

Ergodic capacity analysis for device-to-device communication underlying cellular networks

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Abstract: The ergodic capacity of device-to-device (D2D) communication underlying cellular networks is analyzed. First, the D2D communication model is introduced and the interference during uplink period and downlink period is analyzed. In a D2D communication system, since it is very difficult to obtain the instantaneous channel state information (CSI), assume that only the transmitters know the statistical CSI and the channel coefficient follows an independent complex Gaussian distribution. Based on the assumptions, for the uplink period, the signal to interference plus noise ratio (SINR) of the D2D user equipments (DUEs) is expressed. Then the cumulative distribution function (CDF) and probability distribution function (PDF) formulae of the SINR of the DUEs are presented. Based on the SINR formulae during the uplink period, the ergodic capacity formula of the uplink period is derived. Subsequently, using the same methods, the ergodic capacity formula of the downlink period is derived. The simulation results show that the DUEs can still obtain a high ergodic capacity even in the case of a large number of DUEs. This result can be applied to the design and optimization of D2D communications.

Key words: device-to-device (D2D); ergodic capacity; cellular networks

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In recent years, wireless data traffic has dramatically increased with the emergence of various new mobile applications. The wireless spectrum resource is becoming increasingly scarce with the rapid development of wireless communications services. Device-to-device (D2D) communications can effectively improve resource utilization in cellular networks for the licensed and unlicensed spectrum^[1].

Capacity enhancement is an important research field for D2D communications. Currently, most related papers fo-

cus on resource management and interference suppression to improve capacity. In Ref. [2], optimum resource allocation and power control between the cellular and D2D connections that share the same resources are analyzed for different resource sharing modes. However, they only consider the case that one cellular user and two D2D users share the same radio resources. In Ref. [3], a new interference management scheme is proposed to improve the reliability of D2D communications in the uplink period without reducing the signal to interference plus noise ratio (SINR) of CUEs. However, the scheme is not effective for the strong and small interference regimes. In Ref. [4], the D2D reuses resources of cellular users near the base station (BS), which bring greater improvements in the outage probability of cellular users. However, this scheme is seriously limited by the region. In Ref. [5], an optimal D2D allocation over multi-bands in the heterogeneous networks is analyzed. By allocating D2D users on different bands, it can reduce the interference between D2D and cellular networks and improve D2D transmission capacity. In Ref. [6], a new interference management strategy is proposed to enhance the overall capacity of cellular networks and D2D systems. However, they only focus on the case that one D2D pair and multiple CUEs share the same resources and do not consider the case that multiple D2D pairs and multiple CUEs share the same resources. In Ref. [7], a distributed dynamic spectrum protocol in which ad hoc D2D users opportunistically access the spectrum used by cellular users is developed. This paper shows that two D2D users can communicate with a low outage probability while only minimally affecting the cellular network.

Overall, the related papers rarely focus on the ergodic capacity analysis of D2D communications. In this paper, we analyze the ergodic capacity of D2D communications underlying cellular networks. It is assumed that DUEs and CUEs follow a uniform distribution in the network. To obtain the ergodic capacity of the DUEs, the SINR formula of the DUEs is expressed. Then, based on the SINR formula, the ergodic capacity formula is derived. This result can be applied to the design and optimization of D2D communications.

1 System Model

Let us consider a single cell environment where M

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DUE pairs and N CUEs coexist, as illustrated in Fig. 1. These UEs share the same radio resources. Hence, there is mutual interference between CUEs and DUEs. Overall, there are four types of interference as follows: DUEs to CUEs, DUEs to DUEs, CUEs to CUEs, and CUEs to DUEs. Therefore, the additional interference has an impact on the ergodic capacity. Meanwhile, a smart antenna is deployed at the BS and an omnidirectional antenna is adopted at the UEs. The D2D interference to cellular networks can be effectively managed using the power control scheme which strictly limits the maximum transmitting power of the D2D transmitter^[8]. During the downlink period, one DUE only receives the interference from other DUEs because N multiple antennas facing towards their CUEs are deployed at the BS. However, during the uplink period, the received interference at the DUE consists of two parts. One part is from CUEs, and the other part is from other DUEs.

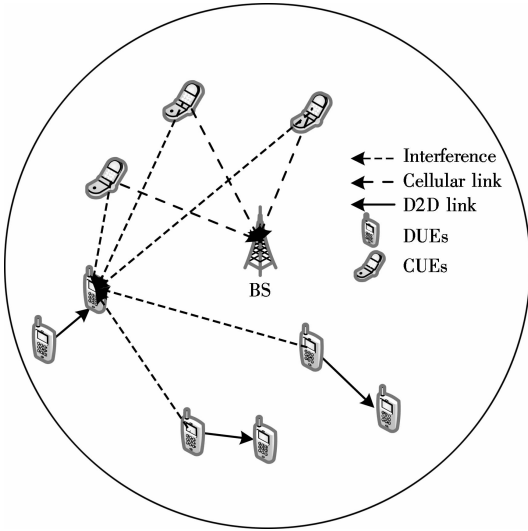


Fig. 1 System model of D2D communication underlying cellular networks

In D2D communications, the communication parties are close together in general, and they can transmit information directly. By this token, the D2D communication link between the transmitter and receiver of a pair of DUEs is similar to that of an ad hoc network with short distance. Therefore, we assume that the DUE links follow a median path loss model having the form $P_R/P_T = 1/r^\alpha$ ^[9]. Where P_R is the received power at the DUE; P_T is the transmitting power of the DUE; r is the distance between the transmitter and receiver of a pair of DUEs; α is the path loss exponent. Meanwhile, we consider that the cellular links and the D2D links between different DUE pairs follow the Rayleigh fading channel model^[10]. Based on the above assumption, the ergodic capacity of D2D communications is analyzed and the corresponding formulae are derived in the next section.

2 Ergodic Capacity Analysis

In D2D communications, two DUEs can directly communicate if they are close in distance. Clearly, D2D communications can effectively improve network capacity. However, at the same time, the additional interference between the CUEs and DUEs is introduced due to using the same frequency band. The additional interference will decrease the network capacity. The ergodic capacity corresponds to the maximum long-term achievable rate averaged over all states of the time-varying channel^[11]. Next, we analyze the uplink ergodic capacity and downlink ergodic capacity, respectively.

2.1 Uplink ergodic capacity

In this paper, we consider that the transmitting powers for all DUEs are the same and denoted as P_T . Then the received SINR at DUE k can be written as

$$\beta_k = \frac{\frac{P_T}{(d_k^{(d)})^\alpha}}{\sum_{i=1, i \neq k}^M \frac{P_T |h_{i,k}|^2}{(d_{i,k}^{(d)})^\alpha} + \sum_{j=1}^N \frac{P_j^{(c)} |\eta_{j,k}|^2}{(d_{j,k}^{(c)})^\alpha} + N_0} \quad (1)$$

where $P_j^{(c)}$ is the transmitting power of CUE j ; M and N are the numbers of DUE pairs and CUEs, respectively; $h_{i,k}$ is the channel coefficient of the link between DUE i and DUE k ; $\eta_{j,k}$ is the channel coefficient of the link between CUE j and DUE k and we assume that $h_{i,k}$ and $\eta_{j,k}$ follow an independent complex Gaussian distribution. In addition, $d_k^{(d)}$ is the distance between the transmitter and receiver of DUE pair k ; $d_{i,k}^{(d)}$ is the distance between DUE i and DUE k ; $d_{j,k}^{(c)}$ is the distance between CUE j and DUE k ; α is the path loss exponent; N_0 is the noise power.

In Eq. (1), the noise power is negligible^[12]. Therefore, the received SINR at DUE k is approximately expressed as

$$\tilde{\beta}_k = \frac{\frac{P_T}{(d_k^{(d)})^\alpha}}{\sum_{i=1, i \neq k}^M \frac{P_T |h_{i,k}|^2}{(d_{i,k}^{(d)})^\alpha} + \sum_{j=1}^N \frac{P_j^{(c)} |\eta_{j,k}|^2}{(d_{j,k}^{(c)})^\alpha}} \quad (2)$$

We assume that the received signal powers at the BS, which are from all CUEs, are controlled at the same power level and denoted as P_R ^[11]. Then the received SINR at DUE k is given by

$$\bar{\beta}_k = \frac{\frac{P_T}{(d_k^{(d)})^\alpha}}{\sum_{i=1, i \neq k}^M \frac{P_T |h_{i,k}|^2}{(d_{i,k}^{(d)})^\alpha} + \sum_{j=1}^N \frac{(l_j)^\alpha P_R |\eta_{j,k}|^2}{(d_{j,k}^{(c)})^\alpha}} \quad (3)$$

where l_j is the distance between CUE j and the BS. Now, let $\lambda_i = \frac{(d_k^{(d)})^\alpha}{(d_{i,k}^{(d)})^\alpha}$ and $\lambda'_j = \frac{(l_j)^\alpha (d_k^{(d)})^\alpha P_R}{(d_{j,k}^{(c)})^\alpha P_T}$. Then we can obtain

$$\tilde{\beta}_k = \frac{1}{\sum_{i=1}^M \lambda_i |h_{i,k}|^2 + \sum_{j=1}^N \lambda'_j |\eta_{j,k}|^2} \quad (4)$$

To make the notation uniform, let $\mu_u = \{1/\lambda_1, \dots, 1/\lambda_M, 1/\lambda'_1, \dots, 1/\lambda'_N\}$.

Proposition 1 If $|h_{i,k}|^2$ and $|\eta_{j,k}|^2$ are independent and identical distributed random variables and follow an exponential distribution, the probability distribution function (PDF) of $\tilde{\beta}_k$ is

$$f(\tilde{\beta}_k) = \left(\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j) \right) \left[\frac{e^{-\mu_u(1)/\tilde{\beta}_k} \tilde{\beta}_k^{-2}}{\prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)/\tilde{\beta}_k} \tilde{\beta}_k^{-2}}{\prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] \quad (5)$$

Proof As $|h_{i,k}|^2$ and $|\eta_{j,k}|^2$ are independent and identical distributed random variables and follow an exponential distribution, we can let $z = |h|^2$. Then the PDF of z is given by $f_z(z) = e^{-z} (z \geq 0)$. Therefore, for any λ_i , the PDF of $\lambda_i z$ is given by $f(\lambda_i z) = \frac{1}{\lambda_i} e^{-z/\lambda_i} (z \geq 0)$.

Meanwhile, the distance among UEs follows a continuous distribution. Therefore, for all UEs, we can assume that all $\lambda_i (i = 1, 2, \dots, M)$ and $\lambda'_j (j = 1, 2, \dots, N)$ are different from each other.

Now, we let $x = \sum_{i=1}^M \lambda_i |h_{i,k}|^2 + \sum_{j=1}^N \lambda'_j |\eta_{j,k}|^2$.

Therefore, the variable x is the sum of multiple exponential random variables with different parameters^[13].

Then we can obtain the PDF of x ,

$$f_X(x) = \begin{cases} \left(\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j) \right) \left[\frac{e^{-\mu_u(1)x}}{\prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)x}}{\prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] & x > 0 \\ 0 & x \leq 0 \end{cases} \quad (6)$$

Next, let $y = 1/x$, and the cumulative distribution function (CDF) of y is obtained as

$$F_Y(y) = P(Y \leq y) = P\left(X \geq \frac{1}{y}\right) = \int_{\frac{1}{y}}^{+\infty} f_X(x) dx = \left(\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j) \right) \left[\frac{e^{-\mu_u(1)/y}}{\mu_u(1) \prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)/y}}{\mu_u(M+N) \prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] \quad (7)$$

Finally, the PDF of y can be obtained from the CDF by differentiation:

$$f_Y(y) = \frac{dF_Y(y)}{dy} = \left(\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j) \right) \left[\frac{e^{-\mu_u(1)/y} y^{-2}}{\prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)/y} y^{-2}}{\prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] \quad (8)$$

Corollary 1 The uplink ergodic capacity of DUE k can be written as

$$C_d = \frac{\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j)}{\ln 2} \left[\frac{\ln \mu_u(1)}{\mu_u(1) \prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{\ln \mu_u(M+N)}{\mu_u(M+N) \prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] + \frac{C}{\ln 2} \quad (9)$$

Proof The uplink ergodic capacity is expressed as^[14]

$$C = \int_0^{\infty} \log_2(1+y) f_Y(y) dy \quad (10)$$

Finally, substituting Eq. (8) into Eq. (10), we obtain

$$C_d = \int_0^{\infty} \left(\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j) \right) \left[\frac{e^{-\mu_u(1)/y} y^{-2}}{\prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)/y} y^{-2}}{\prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] \log_2(1+y) dy = \frac{\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j)}{\ln 2} \int_0^{\infty} \left[\frac{e^{-\mu_u(1)y}}{\prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{e^{-\mu_u(M+N)y}}{\prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] \log_2\left(1 + \frac{1}{y}\right) dy = \frac{\prod_{\substack{j=1 \\ j \neq k}}^{M+N} \mu_u(j)}{\ln 2} \left[\frac{\ln \mu_u(1) - e^{\mu_u(1)} \text{Ei}(-\mu_u(1))}{\mu_u(1) \prod_{\substack{j=2 \\ j \neq k}}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{\ln \mu_u(M+N) - e^{\mu_u(M+N)} \text{Ei}(-\mu_u(M+N))}{\mu_u(M+N) \prod_{\substack{j=1 \\ j \neq k}}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] + \frac{C}{\ln 2} \quad (11)$$

It is easy to verify $e^{\mu_u(M+N)} \text{Ei}(-\mu_u(M+N)) \approx 0$. Therefore, Eq. (11) is simplified to

$$C_d = \frac{\prod_{j=1, j \neq k}^{M+N} \mu_u(j)}{\ln 2} \left[\frac{\ln \mu_u(1)}{\mu_u(1) \prod_{j=2, j \neq k}^{M+N} \mu_u(j) - \mu_u(1)} + \dots + \frac{\ln \mu_u(M+N)}{\mu_u(M+N) \prod_{j=1, j \neq k}^{M+N-1} \mu_u(j) - \mu_u(M+N)} \right] + \frac{C}{\ln 2} \quad (12)$$

where $\text{Ei}(x) = \int_{-\infty}^x \frac{e^t}{t} dt$ when $x < 0$; C is the Euler constant ($C \approx 0.5772$).

2.2 Downlink ergodic capacity

During the downlink period, one DUE only receives the interference from other DUEs. Then the received SINR at DUE k in the downlink period is given by

$$\tilde{\gamma}_k = \frac{\frac{P_T}{(d_k^{(d)})^\alpha}}{\sum_{i=1}^M \frac{P_T |h_{i,k}|^2}{(d_{i,k}^{(d)})^\alpha}} \quad (13)$$

Similarly, we let $\mu_d = \{1/\lambda_1, 1/\lambda_2, \dots, 1/\lambda_M\}$. Then the PDF of $\tilde{\gamma}_k$ can be obtained as

$$f(\tilde{\gamma}_k) = \left(\prod_{j=1, j \neq k}^M \mu_d(j) \right) \left[\frac{e^{-\mu_d(1)/\tilde{\gamma}_k} \tilde{\gamma}_k^{-2}}{\prod_{j=2, j \neq k}^M \mu_d(j) - \mu_d(1)} + \dots + \frac{e^{-\mu_d(M)/\tilde{\gamma}_k} \tilde{\gamma}_k^{-2}}{\prod_{j=1, j \neq k}^{M-1} \mu_d(j) - \mu_d(M)} \right] \quad (14)$$

Finally, the downlink ergodic capacity of DUE k is written as

$$C_k^{(d)} = \frac{\prod_{j=1, j \neq k}^M \mu_d(j)}{\ln 2} \left[\frac{\ln \mu_d(1)}{\mu_d(1) \prod_{j=2, j \neq k}^M \mu_d(j) - \mu_d(1)} + \dots + \frac{\ln \mu_d(M)}{\mu_d(M) \prod_{j=1, j \neq k}^{M-1} \mu_d(j) - \mu_d(M)} \right] + \frac{C}{\ln 2} \quad (15)$$

In conclusion, we can obtain the ergodic capacity of DUE k ,

$$C_k = \frac{C_k^{(d)} T_d + C_k^{(u)} T_u}{T_d + T_u} \quad (16)$$

where T_d and T_u are the downlink duration and uplink duration of DUE k , respectively.

3 Numerical Results and Discussion

3.1 Simulation setup and parameter setting

In our simulations, we consider that DUEs randomly locate in the cell with a radius of R and the transmitter of a DUE pair locates in the circle with a center at the receiver of the DUE pair and radius equal to L . Due to the randomness of the positions of UEs, it is very difficult to obtain the exact value of the ergodic capacity in the real D2D communications. The Monte Carlo simulation is adopted in this paper. Simulation parameters are summarized in Tab. 1.

Tab. 1 Simulation parameters

Parameter	Value	Parameter	Value
R/m	500	$P_T/\mu\text{W}$	1
N_0/dBm	-105	$\frac{P_R}{N_0}/\text{dB}$	10
Path loss factor	4	Run times	10 000

3.2 Numerical results

Fig. 2 shows the CDF of the SINR of the DUEs with $L = 20, 100$. Fig. 2 (a) shows the CDF during the uplink period. Obviously, the SINR of the DUEs becomes smaller with the increase of L . The reason is that the longer the distance between the transmitter and receiver of a DUE pair, the smaller the received signal at the receiver. Meanwhile, given the L , we can see that the SINR becomes smaller with the increase of the numbers of CUEs and DUE pairs in the network. Under the condition of a certain N , the increase of M slightly leads to the decline of the SINR. In other words, the DUE pairs introduce less interference into the network due to their low trans-

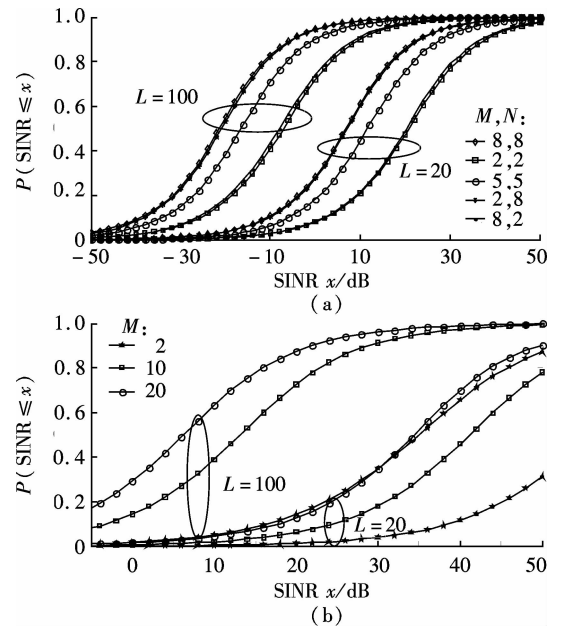


Fig. 2 CDF of the SINR of the DUEs. (a) Uplink; (b) Downlink

mitting powers compared with the CUEs. Therefore, we can see that the number of CUEs plays a dominant role. Fig. 2(b) shows the CDF of the SINR during the downlink period. Likewise, the SINR of the DUEs becomes smaller with the increase of L . During the downlink period, one DUE only receives the interference from other DUEs. Therefore, given the L , the SINR of the DUEs becomes smaller only with the increase in the numbers of the DUE pairs in the network. Meanwhile, we compare the case that $M=2$, $L=100$ with the case that $M=20$, $L=20$, and see that their SINR values are similar. This means that we can decrease L so as to increase the number of the DUE pairs while maintaining a certain SINR.

Fig. 3 demonstrates the average ergodic capacity of the DUEs with $L=20, 50, 100$. Fig. 3(a) shows the average ergodic capacity during the uplink period. Clearly, with the increase of L , the average ergodic capacity becomes smaller because the received signal power at the DUE is smaller with the bigger L . Also, given the L , the average ergodic capacity becomes smaller with the increase in the numbers of CUEs and DUE pairs. Similarly, the number of the CUEs plays a dominant role due to the low transmission powers of the DUEs. Fig. 3(b) shows the average ergodic capacity during the downlink period. Similarly, the average ergodic capacity becomes smaller with the increase of L . Under the condition of a certain L , the average ergodic capacity decreases with the increase of the number of the DUEs pairs in the network.

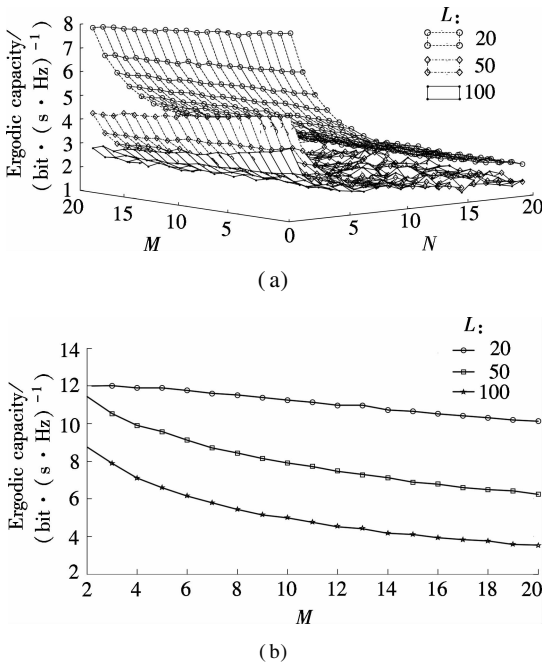


Fig. 3 Average ergodic capacity of the DUE pair. (a) Uplink; (b) Downlink

4 Conclusion

In this paper, a D2D system model where M DUE pairs and N CUEs coexist is described. Then the CDF and

PDF formulae of the SINR of the DUEs are presented. Based on the SINR formulae, the average ergodic capacity of the DUEs in D2D communications is analyzed and the corresponding formulae are derived. The simulation results show that DUEs can still obtain a high ergodic capacity even in the case of a large number of DUEs. This result can be applied to the design and optimization of D2D communications.

References

- [1] Doppler K, Rinne M, Wijting C, et al. Device-to-device communication as an underlay to LTE-advanced networks [J]. *IEEE Communications Magazine*, 2009, **47**(12): 42 – 49.
- [2] Yu C H, Doppler K, Ribeiro C B, et al. Resource sharing optimization for device-to-device communication underlying cellular networks [J]. *IEEE Transactions on Wireless Communications*, 2011, **10**(8): 2752 – 2763.
- [3] Min H, Seo W, Lee J, et al. Reliability improvement using receive mode selection in the device-to-device uplink period underlying cellular networks [J]. *IEEE Transactions on Wireless Communications*, 2011, **10**(2): 413 – 418.
- [4] Xu X, Sun J, Shao S. Transmission capacity of D2D communication under cellular networks [C]// *International Conference on Computer Networks and Communication Engineering*. Beijing, China, 2013: 375 – 379.
- [5] Liu Z, Peng T, Chen H, et al. Optimal D2D user allocation over multi-bands under heterogeneous networks [C]// *IEEE Global Communications Conference*. Anaheim, USA, 2012: 1339 – 1344.
- [6] Min H, Lee J, Park S, et al. Capacity enhancement using an interference limited area for device-to-device uplink underlying cellular networks [J]. *IEEE Transactions on Wireless Communications*, 2011, **10**(12): 3995 – 4000.
- [7] Kaufman B, Lilleberg J, Aazhang B. Spectrum sharing scheme between cellular users and ad-hoc device-to-device users [J]. *IEEE Transactions on Wireless Communications*, 2013, **12**(3): 1038 – 1049.
- [8] Golrezaei N, Molisch A F, Dimakis A G, et al. Femto-caching and device-to-device collaboration: a new architecture for wireless video distribution [J]. *IEEE Communications Magazine*, 2013, **51**(4): 142 – 149.
- [9] Gupta P, Kumar P R. The capacity of wireless networks [J]. *IEEE Transactions on Information Theory*, 2000, **46**(2): 388 – 404.
- [10] Patel C S, Stuber G L, Pratt T G. Comparative analysis of statistical models for the simulation of Rayleigh faded cellular channels [J]. *IEEE Transactions on Communications*, 2005, **53**(6): 1017 – 1026.
- [11] Koutitas G, Karousos A, Tassioulas L. Deployment strategies and energy efficiency of cellular networks [J]. *IEEE Transactions on Wireless Communications*, 2012, **11**(7): 2552 – 2563.
- [12] Goldsmith A. *Wireless communications* [M]. Cambridge: Cambridge University Press, 2005: 56 – 58.
- [13] Amari S V, Misra R B. Closed-form expressions for distribution of sum of exponential random variables [J]. *IEEE Transactions on Reliability*, 1997, **46**(4): 519 – 522.
- [14] Rappaport T S. *Wireless communications: principles and practice* [M]. Englewood, NJ, USA: Prentice Hall PTR, 1996: 102 – 106.

蜂窝网络下 D2D 通信的遍历容量分析

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摘要:针对蜂窝网络下 D2D 通信系统提出了一种遍历容量分析方法. 首先, 对蜂窝网络下 D2D 通信模型进行了概述, 并分析了其上行时隙和下行时隙的干扰情况. 在 D2D 通信系统中很难得到瞬时的信道状态信息, 故假设基站和终端仅知道统计的信道状态信息, 且信道系数服从独立复高斯分布. 基于上述假设, 针对上行时隙得出 DUE 的信干噪比(SINR)表达式, 并基于该公式推导出 DUE 的 SINR 的概率分布函数和概率密度函数, 最终推导出 DUE 的上行遍历容量. 利用相同方法, 推导出下行遍历容量. 仿真结果表明, 即使存在较多 DUE 情况下仍然可以取得较高的遍历容量. 研究结果可用于 D2D 通信系统的设计与优化.

关键词:D2D; 遍历容量; 蜂窝网

中图分类号:TN915