Downlink PDMA in the Heterogeneous Network

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Abstract. Non-orthogonal multiple access (NOMA) is considered as a promising multiple access technology, which could satisfy various incremental requirements of the coming fifth generation (5G) mobile communication system. As a novel NOMA scheme based on the joint design of the transmitter and receiver, pattern division multiple access (PDMA) could enhance spectrum efficiency significantly, compared to traditional orthogonal multiple access (OMA) schemes. In this paper, a particular pattern design of downlink PDMA in heterogeneous network is proposed. In overlapping deployment scenario of macro cells and small cells, the downlink signals are transmitted with a novel spatial and power domain superposition pattern. The user pairing and spatial/power allocation schemes are therefore proposed optimizing the pattern design. Analysis and simulation results illuminate the pattern design of downlink PDMA could enhance the spectrum efficiency obviously.

Keywords: Heterogeneous network · Non-orthogonal multiple access
Pattern division multiple access · Superposition

1 Introduction

Radio access technologies (RATs) for mobile communications are typically characterized by multiple access (MA) schemes. MA allows multiple users to access and share the resources simultaneously. From 1G to 4G, MA techniques vary accompanying with the evolution of wireless communication systems, including frequency-division multiple access (FDMA), time-division multiple access (TDMA), code-division multiple access (CDMA), and orthogonal frequency-division multiple access (OFDMA). In orthogonal multiple access (OMA) schemes, different users are allocated with radio resources which are orthogonal in either the time, frequency, or code domain to avoid or alleviate inter-user interference. The above-mentioned MA schemes are all OMA schemes. With simple single-user detection, OMA can achieve good system-level throughput performance in packet-domain services. However, due to the orthogonal resource allocation mechanisms that OMA schemes take, the maximum number of supported users is strictly limited by the finite resources. Besides, it is known that OMA cannot always achieve the sum rate of multiple user wireless communication systems.

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It is anticipated that explosive data traffic increase will happen in 5G era. Besides, 5G needs to support massive connectivity of users, due to new traffic types and data services are emerging, notably machine-to-machine communications to support concepts such as the smart grid, smart homes and cities, and e-health. In order to guarantee the sustainability of the 3rd Generation Partnership Project (3GPP) RATs over the coming Release 14 and onward, new solutions that are competent to meet prospective challenges must be investigated [1]. Different from conventional OMA schemes, non-orthogonal multiple access (NOMA) can support much more users via non-orthogonal resource allocation. NOMA is expected to be adopted to increase system throughput and accommodate massive connectivity. From the perspective of information theory, NOMA outperforms orthogonal multiple access and it is optimal in the sense of achieving the capacity region of the downlink channel. Successive interference cancellation (SIC) is commonly used in the process of the multi-user signal separation on the receiver side [2, 3]. With the robust performance gain, NOMA scheme could be utilized widely in practical deployment [4].

Pattern division multiple access (PDMA), is novel NOMA scheme evolving from SIC amenable multiple access (SAMA), and it is based on the joint design of the transmitter and receiver to optimize of multi-user communication system. Non-orthogonal pattern is utilized to distinguish different users at the transmitter, and SIC is adopted to achieve the quasi optimal multi-user detection at the receiver. A pattern design of PDMA is presented in this paper to satisfy the downlink channel. In overlapped deployment scenario of macro cells and small cells, the paired users are superposed in the same resource blocks and with appropriate power allocation. Simulation results show that both the average and edge throughput have been greatly improved.

The rest of this paper is organized as follows: Sect. 2 describes the system model of downlink PDMA in the heterogeneous network. Section 3 presents the method of user pairing, the spatial superposition scheme and the power allocation scheme of PDMA. Section 4 introduces the detail simulation model and throughput performance. Finally, Sect. 5 concludes the paper.

2 System Model

In this paper, an overlapped deployment of macro cells and small cells is considered as is shown in Fig. 1. Without loss of generality, only one sector of a macro cell is shown. Small cells are randomly distributed in every sector in the form of clusters to provide hotspot coverage. Users are randomly distributed in macro cells and small cells. The users are divided into two kinds: the hotspot users and common users. Hotspot users are distributed in small cells. Hotspot users are also divided into two kinds: the users distributed in the coverage of small cell and the users in the coverage of small cell cluster but not in the coverage of small cells. Macro base station (BS) and small cell BS could be scheduled uniformly. All users are assumed static when we introduce the spatial domain and power domain allocation scheme.

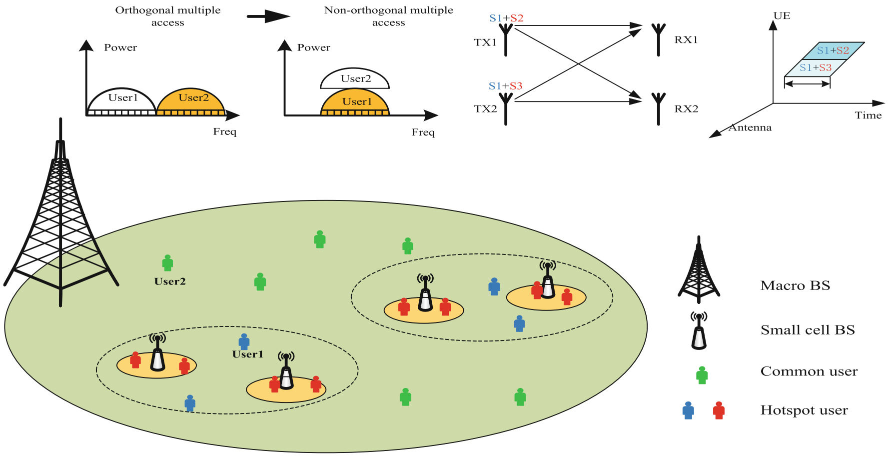

Fig. 1. A overlapped deployment of macro cells and small cells

The basic thought of PDMA is utilizing non-orthogonality of the signal pattern based on power domain, space domain and code domain (jointly or separately) to distinguish signals of different users. And non-orthogonal signals can be separated and detected by SIC receivers effectively. The non-orthogonal transmission on the time-frequency domain realizes the enhancement of spectrum efficiency [5, 6].

The basic principle of PDMA is improving resource utilization through the equivalent diversity. According to the theory of V-BLAST system [7], the equivalent diversity of the ith interference cancellation stage is

$$N_{div} = N_R - N_T + i \tag{1}$$

where N_R denotes the receive diversity and N_T denotes the transmit diversity. The signal processing from transmitter to receiver is shown in Fig. 2.

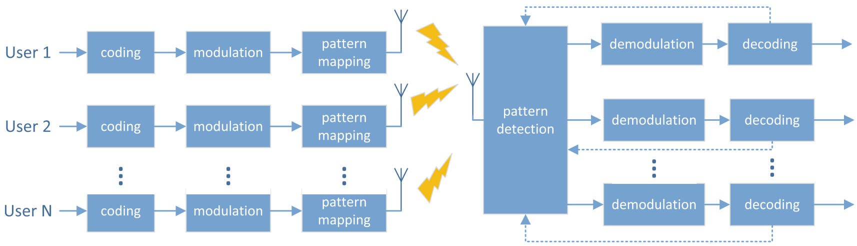

Fig. 2. Signal processing in communication system with PDMA

Multi-user information theory points out that the sum capacity of NOMA scheme could be close to the theoretical limit. The main study point of this paper is applying the PDMA of spatial and power domain to transmitter design in the heterogeneous network. The contents consist the allocation of power, the joint optimization of time-frequency resources combined with power and multiple user clustering. In the power domain PDMA model, User 1 and User 2 are defined as cell-edge user and central user respectively. Different from the orthogonal condition, User 1 and User 2 which are allocated different power in the same frequency band. The spectrum resources are saved in this way with the growth of the corresponding gain. An example is present in Fig. 1 to compare non-orthogonal with orthogonal multi-user access in the power domain. It is assumed that User 1 is the user in the edge small cell cluster and is served by macro BS, and User 2 will be selected from macro BS correspondingly. Macro BS will allocate different transmitted power to User 1 and User 2. If User 1 is served by small cell, the principle is the same. The optimization of spatial resource is also presented in Fig. 1. The data streams are transmitted by the superposed spatial domain.

In the downlink, SIC process is adopted to get the signal of every user. The order of decoding is mainly decided by the decreasing channel gain normalized by noise and inter-cell interference power. Based on the order, it is assumed that any user can correctly decode the signals of any other user which has the prior decoding order before the corresponding user. In this way, the user with higher channel gain could remove the inter-user interference from the user which has the lower channel gain. Assuming successful decoding and no error propagation, every receiver could get the signal accurately.

3 PDMA Transmitter Pattern Design

3.1 User Pairing Strategy

The main research object studied in this paper is the users of the small cell clusters. Cell-edge users and central users are selected by the user pairing strategy. At the initial stage of the system, users access BS according to the reference signal received power (RSRP). Users select their served BS by the formula:

$$BS_{serving}(b) = \underset{b}{argmax}\{SINR_{u,b}\} \tag{2}$$

where b denotes the BS and u denotes the user. Every user selects the served BS according to the polling mechanism. After the selection of BS, the users in the coverage area of small cell cluster which are not in the coverage radius of the small cell are regarded as the cell-edge users. The cell-edge user is called U_{edge} for short. The SIC scheme could separate the mixed signal for the discriminating power allocation. So every cell-edge user will match a central user. The central user is called $U_{central}$ for short. According to the served BS of U_{edge}, the next step is to decide the pairing user to U_{edge}. Because U_{edge} in the small cell cluster but not in the coverage of the small cell, the served BS has two: macro BS and small cell BS. If the served BS of U_{edge} is macro

BS, $U_{central}$ will be chosen from the users served by the macro BS. The selection criteria is shown as follows:

$$\begin{gathered} U_{central} = \underset{m^* \in Mue, m \in Mue,}{argmax} \{\alpha_{m^*,m}\} \\ \alpha_{m^*,m} = \left\| |h_{m^*}|^2 / N_{0,m^*} - |h_m|^2 / N_{0,m} \right\| \end{gathered} \tag{3}$$

where m^* denotes the U_{edge} and m denote the user served by macro BS. m^* and m are in the set of Mue which is the set of users served by macro BS. $|h_{m^*}|^2 \Big/ N_{0,m^*}$ and $|h_m|^2 / N_{0,m}$ express the channel gain respectively. $\alpha_{m^*,m}$ denotes the difference value of the two channel gain.

If the served BS of U_{edge} is small cell BS, $U_{central}$ will be chosen from the users served by the small cell BS. The selection criteria is shown as follows:

$$\begin{gathered} U_{central} = \underset{m^* \in Sue, m \in Sue,}{argmax} \{\alpha_{m^*,m}\} \\ \alpha_{m^*,m} = \left\| |h_{m^*}|^2 / N_{0,m^*} - |h_m|^2 / N_{0,m} \right\| \end{gathered} \tag{4}$$

where m^* denotes the U_{edge} and m denote the user served by small cell BS. m^* and m are in the set of Sue which is the set of users served by small cell BS. $|h_{m*}|^2 / N_{0,m*}$ and $|h_m|^2 / N_{0,m}$ express the channel gain respectively. $\alpha_{m*,m}$ denotes the difference value of the two channel gain.

After the user pairing strategy, every U_{edge} will have a corresponding $U_{central}$. Every $U_{central}$ may have more than one U_{edge}.

3.2 Spatial Domain Enhancement of PDMA

The users in the same group could use the same resources through the design of the pattern in the spatial domain, as shown in Fig. 3(b). In traditional OMA schemes, user 1 sends symbol S1 through antenna TX1, while user 2 sends symbol S2, symbol S3 through antenna TX1, antenna TX2 respectively. However, the performance of the system is poor even SIC receivers are utilized, that TX1 sends S1, S2 simultaneously. In PDMA scheme, simple spatial coding is expected to be adopted. As shown in Fig. 3(b), TX1 sends S1 + S2, while TX2 sends S1 + S3. Thus, S1, S2 and S3 have identical equivalent diversity. The performance of the system can be satisfied by utilizing SIC receivers, for that the data streams on the superposed spatial domain could be separated by the SIC level demodulation. The structure of the spatial pattern is designed as follows:

$$H_{s,2\times 3} = \begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix} \tag{5}$$

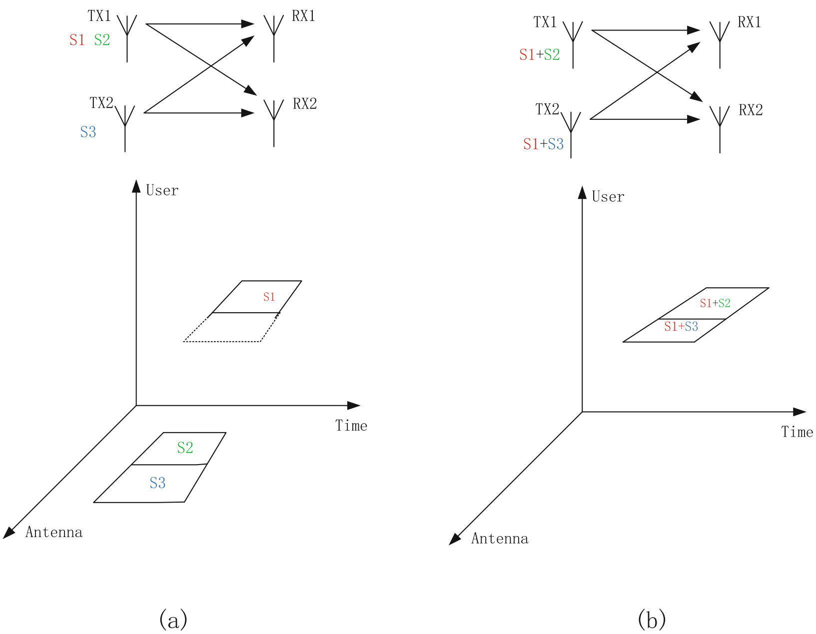

Fig. 3. Illustration of spatial domain scheme with PDMA

3.3 Power Allocation Enhancement of PDMA

The power allocation considers every group of users. It is assumed that the total transmit power $P_b(i_b(k))$ indicates the index of the users. At every sub carrier of bandwidth b is a total of the coded modulation symbols, $d_b(i_b(k))$, of the $i_b(k)$-th user. So the sum signal x_b is superposed as follows:

$$x_b = \sum_{k=1}^{M_b} \sqrt{P_b(i_b(k))} d_b(i_b(k)) \tag{6}$$

where $E\left[|d_b(i_b(k))|^2\right] = 1$ and $P_b(i_b(k))$ is the allocated transmit power to the user $i_b(k)$ at bandwidth b and $\sum_{k=1}^{M_b} P_b(i_b(k)) = P$. The N_r dimensional received signal vector of user $i_b(k)$ at every sub carrier of bandwidth b, $Y_b(i_b(k))$, is represented by

$$\begin{aligned} Y_b(i_b(k)) &= H_{ch}(i_b(k)) * H_s x_b + N_b(i_b(k)) \\ &= H(i_b(k)) x_b + N_b(i_b(k)) \end{aligned} \tag{7}$$

where $H_{ch}(i_b(k))$ is the N_r -dimensional channel coefficient vector of user $i_b(k)$. $H_{ch}(i_b(k))$ consists of distance dependent loss, shadowing loss and instantaneous fading coefficients. $N_b(i_b(k))$ is the N_r -dimensional noise plus inter-cell interference. And $*$means the element-wise product. Let $H = H_{ch} * H_s$.

Assuming that the receiver treats inter-cell interference as white noise, at the receiver maximal ratio combining is applied to $Y_b(i_b(k))$ as follows:

$$\begin{aligned}\tilde{Y}_b(i_b(k)) &= H^H(i_b(k))Y_b(i_b(k))/||H|| \\ &= \sqrt{G_b(i_b(k))}x_b + n_b(i_b(k))\end{aligned} \tag{8}$$

where $G_b(i_b(k)) = \|H(i_b(k))\|^2$ is the combining gain after maximal ratio combining and $n_b(i_b(k)) = H(i_b(k))N_b(i_b(k))/||H_b||$ is the noise plus inter-cell interference after maximal ratio combining. The average power of $n_b(i_b(k))$ is presented as $N_{0,b}(i_b(k)) = E[|n_b(i_b(k))|]^2$. So the $\tilde{Y}_b(i_b(k))$ could be expressed as:

$$\tilde{Y}_b(i_b(k)) = \sqrt{G_b(i_b(k))}\sum_{k=1}^{M_b}\sqrt{P_b(i_b(k))}d_b(i_b(k)) + n_b(i_b(k)) \tag{9}$$

In downlink of the system, the SIC process is implemented at the user receiver. The optimal order for decoding is in the order of decreasing channel gain normalized by noise and inter-cell interference power. It is assumed that any user could correctly decode the signals of other users whose decoding order comes before the corresponding user. Take 3 users for example, User 1, User 2 are the cell-edge users and User 3 is the central user. User 1 and user 3 form user pair 1, while user 2 and user 3 form user pair 2, as illustrated in Fig. 4. Assuming successful decoding and no error propagation, the throughput of User i, Thr_i is represented as

$$Thr_1 = log_2\left(1 + \frac{P_1|h_1|^2}{P_3|h_1|^2 + N_{0,1}}\right) \tag{10}$$

$$Thr_2 = log_2\left(1 + \frac{P_2|h_2|^2}{P_3|h_2|^2 + N_{0,2}}\right) \tag{11}$$

$$Thr_3 = log_2\left(1 + \frac{P_3|h_3|^2}{N_{0,3}}\right) \tag{12}$$

So to get the value of P_i, the sum throughput Thr of User i will be maximized. The expression is shown as follows:

$$Thr = max(Thr_1 + Thr_2 + Thr_3) \tag{13}$$

From (10), (11), (12), it could be seen that power allocation for each user greatly affects the user throughput performance and thus the modulation and coding scheme used for data transmission of each user. So the overall cell throughput, cell-edge throughput, and user fairness are closely related to the power allocation scheme adopted. The exact value of P_i will be got with solving the maximum value of Thr.

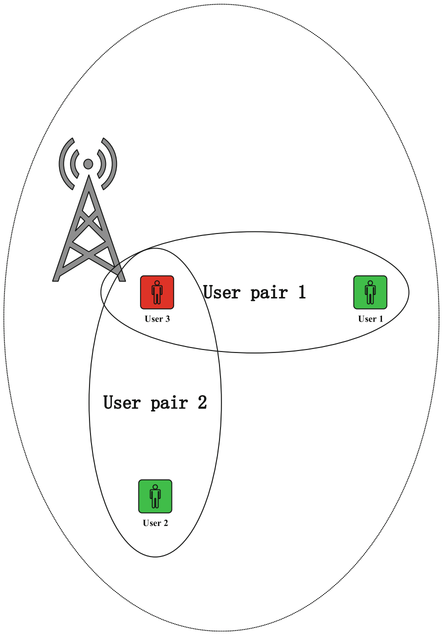

Fig. 4. Illustration of 3 users scenario.

4 Simulation and Analysis

4.1 Simulation Assumptions

We model a heterogeneous cellular network with 19 macro BSs. According to the 3GPP standards [8, 9], macro BS is located in the center of the three hexagonal sectors. The inter-site distance is 500 m. Macro BSs equip with three directional antennas with each antenna covering one sector. In our simulation, there is one small cell cluster randomly distributed in every sector for hotspot deployment. The radius of the small cell cluster is 70 m. There are 4 small cells in every cluster. The small cell BS is located in the center of the small cell. The radius of the small cell is 50 m. The transmitting and receiving antennas are all isotropic antenna in the small cell BSs and users.

Users are dropped randomly with uniform distribution. There are two types of users: common users and hotspot users. Hotspot users are distributed in the coverage area of small cell. Common users are distributed in macro cell. The specific parameters are shown in Table 1.

All the users are stationary, so the total number in each sector remains constant during the simulation.

Table 1. Simulation parameters

Parameter	Statistical characterization
LTE network model	
Cell layout	19 sites/57 sectors
Tx power for macro BS	46 dBm
Tx power for small cell BS	30 dBm
Number of cluster per sector	1
Number of small cell per sector	4
Inter-site distance	500 m
Cluster radius	70 m
Small cell radius	50 m
Carrier frequency	2 GHz
Pathloss model for macro	128.1 + 37.6log(R), R in Kms
Pathloss model for small cell	140.3 + 36.7log(R), R in Kms
Shadowing standard deviation	8 dB
Shadowing correlation distance	50 m
Thermal noise density	−174 dBm/Hz
User model	
Total number of users	60
Hotspot users ratio	2/3
Antenna gain	0 dBi

4.2 Results and Analysis

According to the system level simulation model, we evaluate the system performance of the power allocation scheme with PDMA in power domain. We simulate two representative scenarios for comparison. The scenarios are set as follows:

1. Based on the system model presented in Sect. 2, the system adopts OMA as a comparison scheme. Equal transmission power is allocated to each user.
2. Based on the system model presented in Sect. 2, the signals are transmitted from BS according to the pattern design scheme with PDMA.

The main discriminant standard of system performance is the throughput of the users. So we count user throughput of each scenarios. The cumulative distribution function (CDF) of the user throughput is plotted. Assuming there is one small cell cluster in every sector, the result is shown in Fig. 5.

From the distribution of the user throughput, it is clearly that the pattern design scheme with PDMA really improves the user throughput by more than 20%, more users could get a higher throughput based on the spatial and power domain overlapped transmission. By this way, the total throughput of the system can also be improved correspondingly.

PDMA is more appropriate for multi-user scenarios compared to OMA. With the number of users increasing, pattern design scheme with PDMA will gain more advantages by utilizing non-orthogonal power allocation scheme. From this point of

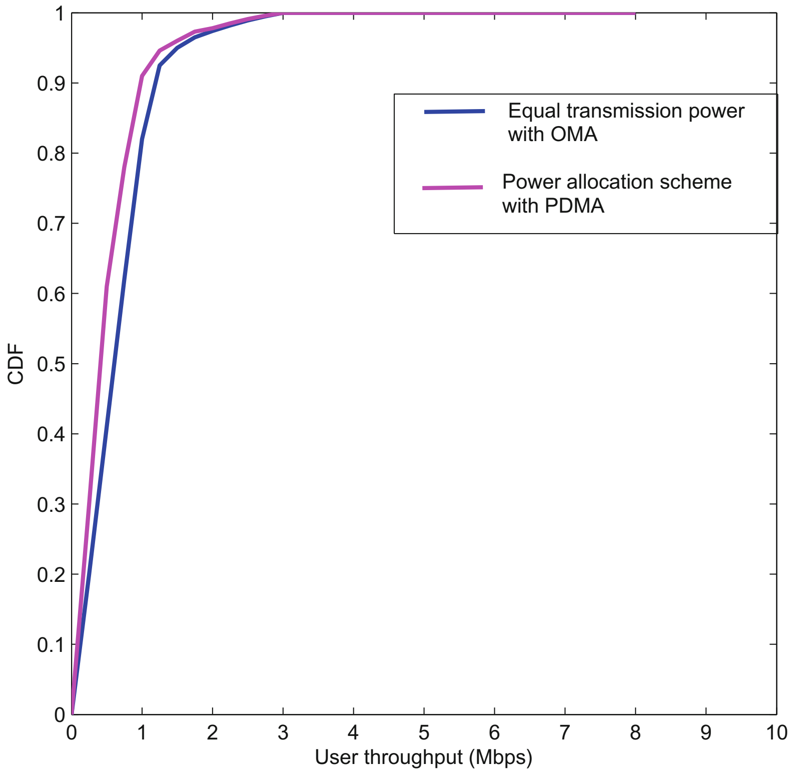

Fig. 5. CDF of users' throughput

view, the pattern design scheme with PDMA is suitable for the dense users distribution case. Moreover, our proposed pattern design scheme with PDMA is of low complexity, which means that it is feasible and cost-effective in practical scenarios.

5 Conclusion

In this paper, we reviewed the multiple access schemes of cellular mobile communications. In the context of 5G, the requirements of further increasing system throughput and supporting massive connectivity prompt the research on NOMA. Some merits of NOMA schemes were listed in this paper. PDMA which is based on the joint-design of the transmitter and receiver could enhance spectrum efficiency and system throughput. The spatial and power domain superposition was considered. In overlapped deployment scenario of macro cells and small cells, the pairing users in the same cluster were superposed in the same resource blocks and allocated with different power. The signals were transmitted with spatial and power domain superposition. The simulation results shed light on the pattern design scheme with PDMA in the heterogeneous network. The CDF of our proposed scheme is superior to that for OMA, and it means that our proposed scheme could enhance the system throughput and have an effect on the following research.

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