Congestion Control of Multi-layer Cellular Networks based on Modeling of Transmit Power

Jiahao Dai1,*, Yongqun Chen2, Yucheng Chen3 and Aodong Meng4
1,2,3,4Science and Technology on Communication Information Security Control Laboratory
1,2,3,4China Electronic Group Corporation NO.36 Institute, Zhejiang Jiaxing, China

*Corresponding author email: 1527586977@qq.com

Abstract. The explosive growth of network traffic and the limited storage node resources make the existing network architecture bear great pressure, and network congestion appears in work and life from time to time. In order to ensure the timeliness and effectiveness of the network, we propose a congestion control method based on transmission power. Different from previous work, we built a multi-layer cellular network consisting of multiple macro stations, small base stations and mobile terminals. On this basis, we establish a congestion control model based on the mixed queuing model of service window and calculate the input/output rate and congestion. Finally, we use simulation to verify the effectiveness of the congestion model. The network builder can use our model to set the appropriate power of macro stations and small base stations to ensure network stability.

Keywords: Multi-layer cellular, networks congestion control, downlink.

1. Introduction

In recent years, the Internet has been rapidly developed and applied in our life, and has become an indispensable part of people's life. With the development of countries in the world in the political, economic and cultural fields, the network plays an important role in these fields, driving the development of politics, economy and culture. According to China's most authoritative report on network security, the Statistical Report on The Development of the Internet in China [1], the number of users of applications such as network broadcast, network music and network video has increased by over 30 million in half a year, and the number of users of online education has reached 232 million as of June 2019. With the impact of the COVID-19 outbreak earlier this year, more and more schools are implementing online courses, and the Internet traffic is bound to explode. However, the resources of store-and-forward nodes deployed in the network architecture are limited, and the explosive growth of network traffic will inevitably lead to the decline of network performance, namely, network congestion.

Multilayer cellular networks [2] is in the traditional network composed of a center station to add some small, composed of base station and a large number of small stations deployed in the network, help reduce center station communication load, enlarge the capacity of system, improve data transmission rate, increase indoor coverage, improves the performance of the center station coverage blind spots, improve the quality of edge user. Compared with the traditional macro cellular base stations, these Small base stations are characterized by Small size, Small coverage, low power consumption and Small transmission power. In wireless communication systems, they are called Small cells. Compared with the traditional macro cellular network, it has many advantages, including improving the wireless
coverage, increasing the total capacity of the system, saving the system energy consumption and improving the utilization of spectrum resources.

In order to avoid the blindness of PID parameter setting trial and error method in Internet router active queue management, literature [3] proposed immune hybrid particle swarm algorithm for PID controller parameter optimization, and constructed an intelligent active queue PID algorithm based on immune hybrid particle swarm optimization. In literature [4], a fair congestion control algorithm based on media sharing is proposed. Nodes calculate the regression rate according to the regression times of competing Shared channels, and then obtain the packet discarding probability, so as to reasonably control the packet sending rate of source nodes and solve the throughput degradation caused by Shared media conflicts and congestion. Literature [5] proposes a link layer hop congestion control algorithm based on pricing mechanism. This algorithm takes MAC time limit and binary ten disturbance model limit into consideration and introduces the transmission failure rate into the congestion price function as one of the control criteria of network congestion.

Although some congestion control methods have been proposed in many literatures, these methods only consider network congestion in simple network environment. Therefore, in this article, we first established a complex cellular networks, two layer is composed of acer station, small base stations and mobile terminals, and then based on FuWuChuang unregular queuing model congestion control model is established, the transfer rate is calculated on the basis of this, finally find the optimal network performance through the simulation of acer stations and small transmission power of base station.

### 2. System Model

#### 2.1. Network Model

In our work, we consider the downlink case of a two-tier cellular network. As shown in Figure 1, several macro stations, small base stations and mobile terminals are randomly located in the downlink cellular network. Each base station is associated with the nearest macro station, which means that the base station can only receive messages from the nearest macro station, thus building the first layer of cellular network. Similarly, a mobile terminal can only receive messages from the nearest small base station, building a second layer of cellular networks.

![Two-layer cellular network model.](image)

In order to facilitate the consultation, we assume that acer standing position follow density $\lambda_M$ of homogeneous poisson point process (PPP) $\Phi_M$. Small base stations and mobile terminal location respectively according to the density of $\lambda_S$ and $\lambda_T$ two other similar to the PPP $\Phi_S, \Phi_T$ distribution in the network. We use the constants $P_M$ and $P_S$ respectively to represent the transmitted power of a macro station and a small base station.
The standard power loss propagation model is a method to express the path loss in communication link. Where, path loss index \( \alpha > 2 \). As for the effect of random channel frailty and shadow, we assume that the mean value of Rayleigh frailty between a macro station and a small base station, and between a small base station and a mobile terminal in general is 1, and the fading coefficient \( h \) of exponential distribution represents channel gain. In this case, the signal power received at distance \( r \) can be expressed as \( prr^{-\alpha} \). Furthermore, we assume that channel resources are sufficient to ensure that all base stations and mobile terminals receive messages. All the results are for single transmit and single receive antennas, which can be expanded to multiple antennas in the future.

For a receiver, jamming signal \( J \) is a signal received from a base station other than the nearest one. There is no interference in the same cell, such as orthogonal multiple access within the cell. Noise is expressed as a constant \( \Delta^2 \) but there is no specific pattern of distribution.

2.2. Congestion Control Model

It can be seen that one of the important reasons for packet loss is that the node cache space is overflowed due to too fast data transmission. Therefore, according to the changes of node cache and local network data flow, the above reasons are evaluated, and the rate control is carried out in advance before the phenomenon of packet loss occurs.

Since there is no interference in the same cell, we only consider the flow of a single node, and adopt the pre rate control method to avoid congestion. When the single node storage space \( L < L_{\text{max}} \) (L is the current occupied space of the node, \( L_{\text{max}} \) is the rate adjustment value), we consider that the node does not appear congestion. When \( L_{\text{max}} < L < m \) (M is the maximum storage space of the node). It is considered that the network may be congested, so adjust the data forwarding rate to avoid congestion.

As the storage space of nodes is limited, the single service window hybrid queuing model M/M/1/ m [6] is adopted to analyze the input and output rates of each node, and its stable state is shown in Figure 2.

![Node steady state](Image)

According to the figure, the steady-state equation of the model is:

**State 0**

\[ \omega^k_i(t) \times p_0 = \mu^k_i(t) \times p_1 \Rightarrow p_1 = \omega^k_i(t)/\mu^k_i(t)p_0 = \rho p_0 \quad \rho = \omega^k_i(t)/\mu^k_i(t) \]

**State 1**

\[ \omega^k_i(t) \times p_1 = \mu^k_i(t) \times p_2 \Rightarrow p_2 = \omega^k_i(t)/\mu^k_i(t)p_0 = \rho^2 p_0 \]

**State m-1**

\[ \omega^k_i(t) \times p_{m-1} = \mu^k_i(t) \times p_m \Rightarrow p_m = \omega^k_i(t)/\mu^k_i(t)p_{m-1} = \rho^m p_0 \]

Then
\[
1 = \sum_{\eta=0}^{m} p_\eta = \sum_{\eta=0}^{m} \rho^\eta p_0 = \frac{1 - \rho^{m-1}}{1 - \rho} p_0
\]

and

\[
p_0 = \frac{1 - \rho}{1 - \rho^{m-1}}
\]

therefore

\[
p_L = \frac{1 - \rho}{1 - \rho^{m-1}} \times \rho^L \quad L = 1, 2, ..., m
\]

According to the literature, in the mobile ad hoc network, if the node cache occupies a certain threshold \(L_{\text{max}}\) of its cache space, the node may be congested, and the probability of node congestion is

\[
P_{\text{con}} = \sum_{L=L_{\text{max}}}^{m} \left( \frac{1 - \rho}{1 - \rho^{m+1}} \times \rho^L \right)
\]

Congestion may occur when the node stores state \(L > L_{\text{max}}\), so the input/output rate of the small base station needs to be adjusted accordingly to

\[
\rho = \frac{m - L}{m - L_{\text{max}}} \times \rho
\]

### 2.3. Transmission Rate Control Model

For any small base station, the probability of congestion depends mainly on the input and output rates. Input rate refers to the rate at which the macro station transmits data to the small base station [7], i.e

\[
\omega = E[\ln(1 + \text{SINR}_{M-S})]
\]

\[
= \int_0^\infty \exp(-\pi\lambda_M r^2) \int_0^\infty \exp(-\mu^2 \pi P_M^{-1} r^2 (e^t - 1)) L_{t_r}(\mu P_M^{-1} r^2 (e^t - 1)) dt 2\pi\lambda_M r dr
\]

and

\[
L_{t_r}(\mu P_M^{-1} r^2 (e^t - 1)) = \exp(-\pi\lambda_M P_M^{-2} \pi^2 (e^t - 1)^2/\alpha) \int_{(e^{t-1})^{-2/\alpha}}^{\infty} \left( \frac{1}{1 + x^{\alpha/2}} \right) dx
\]

As for the output rate, that is, the input rate of the mobile terminal, i.e

\[
\tau = E[\ln(1 + \text{SINR}_{S-T})]
\]

\[
= \int_0^\infty \exp(-\pi\lambda_S r^2) \int_0^\infty \exp(-\mu^2 \pi P_S^{-2} r^2 (e^t - 1)) L_{t_r}(\mu P_S^{-1} r^2 (e^t - 1)) dt 2\pi\lambda_S r dr
\]

and

\[
L_{t_r}(\mu P_S^{-1} r^2 (e^t - 1)) = \exp(-\pi\lambda_S P_S^{-2} \pi^2 (e^t - 1)^2/\alpha) \int_{(e^{t-1})^{-2/\alpha}}^{\infty} \left( \frac{1}{1 + x^{\alpha/2}} \right) dx
\]

When additive channel noise \(\sigma^2 = 0\) and path loss index \(\alpha = 4\)

\[
\rho = \frac{\omega}{\tau} = \frac{\int_0^\infty \frac{1}{1 + P_M^{-2} \sqrt{e^t - 1}} \left( \frac{\pi}{2} - \arctan \left( \frac{1}{\sqrt{e^t - 1}} \right) \right) dt}{\int_0^\infty \frac{1}{1 + P_S^{-2} \sqrt{e^t - 1}} \left( \frac{\pi}{2} - \arctan \left( \frac{1}{\sqrt{e^t - 1}} \right) \right) dt}
\]
3. Simulation Results

3.1. Parameter Setting

In this section, we provide a number of numerical results from our analytical framework and simulations to illustrate congestion control in a network. Select all network parameters according to the LTE instruction, and set the macro station, small base station and mobile terminal in the circular area of 25km². Unless otherwise specified, all parameters are shown in Table 1. All simulations were performed by MATLAB, and these values were averaged over 10,000 simulation iterations.

| parameter                      | value          |
|--------------------------------|----------------|
| Acer station density ($\lambda_M$) | 1 MBS/km²     |
| Base station density ($\lambda_S$)    | 5 SBS/km²     |
| Mobile terminal density ($\lambda_T$)  | 50 MT/km²     |
| Acer Station transmission power ($P_M$) | 5 W – 20 W   |
| Base station transmission power ($P_S$) | 0.5 W – 10 W |
| Path loss index ($\alpha$)           | 4             |
| Channel gain ($\mu$)                | 1             |
| Additive channel noise ($\sigma^2$)  | 0             |

3.2. Simulation Results

Figure 3 shows the value of as the input/output rate of a small base station varies with the power of the macro station and the small base station. The blue line indicates that the power of the macro station rises from 5W to 20W when the power of the small base station remains unchanged. It can be seen that the higher the power of the macro station, the higher the input/output rate ratio of the small base station. In this case, more and more cache space is occupied, which will eventually lead to congestion. The black line indicates that the power of a small base station rises from 0.5W to 10W when the power of the macro station remains unchanged. It can be seen that the larger the power of a small base station is, the smaller the ratio of input and output rates is. When the ratio is less than 1, the less cache space is occupied. The red line divides the result into two parts. Above the red line, the input-output rate ratio is greater than 1, which means that the input is greater than the output, which means that more and more cache space is taken up. So we have to keep the input-output rate below the red line. According to the simulation results, we can find the appropriate power of macro station and small base station.
4. Conclusion
In this paper, we propose a congestion control method for multilayer cellular networks based on transmit power. First, we built a multi-layer cellular network consisting of multiple macro stations, small base stations and mobile terminals. On this basis, we establish a congestion control model based on the mixed queuing model of service window and calculate the input/output rate and congestion. Finally, the simulation results can be used for congestion control to ensure the optimal performance of the network.

References
[1] China Internet Network Information Center. The 43rd Statistical Report on Internet Development in China [J]. Internet World, 2019(7).
[2] Li Shuangchun. Research on energy Saving and Collection Technology in Multi-layer heterogeneous small Cellular Network [D].
[3] Peng Yifei, ZHANG Yingjie. Network Congestion Control Strategy based on Immune Particle Swarm optimization [J]. Journal of Central South University: Natural Science edition, 2011(07):223-228.
[4] Ma Lin, ZHANG Jun, LIU Kai. Congestion Avoidance Strategy of Wireless Ad Hoc Network Based on Media Sharing [J]. Journal of South China University of Technology (Natural Science edition), 2011(09):124-131.
[5] He Rong, Fang Xuming. Congestion control algorithm for wireless multi hop networks based on price mechanism [J]. Journal of Southwest Jiaotong University, 2011.
[6] Xu Xiaofeng. Research on Key Technologies of Routing Trust Evaluation and Data Transmission Control in Wireless Sensor Networks [D]. Beijing University of Posts and Telecommunications.
[7] J. Andrews, F. Baccelli, and R. Ganti, “A tractable approach to coverage and rate in cellular networks,” IEEE Trans. Commun., vol. 59, no. 11, pp. 3122–3134, Nov. 2011.

Figure 3. The relationship between the power of small base station, acer station and $\rho$