical expressions for the coverage probability and average throughput as a function of the distance between two D2D user equipments. Based on the designed framework, we conduct an extensive performance evaluation of the D2D communication link under various D2D deployment scenarios with varying channel effects. We also evaluate the impact of system parameters, including Physical Resource Block (PRB) size, fixed/adaptive MCS, and transmit power, on the performance of D2D communication links. Our results demonstrate the expected performance that can be achieved in practical D2D scenarios.**

***Keywords*—D2D Communication, Public Safety Applications, Performance Measurements.**

I. INTRODUCTION

In order to support mission critical applications for public safety, reliable communication is critical [1]. For example, when a large incident occurs, the network infrastructure could be either damaged or overloaded. In either case, continuous communication between public safety personnel is required to successfully carry out their missions. To this end, Device-to-Device (D2D) communication provides a viable solution, as it is capable of providing a direct communication between the sender and the receiver without relying on the network infrastructure. In addition, when a first responder is out of cell coverage, an in-cell user equipment (UE) can be used as a relay node to extend the cell coverage using the D2D link. In doing so, the connection of the first responder to the cellular network can be established.

The LTE-based D2D communication was introduced by 3^{rd} Generation Partnership Project (3GPP) as the Proximity Service (ProSe) starting in Release 12 [2], providing both D2D communication and D2D discovery services. To support the LTE-based D2D communication, several new physical channels were introduced, including the Physical Sidelink Control Channel (PSCCH) and the Physical Sidelink Shared Channel (PSSCH). PSSCH is the D2D data channel, while PSCCH is used to transmit control information to the receiver, so that the message transmitted on PSSCH can be decoded. Notice that successfully decoding PSSCH depends on whether the control information transmitted over PSCCH can be received correctly. We define PSCCH coverage as the event that the receiver can correctly decode the control messages conveyed on PSCCH. For PSSCH, the coverage probability is defined as the probability that the receiver can correctly decode both the message transmitted on PSCCH and on PSSCH.

There have been a number of research efforts devoted to D2D communication [3], [4]. It is generally agreed that D2D requires UEs to be spatially located close to one another. Thus, the following fundamental issues remain unresolved: *How far apart can D2D UEs be located and still maintain a reliable communication given channel conditions? What is the average throughput that can be achieved?* To address these issues, in this paper we conduct a comprehensive and practical study by considering different channel effects for different deployment scenarios.

To summarize, our contributions are three-fold, outlined as follows: (i) We design a generic framework to assess the performance of a D2D communication link with respect to its coverage probability and average throughput. Our framework considers a variety of D2D deployment scenarios (i.e., Outdoor-to-Outdoor (O2O), Outdoor-to-Indoor (O2I), and Indoor-to-Indoor (I2I) and different channel effects (i.e., path loss, log-normal shadowing, and Nakagami-m small-scale fading), as well as various system parameters (i.e., the Physical Resource Block (PRB) size, fixed/adaptive Modulation and Coding Scheme (MCS), and the transmit power). (ii) Based upon the defined scenarios, we derive mathematical expressions for the coverage probability and average throughput of a D2D communication link. (iii) We conduct extensive performance evaluation to show the performance of a D2D communication link using the framework defined. We also measure the impact of system parameters (PRB size, fixed/adaptive MCS, and transmit power) on the performance of D2D communication links. Monte Carlo simulation results are also presented to support the analytic computation outcomes.

The remainder of this paper is organized as follows: In Section II, we describe channel models used in our analysis. In Section III, we introduce our approach in detail. In Section IV, we show the performance evaluation results. Finally, we conclude the paper in Section V.

TABLE I: Channel Model [5], [6]

Scenario	Path loss (dB)	Log-normal Shadowing (dB)
O2O LOS [5]	$PL_{LOS\_O2O} = 40\log_{10}(d) + 7.56 - 17.3\log_{10}(h'_{BS}) - 17.3\log_{10}(h'_{MS}) + 2.7\log_{10}(f_c) + 20\log_{10}(f_C/f_{REF})$	7 dB
O2O NLOS [5]	$PL_{NLOS\_O2O} = (44.9 - 6.55\log_{10}(h_{BS}))\log_{10}(d) + 5.83\log_{10}(h_{BS}) + 18.38 + 23\log_{10}(f_C)$	7 dB
O2I LOS [5]	$PL_{LOS\_O2I} = PL_{LOS\_O2O} + 20 + 0.5d_{in}$	7 dB
O2I NLOS [5]	$PL_{NLOS\_O2I} = PL_{NLOS\_O2O} + 20 + 0.5d_{in} - 0.8h_{MS}$	7 dB
I2I (different building) [5]	$PL_{I2I_{DB}} = \max(131.1 + 42.8\log_{10}(\frac{d}{1000}), 147.4 + 43.3\log_{10}(\frac{d}{1000})) + 40 + 20\log_{10}(\frac{f_c}{f_{REF}})$	10 dB
I2I (same building) [6]	$PL_{I2I_{SB}} = PL_0 + \begin{cases} 20\log_{10} d & 1 < d < 10\,m \\ 20 + 30\log_{10}\frac{d}{10} & 10 < d < 20\,m \\ 29 + 60\log_{10}\frac{d}{20} & 20 < d < 40\,m \\ 47 + 120\log_{10}\frac{d}{40} & d > 40\,m \end{cases}$	4 dB

II. CHANNEL MODEL

An accurate channel model is critical in the assessment of D2D communication link performance. To evaluate the D2D performance accurately, in our study we consider the following three aspects of the channel model: (i) *Small-scale fading*, which represents the rapid signal power fluctuation over small distance, (ii) *Large-scale fading*, which is also denoted as shadowing, and is obtained via averaging over a small distance to smooth out the rapid fluctuation of the received power, reflecting the slow variation of the local mean of the received power, and (iii) *Path loss*, which represents an area mean obtained by averaging the received power over a large distance to smooth out the shadowing effect.

To characterize path loss, we adopt the 3GPP path loss models for different D2D scenarios [5], which define the path loss for three different deployment scenarios: O2O, O2I, and I2I. Notice that the 3GPP D2D channel models were adapted from the IMT-advanced channel model defined in the ITU document [7]. The ITU I2I model is based on the channel model of indoor RRH/Hotzone [8]. The indoor RRH/Hotzone scenario in [8] considers a single floor of the building, and two hotzones deployed in the middle of the hallway, which is a very specific indoor case. To evaluate the I2I in same building case in a more generic way, we use the Distance-Partitioned model [9], which is obtained through measurements in a multi-story building. In this model, the distance is divided into four regions, and a different path loss exponent is used in each region to account for the wall and floor attenuations in the indoor environment.

Table I summarizes the path loss and the shadowing models used in our evaluation [5], [6]. From the table, d is the distance between the transmitter and the receiver, and h'_{BS} and h'_{MS} are effective antenna heights in meters for the transmitter and the receiver, respectively, f_c is the carrier frequency in GHz, f_{REF} is reference frequency in GHz, and h_{BS} and h_{MS} are the transmitter and the receiver antenna heights in meters. For O2I, d_{in} is the distance from the wall to the indoor UE in meters. For I2I same building case, PL_0 is the free space path loss at 1 m distance.

To derive the average performance, we need to consider both LOS and NLOS cases. The probability of LOS for the O2O scenario, denoted as P_{LOS_O2O}, as a function of the distance between the transmitter and the receiver, can be presented by [5]

$$P_{LOS\_O2O} = \begin{cases} 1, & \text{if } d \leq 2.5\,m \\ 1 - 0.9(1 - (1.24 - 0.61\log_{10}(d))^3)^{\frac{1}{3}}, & \text{if } d > 2.5\,m \end{cases} \quad (1)$$

For the probability of the O2I LOS scenario, denoted as P_{LOS_O2I}, we have [5]: $P_{LOS\_O2I} = \min(\frac{18}{d}, 1)(1 - \exp(\frac{-d}{36})) + \exp(\frac{-d}{36})$, where d is the distance between the transmitter and the receiver.

In our study, the key parameters in the aforementioned equations are set as follows: carrier frequency $f_c = 700\,MHz$, reference frequency $f_{REF} = 2\,GHz$, and $h_{BS} = h_{MS} = 1.5\,m$ to match the average height of a human. The effective transmitter and receiver height $h'_{BS} = h'_{MS}$ are both set to $0.8\,m$, and the break point distance $d'_{BP} = 4h'_{BS}h'_{MS}\frac{f_c}{c} = 5.97\,m$ [5]. It is worth mentioning that up to the break point, the free space path model can be used to compute the path loss. In our analysis, we evaluate D2D communication link performance after the break point, because we care about how far the D2D signals can propagate. For large-scale fading, we use the 3GPP defined Log-normal shadowing model [8], which uses 7 dB standard deviation for O2O and O2I, 4 dB for I2I in same build cases [6] and 10 dB for I2I in different building cases, respectively.

In order to make our analysis more practical, we consider small-scale fading as well. Particularly, we select Nakagami-m fading [10] as our fading model,

$$f(g) = \frac{2m^m g^{2m-1}}{\Gamma(m)\Omega^m}\exp(-\frac{mg^2}{\Omega}), g > 0, \quad (2)$$

where $f(g)$ is the probability density function (PDF) of the magnitude of the received signal envelope due to the fading, m is the fading parameter, Ω is the average received power, and

Γ is the Gamma function, such that $\Gamma(m) = \int_0^{\infty} x^{m-1} e^{-m}\, dx$ and $\Omega = E(g^2)$.

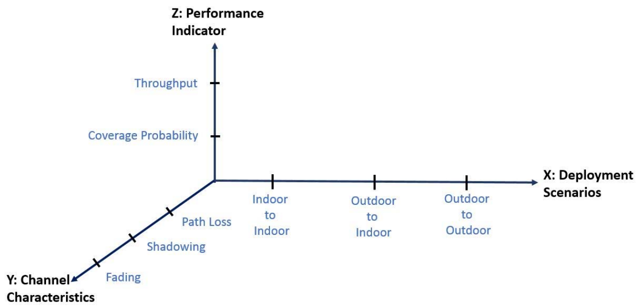

Fig. 1: Problem Space

Here, by varying m, we can simulate channels with different severities of small-scale fading. A smaller m means more severe fading. When m equals 1, Nakagami fading becomes Rayleigh fading.

III. Our Approach

In the following, we first present the problem space, and then show the deriving the mathematical expressions for both coverage probability and average throughput.

A. Problem Space

Figure 1 illustrates the overall problem space, which consists of the following three dimensions: X-axis as deployment scenarios, Y-axis as channel characteristics, and Z-axis as performance indicators. For the deployment scenarios, we consider I2I, I2O, and O2O communications. For I2I, we further consider two cases: (i) both the transmitter and the receiver are in the same building, and (ii) the transmitter and the receiver are located in different buildings. For the channel characteristics, we consider all three aspects of channel effects: the path loss, shadowing, and fading. For the performance indicator, we consider two metrics. One is the coverage probability, and the other is the average throughput, which will be defined later.

Based on the defined problem space, we conduct the performance analysis of the D2D communication link in different scenarios. In our analysis, in addition to the distance between the transmitter and the receiver, we investigate the performance impact of other parameters (e.g., PRB size, fixed/adaptive MCS, and transmit power) on the performance of D2D communication channels.

B. Coverage Probability

Coverage Probability is defined as the probability of the event Pr_c that the received signal power Pow_{RX} is greater than a given receiver sensitivity Pow_{th} (i.e., $Pr_c = Pr\{Pow_{RX} > Pow_{th}\}$). Thus, how to determine the receiver sensitivity Pow_{th}, and derive received signal power Pow_{RX} is the key to our analysis.

In determining the receiver sensitivity Pow_{th}, we consider the following three factors: the thermal noise floor, the device noise figure, and the SNR margin. The thermal noise floor is a function of channel bandwidth with a spectral density of $-174\, dBm/Hz$. We use $9\, dB$ as the noise figure of the receiver (i.e., a UE). The SNR margin is referred to as the minimum required SNR to maintain a reliable D2D communication. The SNR margin depends on the targeted BLER after the 4^{th} transmission, which is the maximum number of HARQ transmissions, along with the adopted MCS [2], [11]. The receiver sensitivity Pow_{th} will be the summation of the noise floor, UE noise figure, and the SNR margin in dB scale.

To derive the received signal power, we consider the following three channel effects: the path gain (inverse of the path loss), shadowing, and small-scale fading. In the linear scale, the received power Pow_{Rx} can be derived by $Pow_{Rx} = Pow_{Tx} \cdot G_{PG} \cdot G_S \cdot G_F$, where Pow_{Tx} is the transmitter power, G_{PG} is the path gain, G_S is the shadowing gain, and G_F is the fading gain. Here, G_S follows the Log-normal distribution, and G_F follows Nakagami-m fading distribution. In our analysis, we compute the coverage probability Pr_c for a given distance d between the transmitter and the receiver.

The PDF of the Log-normal shadowing [12] is $f(\Omega) = \frac{10/\ln 10}{\sqrt{2\pi}\sigma\Omega} \exp(-\frac{(10\log_{10}\Omega - \mu)^2}{2\sigma^2})$, where $\Omega > 0$, σ is the standard deviation of the Log-normal shadowing, and μ is the received power after considering the path loss in dBm.

The PDF of the Nakagami-m fading can be found in Equation (2). Thus, by considering both the Log-normal shadowing and the Nakagami-m fading, the composite PDF of received power can be derived as [12],

$$\begin{aligned} f(x) = \int_0^{\infty} (\frac{m}{w})^m \frac{x^{m-1}}{\Gamma(m)} \exp(-\frac{mx}{w}) \frac{10}{\sqrt{2\pi} w\sigma ln10} \\ \exp(-\frac{(10\log_{10} w - \mu)^2}{2\sigma^2}) \mathrm{d}w, \end{aligned} \tag{3}$$

where w is the local mean of received power. In addition, $\Gamma(m)$ is the $\Gamma(.)$ function.

With the PDF of the received SNR in Equation (3) and a given outage threshold γ, we have

$$\begin{aligned} Pr(x > \gamma) &= \int_{\gamma}^{\infty} f(x)\, dx \\ &= \frac{1}{\sqrt{\pi}\Gamma(m)} \int_{-\infty}^{+\infty} \exp(-x^2) \Gamma(m, \frac{m}{10^{\frac{\sqrt{(2)}\Omega x + \mu}{10}}})\, dx. \end{aligned} \tag{4}$$

Notice that the integral $\int_{-\infty}^{+\infty} \exp(-x^2)\Gamma(m, \frac{m}{10^{\frac{\sqrt{2}\omega x+\mu}{10}}})\, dx$ can be numerically approximated using Gaussian-Hermite Quadrature [12]. In our analysis, we use first 20 Hermite polynomials for the approximation and have $\int_{-\infty}^{+\infty} \exp(-x^2) g(x) = \sum_{i=1}^{i=20} w_i g(x_i)$.

C. Average Throughput

The average throughput is defined as the average number of bits successfully received by the receiver, divided by the time taken to transmit those bits, considering various channel conditions at a given distance between the transmitter and the receiver. To accurately evaluate the average throughput of a D2D communication link, we leverage the D2D BLER performance curve obtained though the link layer simulation in our prior study [11]. We analyze the link level throughput by considering the Adaptive Modulation and Coding (AMC) scheme and the PDF of the received signal power, as well as considering both the shadowing and the Nakagami-m small-scale fading.

To use AMC scheme, it is critical to determine the MCS switching points, which are determined based on the simulated BLER versus SNR curves. We consider the BLER versus SNR curves for the first transmission to find the SNRs corresponding to the $10\,\%$ BLERs. For example, based on our prior results [11], 3.1 dB and 4.3 dB SNRs are required for MCS10 and MCS11 to achieve $10\,\%$ BLER for the first transmission. Thus, if the SNR falls between 3.1 and 4.3 dB, we assume MCS10 is used in the transmission. Notice that, in the throughput analysis, we assume the perfect channel quality feedback so that the AMC scheme can be used.

Before computing the average throughput, we first use an exponential function to curve-fit the PSSCH BLER curves for the sake of computational efficiency. Thus, we have $f_{MCS_i}(\gamma) = a_i e^{b_i \gamma}$, where $f_{MCS_i}(\gamma)$ is the block error rate as a function of SNR γ for a given MCS i ($i \in [0\,20]$), a_i and b_i are the parameters associated with fitted curves. Using the fitted block error rate function, we can obtain the throughput $g_{MCS}(\gamma)$ corresponding to a given SNR γ for a given MCS i by $g_{MCS_i}(\gamma) = S_{TB}(1 - a_i e^{b_i \gamma})$, where S_{TB} is the transport block size.

Using the PDF of the received signal power as Equation (3), we can compute the average throughput by $E(g(\gamma)) = \int_0^{t_1} g_{MCS_0}(\gamma) f(\gamma)\, d\gamma + \sum_{i=1}^{i=20} \int_{t_i}^{t_{i+1}} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma + \int_{t_{20}}^{\infty} g_{MCS_{20}}(\gamma) f(\gamma)\, d\gamma$. Here, t_i is the linear SNR value corresponding to the MCS_i switching point, which is defined as the $10\,\%$ BLER of the 1^{st} transmission. To compute $E(g(\gamma))$, the second term on right side can be computed by $\int_{t_i}^{t_{i+1}} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma = \int_{t_i}^{\infty} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma - \int_{t_{i+1}}^{\infty} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma$, where $\int_{t_i}^{\infty} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma = \int_{t_i}^{\infty} T_{BS}(1 - ae^{b\gamma}) f(\gamma)\, d\gamma = T_{BS}(\int_{t_i}^{\infty} f(\gamma)\, d\gamma - \int_{t_i}^{\infty} ae^{b\gamma} f(\gamma)\, d\gamma)$. The first term can be computed as Equation (4) and to compute the second term, we have

$$\begin{aligned} &\int_{t_i}^{\infty} ae^{bx} f(x)\, dx \\ &= \frac{am^m}{\Gamma(m)\sqrt{\pi}} \int_{-\infty}^{\infty} \exp(-x^2) \frac{1}{(m - b10^{\frac{\sqrt{2}\sigma x + \mu}{10}})^m} \\ &\Gamma(m, (\frac{m}{10^{\frac{\sqrt{2}\sigma x + \mu\omega}{10}}} - b)t_i)\, dx. \end{aligned} \tag{5}$$

Equation (5) can also be solved using Hermite approximation. Hence, the average throughput can be computed via the aforementioned mathematic derivation. Notice that, to derive average throughput for a fixed MCS_i, we have $E(g_{MCS_i}(\gamma)) = \int_0^{\infty} g_{MCS_i}(\gamma) f(\gamma)\, d\gamma$.

IV. Performance Evaluation

To evaluate the performance of D2D communication links, we select the coverage probability and average throughput, defined in Section III, as the two key metrics. To validate the analytic results, we also conducted Monte Carlo simulation. We generate log-normal random variable to simulate the shadowing effect and Gamma random variable with its mean following log-normal distribution to simulate combined shading and fading effect on the received signal power. Both numerical analysis and simulation were implemented in Matlab[1]. The Monte Carlo simulation results match well with the analytic results and they are presented together in each figure.

To successfully receive messages on PSSCH, PSCCH has to be correctly decoded first. In our evaluation, we assume the channel is semi-static (i.e., the received signal power is unchanged for the message transmission duration), including sending channel configuration on PSCCH and delivering the message over PSSCH. Thus, we define the coverage probability of the PSSCH as the probability that the received signal power is above the maximum value of the PSCCH receiver sensitivity threshold and the PSSCH receiver sensitivity threshold.

To evaluate the performance of the D2D communication link, we design the following two sets of experiments: (i) In the first set of experiments, we evaluate the performance of D2D communication links with respect to coverage probability and average throughput by varying the distance between the transmitter and the receiver. In this evaluation, we fix the system parameters. The PRB size is set to 6 and TX transmit power is set to 23 dBm. To evaluate the coverage probability, we use the lowest MCS (i.e., MCS0) to accommodate the worst channel condition. We also set the reliable threshold as $1\,\%$ BLER, meaning that when the transport block error is over $1\,\%$, the communication becomes unreliable, and the communication system experiences outage. Notice that the set of parameters used in this evaluation is for demonstration purposes; the system parameters are easily configurable in our performance evaluation system. (ii) In the second set of experiments, we evaluate the performance of D2D communication links with respect to coverage probability and average throughput by varying system parameters, including PRB size, transmit power, and fixed MCS. In doing so, we can evaluate how these parameters can affect the performance of D2D communication links.

Coverage Probability: We use Equation (4) to compute the coverage probability for LOS and NLOS for a PSCCH channel, respectively. We can derive the average value by

$$Pr_c = Pr_{LOS_c} Pr_{LOS} + Pr_{NLOS_c}(1 - Pr_{LOS}). \tag{6}$$

Here, Pr_c is the average coverage probability, Pr_{LOS_c} is the coverage probability of a LOS link, Pr_{NLOS_c} is the coverage probability of a NLOS link, and Pr_{LOS} is the probability that the transmitter and the receiver have a LOS connection. Notice

[1]Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Coverage Prob.	O2O (m)	O2I (m)	I2I SB (m)	I2I DB (m)
99 %	255 - 374	91 - 138	86 - 108	22 - 33
98 %	284 - 433	109 - 155	89 - 111	27 - 38
95 %	374 - 493	132 - 178	97 - 114	36 - 48
90 %	433 - 552	161 - 207	103 - 117	47 - 58

TABLE II: PSCCH Coverage Probability vs. TX-RX Separation (Distance) for Normal Power UE (23 dBm)

Coverage Prob.	O2O (m)	O2I (m)	I2I SB (m)	I2I DB (m)
99 %	374 - 582	138 - 207	100 - 125	35 - 50
98 %	433 - 642	161 - 231	106 - 128	41 - 58
95 %	552 - 761	198 - 271	114 - 134	55 - 72
90 %	672 - 850	242 - 300	122 - 136	69 - 89

TABLE III: PSCCH Coverage Probability vs. TX-RX Separation (Distance) for High Power UE (31 dBm)

that $1 - Pr_{LOS}$ is the probability of transmitter and receiver having a NLOS connection.

For I2I scenarios, we consider two cases, shown in Table I. The first case is that both UEs are in the same building, and the second case is that the two UEs are located in different buildings.

Figure 2 shows the coverage probability versus the distance between the transmitter and the receiver, in which both Log-normal shadowing and Nakagami-m small-scale fading are considered for O2O scenario. As we can see from the figure, the fading generally decreases the coverage probability. In addition, when the severity of fading increases (e.g., fading parameter m decreases), the transmitter coverage becomes smaller.

For O2I and I2I scenarios, we observe the same trend, and the simulation results are summarized in Table II. Table II lists the D2D communication ranges, which correspond to the distances between no fading and Rayleigh fading cases, to maintain given coverage probabilities with respect to UE with normal power. Notice that I2I SB means the same building for I2I scenario and I2I DB means the different buildings for I2I scenario.

To evaluate the coverage probability of the PSSCH, the coverage probability of the PSCCH shall be considered. Successfully receiving channel configurations on PSCCH is required for decoding PSSCH. PSSCH performance depends on the channel configuration, such as PRBs occupied by the channel. Thus, we observe that PSSCH outperforms PSCCH in certain cases, as shown in Figure 3. In addition, PSSCH with 6 PRBs and MCS0 has a slightly higher coverage probability than PSCCH, which is due to the fact that PSCCH uses the same modulation scheme as PSSCH MCS0 with a slightly higher coding rate. Furthermore, PSSCH has four Hybrid Automatic Repeat reQuest (HARQ) transmissions while PSCCH only transmits two identical copies. Thus, PSSCH performance is limited by PSCCH in this case. When the used PRB size is larger or the adopted MCS is higher, PSSCH performance will become the limiting factor for the coverage performance, as shown in Figures 4 and 5.

Average Throughput: Based on the analysis in Section III-C, we compute the numerical results for the average throughput. Similar to the evaluation of outage probability, since both LOS and NLOS scenarios are considered in the O2O and O2I channel models, we compute the average throughput for LOS and NLOS models separately, and then combine these two results using LOS probability.

With the fixed system parameters, and varying the distance between the transmitter and the receiver, we obtain the average throughput for the O2O scenario if AMC is used, as shown in Figure 6. In this figure, we compare the average throughput for path loss and shadowing only and path loss, shadowing, and Nakagami-m fading with different levels of fading severity ($m = 1, 2, 3$). As shown in the figure, when TX-RX separation (distance) increases, the average throughput declines. Also, fading reduces the average throughput compared to the non-fading case. The maximum throughput of the AMC depends on the allocated PRBs, and can be achieved by using the highest MCS. For O2I and I2I scenarios, we have similar observations to those of the O2O scenarios.

Parameter Sensitivity: In the following, we vary system parameters (PRB size, fixed MCS, and transmitter power), and study how these parameters affect the performance of D2D communication links. Without the loss of generality, all results in the following are based on the O2O scenario, and similar observations can be applied to O2I and I2I scenarios as well.

For UEs to communicate with each other, besides PSCCH, PSSCHs need to be decoded. Since PSSCH can occupy different sizes of PRBs, we evaluate how PRB size can affect the PSSCH coverage probability in Figure 7. In this case, the shadowing and Rayleigh fading are considered. As can be seen in the figure, with the increase of the PRB size, the distance between the transmitter and the receiver declines significantly in order to maintain a given coverage probability. This is because the wider the bandwidth, the higher the thermal noise floor, leading to an increased receiver sensitivity threshold.

In D2D communication, especially in group communication, it can be hard to obtain channel state information. In this case, the fixed resource allocation of MCS and PRB needs to be used. Figure 8 shows the throughput for a fixed MCS of MCS10 and 2 PRBs in an O2O scenario, and TX power of 23 dBm. From the figure, we observe that AMC achieves a higher spectrum efficiency compared with fixed MCS, especially when the transmitter and the receiver are relatively close to each other, where channel conditions are good.

The impact of transmit power on the outage probability for O2O scenario is shown in Figure 9, and Table III lists the D2D communication range to maintain given coverage probability for high power UE.

V. Conclusion

In this paper, we developed a modeling and simulation framework to assess the performance of D2D communication

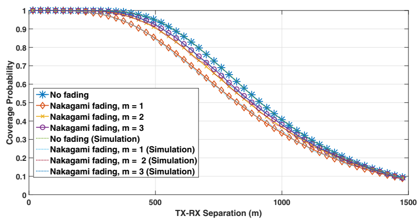

Fig. 2: PSCCH O2O Coverage Probability

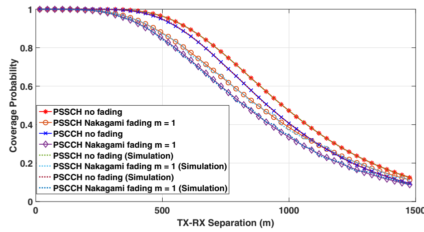

Fig. 3: O2O Coverage Probability of PSCCH vs. PSSCH (PRB = 6, AMC)

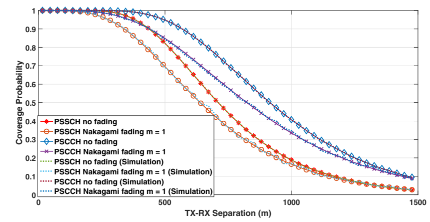

Fig. 4: O2O Coverage Probability of PSCCH vs. PSSCH (PRB = 25, AMC)

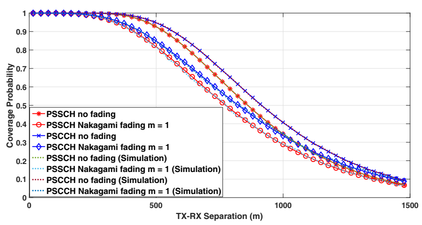

Fig. 5: O2O Coverage Probability of PSCCH vs. PSSCH (PRB = 2, MCS = 10)

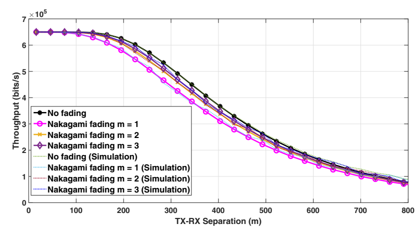

Fig. 6: O2O Throughput (PRB = 6, AMC)

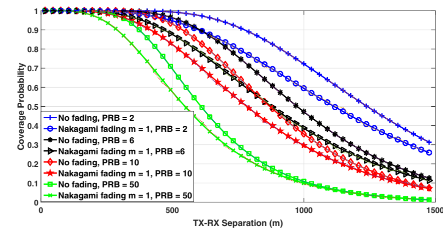

Fig. 7: Coverage Probability vs. PRB Size in PSSCH using AMC for O2O

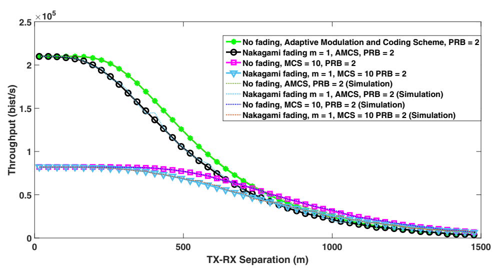

Fig. 8: Throughput of Fixed MCS vs. AMC in PSSCH for O2O Scenario

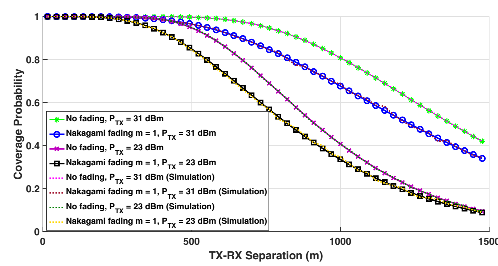

Fig. 9: Coverage Probability vs. Transmit Power in PSCCH

links with respect to coverage probability and average throughput. In our study, we considered various D2D deployment scenarios and channel effects. Based on the framework, we designed different outdoor and indoor scenarios, and derived mathematical expressions for the performance in different scenarios. We conducted an extensive performance evaluation to show the performance of the D2D communication link under various D2D deployment scenarios with different channel effects. We also evaluated the impact of system parameters (PRB size, fixed/adaptive MCS, and transmit power) on the performance of D2D communication links. Our designed framework is generic and can be extended to consider new deployment scenarios via adding or modifying its channel models, as well as reconfiguring system parameters and taking interference into account.

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