Traffic Analysis of a Networks based on Stochastic Geometry to Exclude Malice Flow

Jiahao Dai* and Xiaofeng Xu*

Science and Technology on Communication Information Security Control Laboratory
China Electronic Group Corporation No.36 Institute, Zhejiang Jiaxing, China
Email: 1527586977@qq.com, 554171641@qq.com

Abstract. Based on stochastic geometry, this paper proposes a mathematical method to estimate the traffic in a D2D based cellular network. The purpose is to determine the normal flow of network to exclude heterogeneous Darknet flow (Tor network). Different from previous work, we assume there are two different kinds of receivers, cellular receivers and D2D receivers, each D2D receiver with its D2D trunking constitutes a D2D pair. We assume that the traffic can be generated in the transmission between a BS and a cellular receiver and that between a D2D trunking and a D2D receiver if and only if the received power is larger than a threshold and the rate in the transmission is above a specified rate. The framework is tractable and able to help us analyze how different parameters influence the network traffic. What’s more, we can give the optimal scheme to achieve the maximal network traffic. At the same time, if the results calculated by this paper proposed or traditional formula is not matched, we think that the flow rate may be heterogeneous traffic, such as darknet flow(Tor).

1. Introduction
In recent years, with the rapid growth of receivers and the explosive increase of data traffic, the existing network architecture has been greatly impacted. According to the 2017 Cisco Complete VNI [1], the internet traffic of per month, per receiver will up to 43 GB by 2021. Therefore, in order to achieve better network monitoring and network management, traffic statistics and prediction have become an important part of network security management technical methods. Through the modeling of historical traffic, a constantly relevant network traffic model is established to predict the network traffic interval in the future.

In the existing literature, researchers through the in-depth analysis of network traffic, from the summary of fractal, periodic and chaotic characteristics, application of fractal, multifractal, time series analysis, wavelet analysis, neural networks, chaos theory, etc. A variety of technical means to describe and analyze traffic. Such as: Sabyasachi Basu et al. [2] proposed a time series model suitable for network traffic prediction based on the ARMA (Auto Regression Moving Average Model) model; Rudolf H. Riedi et al. [3] used multi-fractal wavelet model to realize the prediction of network traffic. Yu Jian et al. [4] used adaptive particle swarm optimization to optimize the Elman neural network, which improved the prediction accuracy of network traffic.

Although the above research has reached the goal of network modeling, it has not been able to fully and effectively reflect the state of network behavior and traffic characteristics. For example, the traditional statistical forecasting model (ARMA) is based on rigorous mathematical theory and can characterize short correlation and long correlation, but decreases in accuracy as the step size increases during the prediction process. The neural network as a non-stationary model can compensate for the fact that the stationary model cannot characterize the non-stationary flow defect, but what kind of
neural network is selected in the prediction, and the neural network has no exact structure of the layer structure and number of neurons theoretical basis.

Figure 1. A cellular network with cellular receivers and D2D receivers.

Therefore, we propose a practical network scenario and give a mathematical method to calculate the traffic for a tagged receiver. On the contrary, if the results calculated by this paper proposed or traditional formula is not matched, we think that the flow rate may be heterogeneous traffic, such as darknet flow (Tor). In this scenario, we develop a traditional cellular network, assuming that there are two kinds of receivers, cellular receivers and D2D receivers. Device-to-device (D2D) communication [5] is a key technique in the 5G network to proposed to solve the problem that the network resources are limited. With the help of stochastic geometry [6], we model a network scenario to analyze the network traffic.

The rest of the paper is organized as follows: Section II introduces the network model, channel model, and transmission model. Section III analyzes the measurement of traffic of a tagged receiver. The viability of our proposed framework is demonstrated via numerical and simulations in Section IV. Finally, we conclude the whole paper in Section V.

2. System model

2.1 Network Model

In our article, we consider single-layer BSs and focus on the situation of downlink transmission. As shown in Fig. 1, there are multiple BSs, cellular receivers, D2D trunkings, and D2D receivers located in a downlink cellular network randomly. Cellular receivers and D2D trunkings can receive message from the nearest BS. A D2D delay and a D2D receiver, which is fixed distance $d$ from the D2D receiver, constitute a D2D pair. The D2D receiver can only receive message from the pairing trunking, and the pairing trunking first receives the message from the BS. That is, the cellular receiver receives message with one hop and the D2D receiver receives message with two hops. For simplicity, the cellular link and the D2D link are respectively represented by the link between the BS and the cellular receiver or the D2D trunking and the link between the D2D pair.

To facilitate the formulation of the scenario, we assume that the position of the BS follows the uniform Poisson Point Process (PPP) $\Phi_0$ of the density $\lambda_0$ and causes the Poisson-Volnoy (PV) cell tessellation in the plane. The positions of the cellular receiver and the D2D trunking are distributed in the network according to the other two homogenous PPP $\Phi_1$, $\Phi_2$ of the densities $\lambda_1$ and $\lambda_2$, respectively. We use constant $p_1$ (or $p_2$) to represent the transmit power of the BS (or to represent transmit power of the D2D trunking).

2.2 Channel Model

General power law propagation is a means for the expression of path loss in cellular links and D2D links. Specifically, assuming that the fading coefficient $h$ of the exponential distribution represents the channel gain, the signal power received at a distance $r$ can be expressed as $\text{ph}^{-\alpha}$, where the path loss exponent $\alpha > 2$ and transmission power $p > 0$. In addition, we use $h_1$, $h_2$ to describe different channel conditions in the cellular and D2D links, respectively, and all channel fading parameters are
independent of each other. Moreover, the constant value $\sigma^2$ is used to describe additive channel noise power.

In a D2D-covered multi-channel cellular network, we divide the resources into $N$ orthogonal channels on average, denoted as $N = \{n_1, n_2, ..., n_N\}$. In these $N$ channels, we take a set of channels, $M = \{m_1, m_2, ..., m_M\}$ ($M < N$), for D2D transmissions. The other $N - M$ channels retain data transmissions for cellular transmissions. Obviously, there are no overlapping channels between cellular transmissions and D2D transmissions.

For traditional transmission pattern, one transmitter-receiver pair uses one channel for transmission, however, when the number of cellular receivers and D2D trunkings is much greater than that of cellular channels, some receivers or trunkings may terminate transmission. Therefore, we use the hybrid access mechanism for cellular transmissions operates as follows: for a tagged BS, when the total number of associated cellular receivers and D2D trunkings is greater than $N - M$, they serve by channel-sharing with time proportion. Otherwise, the BS assigns a unique channel from $N - M$ to each of its cellular receivers randomly. Channel-sharing with time proportion is a method that allows all receivers to communicate with the base station. Specifically, we assume that the receiver can occupy a channel with one slot. The receiver receives the message through channel $n$ and interference will be disturbed by other transmitters using the same channel.

2.3 Transmission Model
Different from previous work, we propose two conditions for a transmission successfully. The first condition is that the power received at point $y$ from point $x$ should be larger than a threshold $P_0 > 0$, otherwise the transmissions break off. Note that if $P_0$ is too small, all of the transmitters can transmit data to the receivers and none of the receivers suffer from outage which necessarily leads to low spectrum efficiency. On the other hand, if the value of $P_0$ is too big, only a small part of receivers can compensate for the path-loss but a large number of receivers suffer from outage. Therefore, the value of $P_0$ should be tuned carefully. The second condition is that the $\ln(1 + \text{SINR}(x,y))$ at point $y$ should be larger than a threshold $C$. In particular, $C$ determines the traffic. Therefore, the two conditions can be expressed as:

$$\left\{ \begin{array}{l} P_x h_y d(x, y) > P_0 \\ \ln(1 + \text{SINR}(x, y)) > C. \end{array} \right.$$

(1)

3. Traffic Measurement
3.1 Basic Results
Noticed that the BS chooses a subchannel for transmission randomly, the probabilities of subchannel being selected are similar, which is described by

$$p = \frac{1}{N - M} \sum_{i=0}^{\infty} \min\{i, N - M\} \rho(i),$$

(2)

Where

$$\rho(i) = \left( \frac{\gamma^2}{\pi} \lambda_0 \right)^i \exp\left( \frac{-\pi \lambda_0 v}{p_1} \right),$$

(3)

is the probability of having $i$ cellular receivers connecting with a BS. The detailed derivations of (3) can be found in [7].

In a single-tier downlink cellular network, the distance between BSs and cellular receivers is not a fixed value. That is, $\xi_1$, the probability that the received power is greater than a threshold in cellular transmissions, depends on the transmit power, channel gain and transmission distance, can be determined as

$$\xi_1 = \Pr(p_1 h_1 r^{-\alpha} > P_0)$$

$$= E_r \left[ \Pr \left( h_1 > \frac{P_0 r^{-\alpha}}{p_1} \right) \right]$$

$$= \pi \lambda_0 \int_0^{\rho_0} \exp \left( -\pi \lambda_0 v - \frac{\mu P_0}{p_1} r^{-\alpha} v^2 \right) dv.$$  

(4)
Different from the cellular transmissions, the received power in D2D transmissions only depends on the channel gain as the transmit power and transmission distance will not change in the transmissions. Therefore, the probability that the received power is greater than a threshold in D2D transmissions can be described by

\[
\mathcal{P}_c = \text{Pr}\left(\frac{p_2 h_2 d^{-\alpha}}{P_0} > \frac{P_0}{p_2}\right) = \text{Pr}\left(\frac{h_2}{\frac{P_0}{p_2}} > \frac{1}{\frac{P_0}{p_2}}\right) = \exp\left(-\frac{\mu P_0 d^\alpha}{p_2}\right).
\]

(5)

According to the conclusion of [8], the Laplace transform of interference measured at the receivers can be expressed by

\[
\mathcal{L}(\chi) = \exp\left(-\frac{\pi \lambda_0}{\chi p} \frac{2 \int_0^\infty \frac{1}{r^2(x^2+1)} \frac{1}{x^2} \frac{1}{x} \text{d}x}{\pi^2} \right).
\]

(6)

3.2 Traffic

In the cellular network, we use \( R_1 \) and \( R_2 \) to represent the rate of cellular links and D2D links, respectively. Note that for a tagged D2D receiver, the rate depends on the lower one between the rate of cellular link and that of D2D link. \( \frac{\lambda_1}{\lambda_1 + \lambda_2} \) and \( \frac{\lambda_2}{\lambda_1 + \lambda_2} \) denote the proportion of cellular receivers and the proportion of D2D receivers, respectively. \( \Delta t \) represents the transmission time. Therefore, the traffic received at a receiver can be expressed by

\[
T_{\text{total}} = \left\{ \frac{\lambda_1}{\lambda_1 + \lambda_2} R_1 \xi_1 + \frac{\lambda_2}{\lambda_1 + \lambda_2} \min(R_1, R_2) \xi_2 \right\} \Delta t\]

(7)

First, we analyze the rate of cellular links, \( R_1 \). For a tagged cellular receiver, the rate is consist of two parts, \( \omega \), the time of a cellular receiver occupied the channel and \( \tau \), the rate of a cellular receiver in a time slot. According to the method of channel-sharing with time proportion, \( \omega \) is given by

\[
\omega = \frac{\sum_{i=1}^{N-M} \rho(i)}{1 - \rho(0)}
\]

(8)

as the frequency resources are evenly divided into \( N \) orthogonal channels, we can use \( 1/N \) to represent the frequency bandwidth of a single channel, therefore \( \tau \) can be expressed

\[
\tau = \frac{1}{N} \mathbb{E}[\ln(1 + \text{SINR})] = \frac{1}{N} \int_0^\infty e^{-\pi \lambda_0 r^2} 2\pi \lambda_1 r \int_0^\infty \text{Pr}\left[\ln\left(1 + \frac{p_1 h_1 r^{-\alpha}}{\sigma^2 + I}\right) > C\right] \text{d}C \text{d}r
\]

\[
= \frac{1}{N} \int_0^\infty e^{-\pi \lambda_0 r^2} 2\pi \lambda_1 r \int_0^\infty \text{Pr}\left[h_1 > \frac{r^2 \sigma^2 + I}{p_1}\right] \text{d}C \text{d}r
\]

\[
= \frac{1}{N} \int_0^\infty e^{-\pi \lambda_0 r^2} 2\pi \lambda_1 r \int_0^\infty \exp\left(-\frac{\mu r^2 \sigma^2 (e^C - 1)}{p_1}\right) \text{d}C \text{d}r
\]

(9)

where \( L = \mathcal{L}\left(-\frac{\mu r^2 \sigma^2 (e^C - 1)}{p_1}\right) \). Therefore, rate of cellular links can be calculated as \( R_1 = \omega \tau \).

As for the rate of D2D links, the rate can be expressed by

\[
R_2 = \frac{1}{N} \int_0^\infty \exp\left(-\frac{\mu d^a \sigma^2 (e^C - 1)}{p_1}\right) \mathcal{L}\left(-\frac{\mu d^a \sigma (e^C - 1)}{p_1}\right) \text{d}C,
\]

(10)

the derivation of (10) is similar. Substituting (9) and (10) into (7), the traffic received at a receiver is obtained.
Table 1. Simulation parameters

| Parameter                                      | Value         |
|-----------------------------------------------|---------------|
| Density of BSs ($\lambda_0$)                 | 1 BS/km²      |
| Density of cellular receivers ($\lambda_0$)   | 20 UE/km²     |
| Density of D2D trunkings ($\lambda_0$)       | 20 UE/km²     |
| Transmit power of BSs ($p_1$)                | 46 dBm        |
| Transmit power of D2D trunkings ($p_2$)       | 24 dBm        |
| Path loss exponent ($\alpha$)                | 4             |
| Distance between a D2D trunking and a D2D receiver ($d$) | 40 m          |
| Mean channel gain ($\mu$)                    | 1             |
| The sum of channels for both cellular transmissions and D2D transmissions ($N$) | 40            |
| Additive channel noise power ($\sigma^2$)    | 0             |
| Simulation time slot ($\Delta t$)            | 10 s           |

Figure 2. Theoretical results and simulation results under different simulation time $\Delta t$, with $\lambda_0 = 1$ BS/km².

Figure 3. Impact of $\lambda_2/\lambda_1$ on the traffic of a tagged receiver in the network with different D2D distance $d$.

4. Numerical Results

4.1 Parameter Settings

In this section, extensive numerical results which are obtained from our analytical framework as well as simulations are presented to illustrate the traffic in the network. All the network parameters are selected according to the LTE instruction and we set the BSs and receivers in a circular region of area 25 km². Table 1 shows the detailed description of the simulation parameters unless otherwise stated. All simulations are performed by MATLAB and the values are averaged over 10000 simulation iterations.

4.2 Model Validation

We validate the theoretical results of traffic from (7) against simulation experiments. We use lines and dots to represent the theoretical results and simulation results, respectively, with all network parameters adopted as in the previous subsection. One can easily observe from Fig. 2 the analytical and simulation results are almost identical for all the different settings of $\lambda_1$ and $\lambda_2$, which means that our stochastic geometry based theoretical framework can be used to efficiently characterize the interference behavior of considered network. In the following subsection we use our analytical framework to explore the traffic changement.
4.3 Traffic
We summarize the relationship between traffic and $\lambda_2/\lambda_1$ in Fig. 3. The dashed curve and the dashed curve can be easily found keep constant and then drops monotonously. The reason is that for D2D receivers, the traffic depends on the minimum rate between the cellular links and the D2D links. As the number of D2D receivers in the network increases, the D2D links rate slows down. When the D2D rate $R_2$ is not greater than the cellular rate $R_1$, the average rate decreases, then the traffic decreases. Interestingly, when $d = 0.08$ km, the traffic maintains a fixed value, because no matter how much the $\lambda_2$ is, the D2D link traffic is always larger than that of the cellular link.

Fig. 4 illustrates how the traffic varies with the sum of channel number $N$. It is very interesting to observe that there exists an optimal setting resulting in a maximum traffic. This is because with $N$ increasing, the frequency bandwidth of a single channel decreases but the time of a channel occupied by cellular receivers or D2D trunks increases.

Fig. 5 shows the relationship between the traffic and the number of D2D channels $M$ in the condition of the sum channels $N = 40$. Obviously, for different spatial densities of BS $\lambda_0$, there also exists optimal settings of $M$ to achieve the maximum traffic. The reason is that with $M$ increasing, the traffic of cellular links decreases but the traffic of D2D links increases, which leads to high traffic in cellular transmission and low traffic in D2D transmission.

5. Conclusions
This paper provided a stochastic geometry based theoretical framework to analyze the network traffic for a proposed D2D cellular network to exclude heterogeneous flow. We first derived the theoretical results of traffic, then validated them by extensive simulation results. The analysis has revealed that different parameters, such as $\lambda_2/\lambda_1$, $N$, $M$ can affect the traffic in quite different ways. Furthermore, our results have shown that there exists optimal resources allocation to achieve the optimal network traffic.

6. References
[1] Cisco, “Cisco visual networking index: Forecast and methodology, 2016-2021,” May 2017.
[2] B. S and M. A., “Time series models for internet traffic,” Technical Reprot CIT-CC-95-27, Georgia Institute of Technology, 1996.
[3] R. H. R, M. S. C, and V. J. R., “A multifractal wavelet model with application to network traffic,” IEEE Transactions on Information Theory, vol. 45, no. 3, pp. 992–1018, 1999.
[4] Y. Jian and G. Ping., “Application of optimized elman neural network to network traffic prediction,” Computer Engineering and Design, vol. 29, no. 17, pp. 4531–4534, 2008.
[5] A. Asadi, Q. Wang, and V. Mancuso, “A survey on device-to-device communication in cellular networks,” IEEE Communications Surveys and Tutorials, vol. 16, no. 4, pp. 1801–1819, 2014.
[6] D. Stoyan, W. S. Kendall, and J. Mecke, *Stochastic Geometry and its Applications*. Wiley, 1995.

[7] Y. Zhong and W. Zhang, “Multi-channel hybrid access femtocells: A stochastic geometric analysis,” *IEEE Transactions on Communications*, vol. 61, no. 7, pp. 3016–3026, 2013.

[8] J. Andrews, F. Baccelli, and R. Ganti, “A tractable approach to coverage and rate in cellular networks,” *IEEE Transactions on Communications*, vol. 59, no. 11, pp. 3122–3134, 2011.