Iranian Journal of
Information Technology &
Communication

No.33-34, Vol.9, Fall & Winter 2018
PP: 35-44

Iranian Society of Information Communication Technology

Performance Analysis of Device to Device Communications Overlaying/Underlaying Cellular Network

[*] Hossein Ghavami [**] Shahriar Shirvani Moghaddam

[*] Digital Communications Signal Processing (DCSP) Research Lab., Shahid Rajaee Teacher Training University (SRTTU), Tehran, Iran
[**] Faculty of Electrical Engineering, Shahid Rajaee Teacher Training University (SRTTU), 16788-15811, Tehran, Iran

Abstract

Minimizing the outage probability and maximizing throughput are two important aspects in device to device (D2D) communications, which are greatly related to each other. In this paper, first, the exact formulas of the outage probability for D2D communications underlaying or overlaying cellular network are derived which jointly experience Additive White Gaussian Noise (AWGN) and Rayleigh multipath fading. Then, simulation results of the exact formulas and previously respected approximate formulas are compared in MATLAB for both underlay and overlay scenarios. It is shown that the approximate formula in underlay scenario is a good estimate for exact one while approximate formula for overlaying scenario is a good approximation when the average distance between the transmit/receive nodes of D2D pair is less than half of the maximum distance between these nodes or variance of multipath fading is greater than 1.5. In addition, the probability density functions of Signal to Interference plus Noise Ratio (SINR) for underlay and overlay scenarios are found. Moreover, a new scenario is proposed which jointly considers overlay and underlay scenarios. Furthermore, exact and approximate formulas for outage probability and throughput of D2D users in the proposed scenario are derived. Finally, these formulas are compared to underlay and overlay scenarios in three special cases, low, moderate and high traffic loads.

Keywords: Device to Device Communications; Overlay; Underlay; Outage probability; Throughput.

1. Introduction

Device to Device (D2D) communications is considered as a key solution for spectrum scarcity in the 3rd Generation Partnership Project (3GPP), Long Term Evolution (LTE) [1]. In a cellular communications system, the user equipment (UE) need to use an interface such as cellular Base Station (BS) or Relay Station (RS) to be connected to another UE. Unlike cellular users, in direct D2D communications, two nearby users communicate with each other without sending their data to BS or RS [2]. D2D communications improves network capacity and this type of communications is a keyway in 5G for achieving higher data rates, which is in the spotlight of researchers [3].

In D2D communications, receive node of D2D pair directly receives signal transmitted from respected transmit node. D2D communications can be realized in two scenarios, underlaying and overlaying cellular network. In overlay scenario, radio resource of D2D user is orthogonal to that for cellular user. Despite there is no interference, but compared to other underlay resource reuse scenarios, spectral efficiency is low [4]. On the contrary, in the underlay scenario, D2D user reuses similar radio resource of a cellular user. Underlay scenario causes interference for both D2D and cellular users while the spectral efficiency is improved. Moreover, this type of communications can be available faster whenever there is heavy traffic on the network and system throughput achieved by reusing of resources can be increased [5, 6].

In general, D2D communications can increase physical layer security, enhance connecting probability, improve cell coverage, decrease transmission delay, and reduce the burden on base station [2, 7].

One of the research topics considered in the D2D communications is minimizing outage probability and maximizing throughput in order to efficient resource allocation for cellular users. In the other words, the aim is to minimize the outage probability "The probability that the received Signal to Interference plus Noise Ratio (SINR) is less than the threshold" [8] and to maximize throughput "a nonlinear objective function on SINR".

Previous studies [4, 8-12] presented only the approximate equations for outage probability in underlay and overlay scenarios, but exact equations have not been reported in these studies.

In this paper, the exact formulas for both outage probability and throughput in underlay and overlay scenarios are extracted in the case of Additive White Gaussian Noise (AWGN) and multipath Rayleigh fading channel. In addition, as a comparative study, numerical results of the new acquired exact formulas for underlay and overlay scenarios and previously reported approximate formulas are compared with simulation results in MATLAB. Finally, a new scenario is proposed which considers jointly overlay and underlay scenarios.

This paper is structured as follows. In Section 2, system model for D2D communications underlaying and overlaying cellular network is illustrated. In Section 3, exact and approximate formulas of outage probability for both underlay and overlay scenarios are obtained. In Section 4, first numerical analysis of scenarios 1 and 2 is presented which let us to compare the analytical (exact and approximate formulas) and simulation results. The overlay/underlay scenario is proposed in Section 5. In this section, exact and approximate formulas for outage probability and throughput are presented. Second numerical analysis is reported in Section 6. Finally, Section 7 concludes this paper.

2. System model

As shown in Figure 1, an omni-directional base station is located in the center of a cell radius of 1000m. This one-cell model is including M cellular users and N D2D pairs uniformly distributed throughout the cell. It is assumed that small-scale fading is in accordance with a Rayleigh distribution and a Line Of Sight (L.O.S) path loss model is considered for radio channels between cellular user and D2D pair and transmit/receive nodes of D2D pair. Moreover, each D2D pair allowed to use one idle radio resource in overlay and reuse just one radio resource in underlay manner.

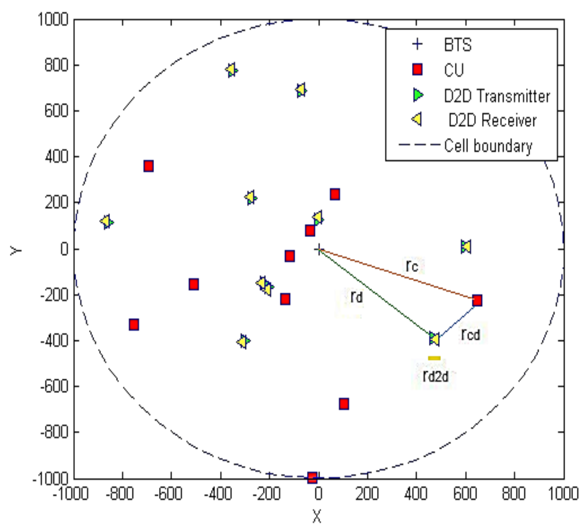

Fig. 1.System model for D2D communications in a cellular system

2.1. Overlaying Scenario

In overlay scenario, radio resources of both D2D pairs and cellular users are orthogonal. It means that cellular users and D2D pairs does not interfere with each other. Hence, the received signal at the receive node of a D2D pair is as (1):

$$x_{ij} = h_{D_i} x_{D_i} \sqrt{P_d (r_{d2d})^{-\alpha}} + n_0 \quad (1)$$

Since overlaying scenario is interference-free, SINR equals to Signal to Noise Ratio (SNR). It means that SINR is as (2) [9]:

$$SINR_{ij} = \frac{P_i h_{D_i}{}^2}{\sigma^2} \quad (2)$$

2.2. Underlaying Scenario

In this scenario, resources of D2D pairs are not orthogonal to the cellular user resources, which means that cellular users make interference on D2D users and vice versa. Hence, the received signal at the receive node of a D2D pair is as (3) [10]:

$$x_{ij} = h_{D_i} x_{D_i} \sqrt{P_d (r_{d2d})^{-\alpha}} + h_{C_j} x_{C_j} \sqrt{P_c (r_{c_j d_i})^{-\alpha}} + n_0 \quad (3)$$

SINR on the i-th D2D pair, which reuses the radio resource of the j-th cellular user, is as (4) [8, 11]:

$$SINR_{ij} = \frac{P_i h_{D_i}{}^2}{P_{ij} h_{C_j}{}^2 + \sigma^2} \quad (4)$$

where x_{D_i} is the signal transmitted from the transmit node of the i-th D2D pair, P_c and P_d are the transmit powers of the cellular user and D2D pair, respectively. r_{d2d} is the distance between the transmit and receive nodes of a D2D pair. $r_{c_j d_i}$ is the distance of the i-th D2D pair from j-th cellular user. h_{D_i} and h_{C_j} are in accordance with Rayleigh fading channels for the i-th D2D pair and j-th cellular user. α is the path loss exponent factor.

In formulas (2), (4) we have

$$P_i = P_d (r_{d2d})^{-\alpha} \quad (5)$$

$$P_{ij} = P_c (r_{c_j d_i})^{-\alpha} \quad (6)$$

where respectively are the powers in the receive node of D2D pair received from the transmitters of D2D pair and cellular user.

Considering the power spectral density of noise, *$N_0/2$* and receiver bandwidth *BW*, the noise power is as (7)

$$\sigma^2 = N_0 BW \quad (7)$$

3. Outage Probability for Underlaying and Overlaying Scenarios

3.1. Underlay scenario

According to formula (4), we have

$$Z = \frac{X}{Y_1 + Y_2} \quad (8)$$

So that

$$X = P_i h_{D_i}{}^2 \quad (9)$$

$$Y_1 = P_{ij} h_{C_j}{}^2 \quad (10)$$

where h_{D_i} and h_{C_j} are Rayleigh faded channel responses with variance of δ^2. According to this fact that the statistical distribution of channel power gain is exponential and based on [13 (Equation 5-18)], we have the probability density functions (pdfs) of X and Y_1, respectively as (11) and (12).

$$f_X(x) = \frac{1}{2\delta^2 P_i} e^{\frac{-x}{2\delta^2 P_i}} \quad (11)$$

$$f_{Y_1}(y_1) = \frac{1}{2\delta^2 P_{ij}} e^{\frac{-y_1}{2\delta^2 P_{ij}}} \quad (12)$$

In order to find the exact formula, it is assumed that noise (n_0) is a zero-mean Gaussian random variable with variance of $\sigma^2/2$. By considering

$$Y_2 = n_0{}^2 \quad (13)$$

the probability density function of Y_2 is

$$f_{Y_2}(y_2) = \frac{1}{\sqrt{\pi\sigma^2 y_2}} e^{\frac{-y_2}{\sigma^2}} \quad (14)$$

By supposing

$$Y = Y_1 + Y_2 \quad (15)$$

and considering [13 (Equation 6-45)], we have

$$f_Y(y)=\frac{1}{2\delta^2 P_{ij}}\sqrt{\frac{2\delta^2 P_{ij}}{2\delta^2 P_{ij}-\sigma^2}}\,e^{\frac{-y}{2\delta^2 P_{ij}}} \quad (16)$$

SINR which is needed to be modeled for finding the outage probability and throughput, is as the form

$$Z=\frac{X}{Y} \quad (17)$$

Applying [13 (Equation 6-59)], we can find the probability density function of SINR as

$$f_Z(z)=P_{ij}P_i\left(\frac{1}{P_i+zP_{ij}}\right)^2\sqrt{\frac{2\delta^2 P_{ij}}{2\delta^2 P_{ij}-\sigma^2}} \quad (18)$$

According to (19), exact formula of outage probability for underlay scenario is as (20).

$$F_Z(y_{th})=\int_{z=0}^{y_{th}} f_z(z)\,dz \quad (19)$$

$$F_Z(y_{th})=\left(1-\frac{P_i}{P_i+y_{th}P_{ij}}\right)\sqrt{\frac{2\delta^2 P_{ij}}{2\delta^2 P_{ij}-\sigma^2}} \quad (20)$$

In approximate equation [4, 12], it is assumed that $Y_2=\sigma^2$ is constant. Hence, considering [13 (Equation 5-18)], we have

$$f_Y(y)=\frac{1}{2\delta^2 P_{ij}}\,e^{\frac{-y+\sigma^2}{2\delta^2 P_{ij}}} \quad (21)$$

and consequently according to [13 (Equation 6-59)], we have

$$f_Z(z)=\left(\frac{1}{2\delta^2}\right)\left(\frac{\sigma^2}{(P_{ij}z+P_i)}-\frac{2\delta^2 P_i P_{ij}}{(P_{ij}z+P_i)^2}\right)e^{-\frac{zy_{th}}{2\delta^2 P_i}} \quad (22)$$

Finally, according to [4, 12] and Equation (19), approximate formula of outage probability for underlay scenario is as (23):

$$F_Z(y_{th})=1-\frac{P_i}{P_i+y_{th}P_{ij}}\,e^{-\frac{\sigma^2 y_{th}}{2\delta^2 P_i}} \quad (23)$$

3.2. Overlay scenario

According to Equation (2), we have

$$Z=\frac{X}{Y} \quad (24)$$

So that

$$X=P_i h_{D_i}^{\ 2} \quad (25)$$

where h_{D_i} is Rayleigh distributions with variance of δ^2. It is clear that the statistical distribution of channel gain is exponential, and based on [13 (Equation 5-18)], we have

$$f_X(x)=\frac{1}{2\delta^2 P_i}\,e^{\frac{-x}{2\delta^2 P_i}} \quad (26)$$

as the probability density function of X. In order to find the exact formula, it is assumed that noise (n_0) is a zero-mean Gaussian random variable with variance of $\sigma^2/2$. By considering

$$Y=n_0^{\ 2} \quad (27)$$

the probability density function of Y is

$$f_Y(y)=\frac{1}{\sqrt{\pi\sigma^2 y}}\,e^{\frac{-y}{\sigma^2}} \quad (28)$$

Applying [13 (Equation 6-59)], we can find the probability density function of SINR as

$$f_Z(z)=\left(\frac{3\sqrt{\pi}}{2}\right)\sqrt{\left(\frac{2\delta^2\sigma^2 P_i}{z\sigma^2+2\delta^2 P_i}\right)^3} \quad (29)$$

According to Equation (19), the exact formula of outage probability for overlay scenario is as (30).

$$F_Z(y_{th})=6\delta^2 P_i\sqrt{\sigma^2\pi}\left(1-\sqrt{\frac{2\delta^2 P_i}{2\delta^2 P_i+\sigma^2 y_{th}}}\right) \quad (30)$$

In approximate Equation [9], $Y=\sigma^2$ is a constant value. Hence, considering [13 (Equation 5-18)], we have

$$f_Z(z)=\frac{\sigma^2}{2\delta^2 P_i}\,e^{\frac{-\sigma^2 z}{2\delta^2 P_i}} \quad (31)$$

Finally, according to [9] and Equation (19), approximate formula of outage probability for overlay scenario is as (32).

$$F_Z(y_{th}) = 1 - e^{-\frac{\sigma^2 y_{th}}{2\delta^2 P_i}} \qquad (32)$$

4. Numerical Analysis of Scenarios 1 & 2

In this section, simulation results of underlay and overlay scenarios are compared with numerical results of above-mentioned approximate and exact formulas. According to the system model presented in the previous section, parameters for numerical analysis are as Table 1.

In order to simulate underlay scenario, it is assumed that there are ten D2D pairs and each D2D pair can randomly reuse one radio resource of one cellular user. Figure 2 shows the outage probability of D2D users versus the average distance between D2D pair and cellular user for underlay scenario.

Parameter	Symbol	Value
Path loss exponent	α	4
Cell radius	R	1000m
Maximum number of active CUEs	M	10
White noise power spectral density	$N_0/2$	-156dBm/Hz
Predetermined protection ratio	y_{th}	0dBm
Transmit power of CUEs	P_c	20dBm
Transmit power of D2D pairs	P_d	10dBm
Radio link bandwidth	$B.W$	180kHz
Variance of Rayleigh fading	δ^2	0.5
Average distance between the nodes of a D2D pair	r_d	50m

Table I. Parameters for Numerical Analysis

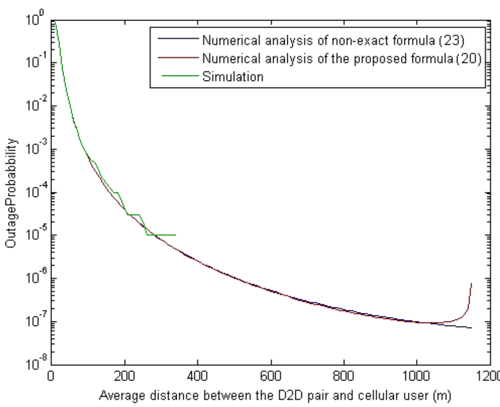

Fig. 2. Outage probability vs. the distance between the D2D pair and cellular user for underlay scenario

In Figure 2, as long as the distance of the D2D pair from cellular users is less than 1000m, the simulation result is coincided with the exact and approximate formulas. Because underlay scenarion is interference-dominant, increasing the distance between D2D pair and cellular user is the reason for decreasing outage probability.

In Figure 3, the outage probability of D2D users for underlay scenario versus the disance between transmit/receive nodes of a D2D pair is shown. It is clear that outage probability increases when the distance between transmit/receive nodes increases. In addition, there is a good agreement between analytical and simulation resulsts.

In overlay scenario, it is assumed that there is just one D2D pair because radio resources are orthogonal. Figure 4 demonstrates the outage probability of D2D users versus the distance between transmit/receive nodes of D2D pair for overlay scenario. As depicted in Figure 4, despite the simulation results and numerical results of exact formula are the same but it is not valid for approximate formula. In other words, outage probability obtained from simulation and approximate formula are equal just for distances lower than 25m.

Figure 5 shows the outage probability for overlay scenario by changing the variance of Rayleigh fading. As shown in Figure 5, numerical analysis of exact formula and simulation results have similar values in different variances but outage probability of approximate formula differs for variances of Rayleigh fading greater than 1.5.

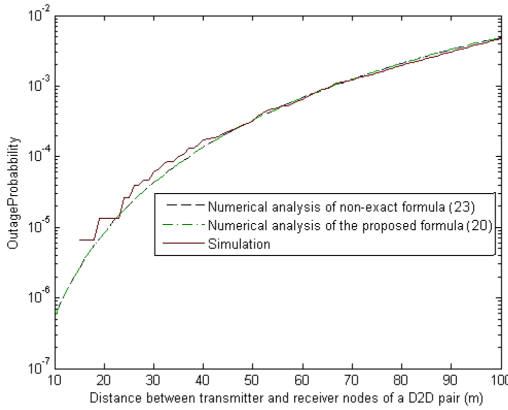

Fig. 3.Outage probability vs. the distance between the transmit and receive nodes of a D2D pair for underlay scenario

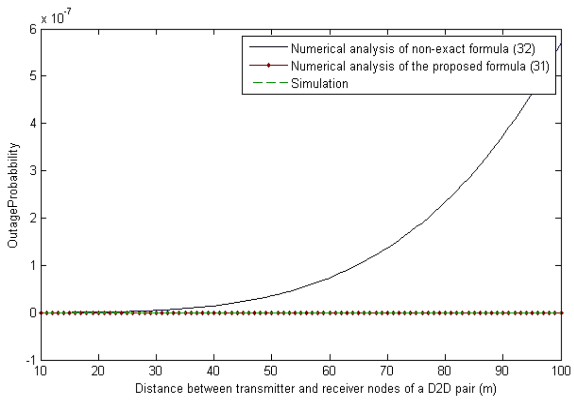

Fig. 4.Outage probability vs. the distance between the D2D pair and cellular user for overlay scenario

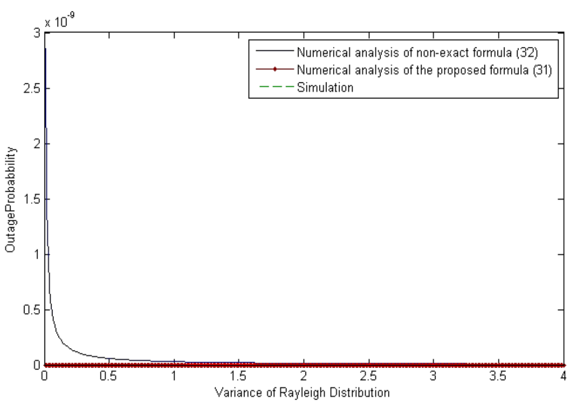

Fig. 5.Outage probability vs. the variance of Rayleigh fading for overlay scenario

5. Underlay/Overlay Scenario

Assuming that the number of assigned radio resources to each cell is M (equal to maximum number of active cellular users), the number of idle radio resources is m, and the number of D2D requests is greater than active cellular users $(N \geq M)$, then m radio resources can be activated by D2D pairs in overlaying manner and $(M-m)$ radio resources in underlay scenario. It means that, M D2D users, underlaying and/or overlaying cellular users are able to use radio resources.

Overlay scenario needs to find idle radio resources (white spaces) by using spectrum sensing methods. In this scenario, D2D and cellular users are interference-free. Unlike overlay, underlay scenario does not need to find idle channel. It reuses the channels engaged by cellular users, which causes D2D pairs and respected cellular users experience interference.

Overlay/underlay scenario activate some D2D pairs (m) by overlay scenario and the other ones $(M-m)$ by underlay scenario. By using this combined scenario, the number of active D2D pairs will be increased respect to two above-mentioned scenarios meanwhile the interference is controlled. For low traffic loads of cellular users, most of D2D users will be served by overlay scenario while in high traffic loads, underlay scenario is dominant. Outage probability for overlay/underlay scenario can be derived as (33).

$$P_{out_{under/over}} = \frac{m}{M} P_{out_{over}} + \frac{M-m}{M} P_{out_{under}} \quad (33)$$

where exact and approximate formulas for $P_{out_{under}}$ are as (20), (23) and those for $P_{out_{over}}$ are as (30), (32). Therefore, exact and approximate formulas of outage probability for D2D users in overlaying/underlaying cellular network are respectively as (34), (35).

$$P_{out_{under/over}} = \frac{M-m}{M}\left(\frac{y_{th}P_{ij}}{P_i + y_{th}P_{ij}}\right)\sqrt{\frac{2\delta^2 P_{ij}}{2\delta^2 P_{ij} - \sigma^2}} + \frac{m}{M}6\delta^2 P_i\sqrt{\sigma^2\pi}\left(1-\sqrt{\frac{2\delta^2 P_i}{2\delta^2 P_i + \sigma^2 y_{th}}}\right) \quad (34)$$

$$P_{out_{under/over}} = \left(1-\frac{P_i}{P_i + y_{th}P_{ij}}e^{-\frac{\sigma^2 y_{th}}{2\delta^2 P_i}}\right) - \frac{m}{M}e^{-\frac{\sigma^2 y_{th}}{2\delta^2 P_i}}\left(1-\frac{P_i}{P_i + y_{th}P_{ij}}\right) \quad (35)$$

For high traffic loads of cellular users, the number of idle channels tends to be zero ($m = 0$). Hence, formulas (34), (35) are equal to those in underlay case, formulas (20), (23), respectively. In contrast, for low traffic loads of cellular users, the number of idle channels go to be as maximum as ($m = M$). Hence, in this case, formulas (34), (35) are the same as overlaying case (noise-dominant), formulas (30), (32), respectively. Finally, outage probability of D2D users for moderate traffic loads of cellular users ($m = M/2$), are as (36).

$$P_{out_{under/over}} = \frac{1}{2}\left(P_{out_{over}} + P_{out_{under}}\right) \quad (36)$$

In this case, exact formula is as (37) and approximate formula is as (38).

$$P_{out_{under/over}} = \left(\frac{y_{th}P_{ij}}{P_i + y_{th}P_{ij}}\right)\sqrt{\frac{\delta^2 P_{ij}}{4\delta^2 P_{ij} - 2\sigma^2}} + 3\delta^2 P_i\sqrt{\sigma^2\pi}\left(1-\sqrt{\frac{2\delta^2 P_i}{2\delta^2 P_i + \sigma^2 y_{th}}}\right) \quad (37)$$

$$P_{out_{under/over}} = 1 - \frac{P_i + \frac{y_{th}P_{ij}}{2}}{(P_i + y_{th}P_{ij})}e^{-\frac{\sigma^2 y_{th}}{2\delta^2 P_i}} \quad (38)$$

In order to find throughput of the proposed scenario, throughput per user is defined. Throughput per user equals to average throughput for one D2D user, which equals to total throughput for D2D users normalized by the number of active D2D pairs. By using new proposed criterion, normalized throughput, we are able to have a fair comparison in different traffic loads and bandwidths. Normalized throughput for D2D users in overlaying scenario (Noise-dominant case) is as (39) and that for underlay scenario (Interference-dominant case) is as (40).

$$Throughput_{over} = \log_2(1+\mathrm{SNR}_i) \quad (39)$$

$$Throughput_{under} = \log_2(1+\mathrm{SINR}_{ij}) \quad (40)$$

For the proposed overlay/underlay scenario, normalized throughput is as (41)

$$Throughput_{under/over} = \frac{m}{M}Throughput_{over} + \frac{M-m}{M}Throughput_{under} \quad (41)$$

or

$$Throughput_{under/over} = \frac{m}{M}\log_2(1+\mathrm{SNR}_i) + \frac{M-m}{M}(\log_2(1+\mathrm{SINR}_{ij})) \quad (42)$$

or finally as

$$Throughput_{under/over} = \frac{m}{M}\log_2\left(1+\frac{P_i {h_{D_i}}^2}{\sigma^2}\right) + \frac{M-m}{M}\log_2\left(1+\frac{P_i {h_{D_i}}^2}{P_{ij}{h_{C_j}}^2 + \sigma^2}\right) \quad (43)$$

For overlay/underlay scenario, when traffic load of cellular users is high, or the number of idle channels tends to be zero ($m = 0$), formula (43) is the same as underlay case, like (39). In contrast, when the traffic load of cellular users is low, or equivalently the number of idle channels go to be as maximum as ($m = M$), formula (43) is the same as overlaying noise-dominant case, i.e., (40). Finally, normalized throughput of D2D users for moderate traffic load of cellular users, ($m = M/2$), is as (44).

$$Throughput_{under/over} = \frac{1}{2}\log_2((1+\frac{P_i\, h_{D_i}{}^2}{\sigma^2}) \times (1+\frac{P_i\, h_{D_i}{}^2}{P_{ij}\, h_{C_j}{}^2+\sigma^2})) \quad (44)$$

6. Numerical Analysis of the Proposed Scenario

In this section, simulation results of overlay/underlay scenario are compared with simulation results of underlay and overlay scenarios. It is assumed that there exist ten D2D pairs, the average distance between the D2D pair and cellular user is 500m, the average distance between transmit/receive nodes of a D2D pair is 25m, and each D2D pair randomly uses one radio resource.

In the proposed scenario, the D2D requests first will be served by idle channels in overlaying manner. Then, the other requests can be served in underlay manner by reusing the channels engaged by cellular users. In this scenario, all D2D pairs are able to find radio resources to communication. For high traffic loads, all D2D communications are in underlay manner while for low traffic loads, overlaying manner is dominant. In other words, M D2D pairs find M radio resources in all traffic loads of cellular users.

In overlaying scenario, for high traffic loads, the D2D requests will be failed. If the number of idle channels is n $(n \le M)$, then $(M-n)$ D2D requests will be disconnected. The outage probability and throughput for these D2D pairs are 1 and 0, respectively. In underlay scenario, for low traffic, the D2D requests will be failed. If the number of idle channels is n $(n \le M)$, then n D2D requests will be disconnected. The outage probability and throughput for these D2D pairs are 1 and 0, respectively.

Figure 6 shows the outage probability of D2D pair for three scenarios, overlay, underlay, and overlay/underlay in different number of idle channels. It is clear that overlay/underlay scenario offers lower outage probability compared to that for conventional underlay and overlay scenarios, in different number of idle channels.

It can be seen that for high traffic loads of cellular users, the number of idle channels is zero $(m = 0)$ that means overlay/underlay scenario is the same as underlay scenario. In contrast, for low traffic loads of cellular users, the number of idle channels is maximum $(m = M)$, which means that in this case, the proposed scenario is the same as overlay scenario.

Figure 7 shows the normalized throughput of D2D user for overlay, underlay, and overlay/underlay scenarios in terms of the number of idle channels. As shown in this figure, overlay/underlay scenario offers higher normalized throughput compared to that for conventional underlay and overlay scenarios, in different number of idle channels.

It is clear that for high traffic loads of cellular users, $m = 0$, the result of overlay/underlay scenario is the same as that for underlay scenario. In contrast, for low traffic loads of cellular users,$m = M$, the normalized throughput of overlay/underlay scenario equals to that for overlay scenario.

Figure 7 shows the normalized throughput of D2D user for overlay, underlay, and overlay/underlay scenarios in terms of the number of idle channels. As shown in this figure, overlay/underlay scenario offers higher normalized throughput compared to that for conventional underlay and overlay scenarios, in different number of idle channels.

It is clear that for high traffic loads of cellular users, $m = 0$, the result of overlay/underlay scenario is the same as that for underlay scenario. In contrast, for low traffic loads of cellular users,$m = M$, the normalized throughput of overlay/underlay scenario equals to that for overlay scenario.

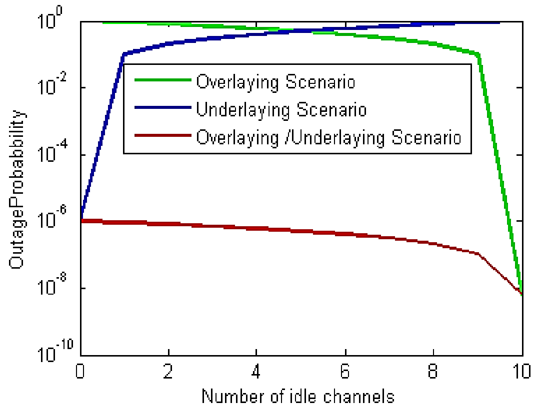

Fig. 6. Outage probability vs. the number of idle channels

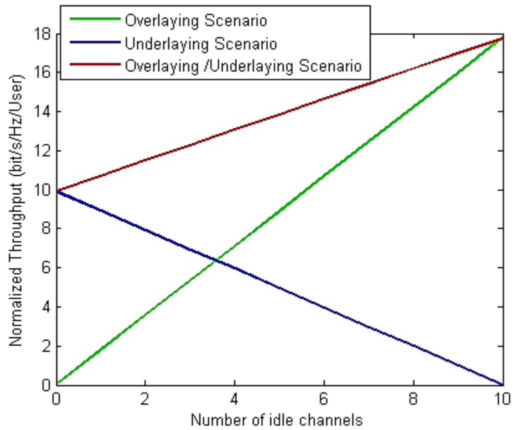

Fig. 7. Normalized throughput vs. the number of idle channels

7. Conclusion

First, in AWGN multipath Rayleigh fading channel, the exact and approximate formulas of outage probability for D2D communications underlaying or overlaying cellular network were found. By comparing simulation results and numerical analysis of obtained exact and approximate formulas, the following results were given:

1. In underlay scenario, approximate and exact formulas have the same outage probability.

2. In overlay scenario, the approximate formula is valid when the average distance between transmit/receive of D2D pair is less than half of the maximum distance between transmit/receive nodes of a D2D or variance of Rayleigh fading is greater than 1.5.

In addition, a new scenario was proposed which jointly uses overlay and underlay scenarios. For the proposed scenario, outage probability and throughput per user were analyzed, theoretically and numerically. Simulations results showed that the proposed scenario offers higher performance compared to conventional scenarios in different traffic loads of cellular users.

References

[1] K. Doppler, M. P. Rinne, C. Wijting, C. B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks," IEEE s Communications Magazine, vol. 47, no. 12, pp. 42-49, 2009.

[2] D. Feng, L. Lu, Y. Yuan-Wu, G. Li, S. Li, and G. Feng, "Device to device communications in cellular networks," Communications Magazine, vol. 52, no. 4, pp. 49 - 55, 2014.

[3] D. Feng, L. Lu, Y. Yuan-Wu, G.Li, G. Feng, and S. Li, "Device to device communications underlaying cellular networks," IEEE Transactions on Communications, vol. 61, no. 8, pp. 3541–51, 2013.

[4] P. Sartori, H. Bagheri, V. Desai, B. Classon, A. Soong, M. Al-Shalash, et al., "Design of a D2D overlay for next generation LTE," In: 80th IEEE Vehicular Technology Conference (VTC Fall), Vancouver, Canada, pp. 1-5, 2014.

[5] M. Hasan, E. Hossain, and D. I. Kim, "Resource allocation under channel uncertainties for relay-aided device-to-device communication underlaying LTE-A cellular networks," IEEE Transactions on Wireless Communications, vol. 13, no. 4, pp. 2322 - 2338, 2014 .

[6] J. Liu, N. Kato, J. Ma, and N. Kadowaki, "Device-to-device communication in LTE-advanced networks: A survey," IEEE Communications Surveys and Tutorials, vol. 17, no. 4, pp. 1923-1940, 2015.

[7] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, "Reliability improvement using receive mode selection in the device-to-device uplink period underlaying cellular networks," IEEE Transactions on Wireless Communications, vol. 10, no. 2, pp. 413-418, 2011.

[8] Q. Duong, Y. Shin, and O.-S. Shin, "Resource allocation scheme for device-to-device communications underlaying cellular networks," In: 2013 International Conference on Computing, Management and Telecommunications, Ho Chi Min City, Vietnam, pp. 66-69, 2013.

[9] G. George, R. K. Mungara, and A. Lozano, "Overlaid device-to-device communication in cellular networks," In: IEEE Global Communications Conference, Austin, USA, pp. 3659-3664, 2014.

[10] H. Wang and X. Chu, "Distance-constrained resource-sharing criteria for device-to-device communications underlaying cellular networks," IET Electronics Letters., vol. 48, no. 9, pp. 528-530, Apr. 2012.

[11] Han, Q. Cui, C. Yang, and X. Tao, "Bipartite matching approach to optimal resource allocation in device to device underlaying cellular network," IET Electronics Letters, vol. 50, no. 3, pp. 212-214, 2014.

[12] B. Wang, L. Chen, X. Chen, X. Zhang, and D. Yang, "Resource allocation optimization for device-to-device communications in cellular networks," In: IEEE 73rd Vehicular Technology Conference (VTC Spring), Budapest, Hungary, pp. 1-6, 2011.

[13] A. Papoulis and S. U. Pillai, "Probability, Random Variables and Stochastic Process," 4th edition. McGraw-Hill, 2002.