A Call Admission Control for Multimedia Traffic in CDMA/TDD System

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Abstract

This paper proposes a Call Admission Control (CAC) scheme for multimedia services in Code Division Multiple Access (CDMA) with Time Division Duplex mode (TDD) mobile communication system with asymmetric traffic. The call admission decision in the proposed scheme is based on load factors that vary according to service classes and adopts adaptive guard load as the priority mechanism. The proposed scheme guarantees the priority of handoff call requests over new call requests and guarantees the Quality of Service (QoS) of the ongoing calls while an incoming call is admitted. The performance is measured on the blocking probability, the handoff failure probability, the outage probability of a call in progress, and the utilization of resources. As a result, we show that the proposed scheme can operate efficiently in CDMA/TDD communication system supporting multimedia services.

Keywords: Call Admission Control, CDMA, Time Division Duplex

1. Introduction

Since the requirements of the radio spectrum are increasing while the spectrum is limited, traffic congestion occurs. To solve this problem, the network operator should be able to manage the resource by using Radio Resource Management (RRM). RRM can be classified into handoff control, power control, call admission control and load control, etc. Among these, we focus on the Call Admission Control (CAC) scheme. The core idea of CAC is to admit users only if there are available resources to support their service requirements in uplink and downlink.

Basically, CAC can be categorized into 2 categories: CAC scheme based on hard capacity when the system capacity is limited by the amount of hardware or by the amount of connections and CAC scheme based on soft capacity when the system capacity is limited by interference. In [1], they proposed a CAC scheme based on hard capacity. It takes shorter processing time than the other schemes but it cannot guarantee the QoS of call when there are many ongoing calls with higher interference and this causes call dropping. In [2], they proposed a CAC scheme based on soft capacity. It takes longer processing time but can guarantee the QoS of call and is suitable for a CDMA system because the system capacity is limited by interference. The CAC scheme for CDMA system should be able to consider interference. From the advantage points of [1] and [2], [3, 4] a new type of CAC scheme was proposed by converting soft capacity into semi-hard capacity [5]. So, this CAC scheme uses shorter processing time than that based on soft capacity and can guarantee the QoS of call.

This paper proposes a CAC scheme with the same decision parameters as in [3, 4] i.e. load factors and interference. The differences from [3, 4] are in the priority mechanism. We adopt adaptive guard load, that changes according to arrival rate of call, as the priority mechanism. We also adopt the proposed CAC scheme for the system supporting asymmetric multimedia traffic between uplink and downlink.

In the proposed CAC scheme, using load factor and adaptive guard load, in order to make processing time shorter, can guarantee the QoS of call, be suitable for all environments, and is suitable for CDMA systems.

Moreover, when the system supports multimedia services, a traffic imbalance between uplink and downlink occurs. If both links utilize equal resources, the system capacity is limited by the congested link. This, in turn, results in bandwidth waste and capacity degradation [6]. To overcome this problem, some systems assign the total available radio resources in a cell to the uplink and the downlink asymmetrically. An example is the Code Division Multiple Access system with Time Division Duplex mode (CDMA/TDD system). We apply the proposed CAC scheme in this environment in order to show that the performance of an asymmetric system with the proposed CAC scheme is better than that in a symmetric system.

The remainder of this paper is organized as follows: Section 2 describes the system model and the proposed scheme. In section 3 we evaluate the system performance. Section 4 presents some results with discussion. The paper is concluded in section 5.

2. System model and call admission control

Hereafter, the term "call" at air interface means a connection for any multimedia application. We will use notation according to the following manner: u and d denote uplink and downlink, respectively, and are used as either superscripts or subscripts. Also used as either superscripts or subscripts, n and h mean new call and handoff call, respectively. We denote the bit-energy-to-noise density ratio by E_b / N_0.

2.1 Multiple-class calls

We assume that there are D classes of calls in the system and a call with class-i has higher priority over a call of class-j in call admission, if $i<j$. Call requests with class-i ($0 \le i \le D-1$) are classified into handoff call and new call requests. We assume that a handoff call, irrespective of its class, has higher priority over new calls of any class. As a result, a handoff call of class $D-1$ is served with higher priority than a new call class-0.

2.2 Call admission control

When a class-i call request arrives at a base station, the base station decides whether to admit or reject the request. If all receiver elements have been already assigned to ongoing calls or there is no available spreading code, the call request is rejected. If both receiver elements and spreading codes are available, the proposed CAC scheme is used to guarantee QoS of ongoing call.

As stated before, the class-i call request can obtain an admission only when the fractional load of the system does not exceed a threshold.

The CAC procedure consists of three stages.

Stage 1: Let us first consider the fractional load of the total ongoing calls. Let η_u denote the uplink fractional load and η_d denotes the downlink fractional load as follows [7]:

$$\eta_u = (1+f_u) \cdot \sum_{i=0}^{D-1} n_i \cdot L_i \quad (1)$$

$$\eta_d = [(1-\rho)+f_d] \cdot \sum_{i=0}^{D-1} \frac{1}{1-z} \cdot n_i \cdot \alpha_i \quad (2)$$

L_i denotes the uplink load factor and α_i denotes the downlink load factor of the class-i call, as follows [7]:

$$L_i = \frac{\upsilon_i^u \cdot R_i^u \cdot \gamma_i^u}{W_u} \quad (3)$$

$$\alpha_i = \frac{\upsilon_i^d \cdot R_i^d \cdot \gamma_i^d}{W_d} \quad (4)$$

where n_i is the number of class-i calls in progress within the cell. W_u and W_d are the spreading bandwidth of uplink and downlink, respectively. R_i^u and R_i^d, respectively, are the uplink and downlink data rate of a class-i call. γ_i^u and γ_i^d are E_b/N_0 of a class-i call in uplink and downlink, respectively. The uplink and downlink activity factors of a class-i call are denoted by υ_i^u and υ_i^d, respectively. f_u and f_d denote the ratio of the interference from other cells to that of the home cell. ρ is the average orthogonality factor in downlink and z is the portion of overhead channel (e.g., pilot channel) power (P_{oh}) for the maximum transmission power of a base station ($P_{\max}$). That is, $z = P_{oh} / P_{\max}$ and is assumed to be a fixed value.

Stage 2: Consider the priority of the incoming call. As stated in section 1, we adopt adaptive guard load as the priority mechanism. Now, we introduce the guard load of class-i handoff calls, denoted by $L_{h,i}^{G}$ for uplink and $\alpha_{h,i}^{G}$ for downlink. Then:

$$L_{h,i}^{G}=\Delta_i\left(\sum_{k=0}^{i-1}\frac{\lambda_k L_k}{\nu_k+\mu_k}\right) \tag{5}$$

$$\alpha_{h,i}^{G}=\Delta_i\left(\sum_{k=0}^{i-1}\frac{\lambda_k \alpha_k}{\nu_k+\mu_k}\right) \tag{6}$$

where λ_k is arrival rate of class-k handoff calls (class-k service is the service with higher priority than class-i service), $1/\nu_k$ and $1/\mu_k$ are the mean dwell time and the mean service time of a class-k call, respectively. The coefficient Δ_i provides the tradeoff between performance in the handoff failure probability and that in the frequency efficiency because the larger Δ_i implies the wider guard load that results in lower handoff failure probability and lower frequency efficiency in the system. We usually set $0<\Delta_i<1$.

Now, we define the fractional guard load of class-i new calls, denoted by $L_{n,i}^{G}$ for uplink and $\alpha_{n,i}^{G}$ for downlink. They are defined as:

$$L_{n,i}^{G}=\Delta_i\left(\sum_{k=0}^{D-1}\frac{\lambda_k L_k}{\nu_k+\mu_k}+\sum_{j=0}^{i-1}\frac{\Lambda_j L_j}{\nu_j+\mu_j}\right) \tag{7}$$

$$\alpha_{n,i}^{G}=\Delta_i\left(\sum_{k=0}^{D-1}\frac{\lambda_k \alpha_k}{\nu_k+\mu_k}+\sum_{j=0}^{i-1}\frac{\Lambda_j \alpha_j}{\nu_j+\mu_j}\right) \tag{8}$$

where Λ_i is arrival rate of class-i new calls.

Stage 3: Let η_{u_th} and η_{d_th}, respectively, denote the uplink and downlink load threshold. When we use the priority mechanism, the conditions change from the basic conditions in [7] to the following. The proposed CAC scheme accepts a new call request of class-i if the following conditions are satisfied:

$$\eta_u+L_i+L_{n,i}^{G}<\eta_{u\_th} \tag{9}$$

$$\eta_d+\alpha_i+\alpha_{n,i}^{G}<\eta_{d\_th} \tag{10}$$

Similarly, if a class-i handoff call arrives, the CAC scheme decides whether to admit or reject the call if the results of (11) and (12) are true.

$$\eta_u+L_i+L_{h,i}^{G}<\eta_{u\_th} \tag{11}$$

$$\eta_d+\alpha_i+\alpha_{h,i}^{G}<\eta_{d\_th} \tag{12}$$

3. Performance analysis

A cellular system consists of several cells. We assume that the overall system is homogeneous and in statistical equilibrium. For a homogeneous system, a cell is statistically the same as any other cell. Thus, for each class, the mean handoff arrival rate to a cell should be equal to the mean handoff departure rate from the cell. With this observation, we can evaluate the system performance by analyzing the performance of the proposed CAC by focusing on the operation of an arbitrary cell.

3.1 Assumptions

1. New calls of class-i, $0\le i\le D-1$, arrive at the cell according to a Poisson process with rate Λ_i.

2. The dwell time of a class-i call in a cell is exponentially distributed with mean $1/\nu_i$.

3. The service time of a class-i call in a cell is exponentially distributed with mean $1/\mu_i$.

Remark 1: According to assumptions 1-3, handoff calls of class-i arrive from adjacent cells according to a Poisson process. We denote this arrival rate of class-i handoff calls as λ_i.

3.2 Performance measures

The primary performance measures are the handoff failure probability and the blocking probability of new call. Let ψ_i be the blocking probability of class-i new call and χ_i be the failure probability of class-i handoff call.

Let Γ_u and Γ_d be the throughput of data in uplink and downlink, respectively. Then:

$$\Gamma_u=\sum_{i=0}^{D-1}N_i\cdot\upsilon_i^{u}\cdot R_i^{u} \tag{13}$$

$$\Gamma_d=\sum_{i=0}^{D-1}N_i\cdot\upsilon_i^{d}\cdot R_i^{d} \tag{14}$$

The total bandwidth utilization U_T is:

$$U_T = \frac{\Gamma_u + \Gamma_d}{W_u + W_d} \quad (15)$$

where the mean of class-i calls in process N_i is:

$$N_i = \frac{1}{v_i + \mu_i}\{\Lambda_i(1-\psi_i) + \lambda_i(1-\chi_i)\} \quad (16)$$

Another performance measure is the outage probability of a call in progress. The outage probability of a call is the probability that the measured E_b/N_0 of the call is lower than the required E_b/N_0 for maintaining adequate transmission quality. Let M_i^u and M_i^d denote the average of the measured uplink and downlink E_b/N_0 for class-i calls, respectively.

$$M_i^u = \frac{W_u \gamma_i^u}{(1+f^u)\sum_{j=0}^{D-1} n_j \upsilon_j^u R_j^u \gamma_j^u - \upsilon_i^u R_i^u \gamma_i^u} \quad (17)$$

$$M_i^d = \frac{W_d \gamma_i^d}{\frac{(1-\rho+f^d)}{(1-z)} \cdot \sum_{j=0}^{D-1} n_j \upsilon_j^d R_j^d \gamma_j^d - (1-\rho)\upsilon_i^d R_i^d \gamma_i^d} \quad (18)$$

3.3 Determination of handoff call arrival rates

Since the overall system is assumed to be homogeneous and in statistical equilibrium, the mean handoff arrival rate of class-i calls should be equal to the mean departure rate of class-i calls toward neighboring cells. That is:

$$\lambda_i = P_{h,i}\{\Lambda_i(1-\psi_i) + \lambda_i(1-\chi_i)\} \quad (19)$$

where $P_{h,i}$ is the probability that the connection is released by handoff departure.

$$P_{h,i} = \frac{v_i}{\mu_i + v_i} \quad (20)$$

As seen in (19), the handoff arrival rates are dependent on blocking probability and handoff failure probability, while the blocking probability and handoff failure probability are measured using the handoff arrival rates. To find the relation among the handoff arrival rates, the blocking probability, and handoff failure probability, we use the following iterative algorithm that begins with the initial guess for handoff arrival rates.

Step 1: Set an initial value for λ_i $(0 \le i \le D-1)$.

From (19), assuming that $\psi_i << 1$ and $\chi_i << 1$:

$$\lambda_i \approx \frac{v_i}{\mu_i}\Lambda_i \quad (21)$$

We set the initial value of λ_i as in (21).

Step 2: measure the blocking probability and handoff failure probability.

Step 3: Compute the mean handoff arrival rate using (22):

$$\lambda_{i,new} = P_{h,i}\{\Lambda_i(1-\psi_i) + \lambda_i(1-\chi_i)\} \quad (22)$$

Step 4: Let ε (>0) be a predefined small value. We introduce a function δ_i to indicate whether the difference between the departure rate and the arrival rate for class-i handoff calls is smaller than ε. Then, δ_i is expressed as:

$$\delta_i = \begin{cases} 1, & \text{if} \left|1 - \frac{\lambda_{i,new}}{\lambda_i}\right| < \varepsilon \\ 0, & \text{otherwise} \end{cases} \quad (23)$$

Step 5: $\lambda_i \leftarrow \lambda_{i,new}$ for $0 \le i \le D-1$. If $\prod_{i=0}^{D-1}\delta_i = 0$, go to *Step 2*.

Step 6: Compute the bandwidth utilization U_T, using (13)-(16).

4. Simulation and numerical results

4.1 Traffic Model

The nominal parameter values used in this section are based on those for spectrum calculation for IMT-2000 systems and are listed in Table 1.

Note in Table 1 that a class-0 call requires the same bandwidth for both uplink and downlink, whereas a class-1 call needs much more bandwidth for downlink. New calls arrive according to a poisson process with rate Λ. A new call is randomly determined as a class-0 call with the probability of 0.85, or a class-1 call with the probability of 0.15. Since the new call arrival process for each class is a decomposed process, it is also a poisson process.

Table 1
Traffic Model

	Class-0 Call (Voice Traffic is the main traffic)		Class-1 Call (Internet Traffic is the main traffic)	
Link	Uplink	Downlink	Uplink	Downlink
Information Rate, I	16 kbps	16 kbps	64 kbps	384 kbps
Voice (Data) Activity Factor, υ	0.5	0.5	0.00285	0.015
Bit energy to noise density ratio, E_b / N_0	4 dB	4 dB	4 dB	4 dB
Effective Bandwidth Required per Call, B = υ I	8 kbps	8 kbps	182.4 bps	5.76 kbps
Probability of New Call Arrivals	0.85		0.15	
Mean Call Duration, $1/\mu$	120 sec		3000 sec	
Mean Cell Dwell Time, $1/\nu$	300 sec		1200 sec	
Priority	Higher		Lower	

In the following numerical results, we set $\Delta_0 = \Delta_1$ and denote it by Δ. Unless noted otherwise, we use $\Delta = 0.05$ and 4 Mbps of total bandwidth is assumed in a cell. We set $f_u = f_d = 0.5$, and $z = 0.3$. The bandwidth is shared by uplink and downlink. We test two strategies for the proposed scheme.

1) Symmetric Bandwidth (SB) allocation: both links use the same bandwidth, that is, uplink and downlink use 2 Mbps, respectively.

2) Asymmetric Bandwidth (AB) allocation: the uplink bandwidth is 1.76 Mbps, whereas the downlink bandwidth is 2.24 Mbps. The example of AB strategy can be found in the CDMA/TDD system.

4.2 Results

First, we compare the system performances between the bandwidth-based CAC scheme [1] and the proposed CAC scheme.

Fig. 1 illustrates the handoff failure probability and the blocking probability of a new call in the system with the bandwidth-based CAC scheme and the proposed scheme, respectively. As seen in (9)-(12), the guard load size of a traffic class increases as the offered load of traffic with higher priorities increases. Also, for the given load, the lower the priority a traffic type is, the larger its guard load size becomes. This makes the priority mechanism operate well in the proposed CAC scheme, and independent of the offered load. We can see from Fig. 1 that for the given offered load, the call blocking probability increases in the decreasing order of traffic priorities.

When we use the proposed scheme as the CAC scheme, the system with bandwidth-based scheme will outperform that with the proposed scheme. That is, we can see in Fig. 1 that the handoff failure probability and the new call blocking probability with the bandwidth-based scheme are much lower than those with the proposed scheme.

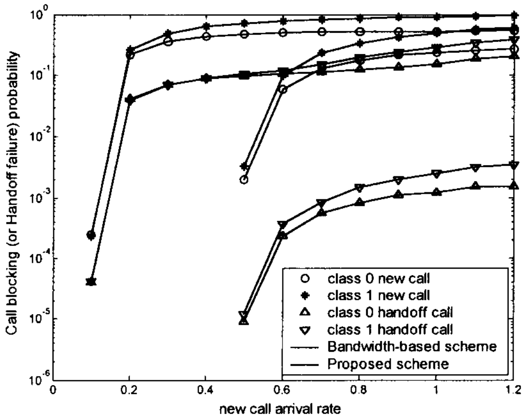

Fig.1. Performance comparison between bandwidth-based scheme and proposed scheme in the aspect of call blocking probability and handoff failure probability.

As the result, the system utilization with the proposed scheme is lower than the bandwidth-based scheme, as seen in Fig. 2, at new call arrival rate of 1.2 call/s, the proposed scheme gives the utilization lower than the bandwidth-based scheme for about 45%. The low utilization with the proposed scheme is caused by the fact that the proposed scheme considers the interference from the calls in the reference cell and adjacent cells, that is, the measured fractional load of the system is higher than the real fractional load from the calls in the reference cell. So, many call requests could be rejected by the lack of available fractional load even if there is sufficient bandwidth.

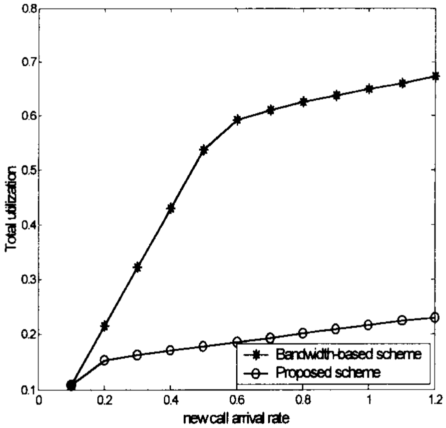

Fig. 2. Performance comparison between bandwidth-based scheme and proposed scheme in the aspect of total utilization.

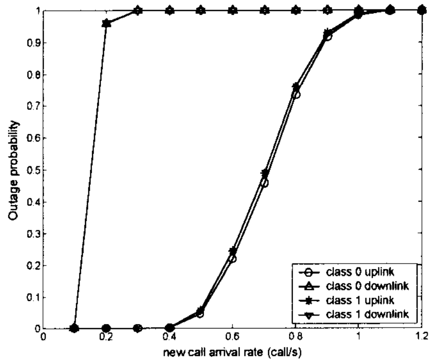

Fig. 3. Outage probabilities according to new call arrival rate for the bandwidth-based scheme.

Fig. 3 and Fig. 4 depict the outage probabilities of uplink and downlink for bandwidth-based scheme and proposed scheme, respectively. They show that the proposed scheme outperforms the bandwidth-based scheme in the aspect of outage probability, whereas the bandwidth-based scheme gives better total utilization over the proposed scheme. Let us observe at new call arrival rate of 1.2 call/s, the outage probability of the proposed scheme is lower than that of the bandwidth-based scheme by about 100 %.

This results from the fact that more calls are blocked in the proposed scheme, so the interference from the ongoing calls in the reference cell and adjacent cells are lower than that in the bandwidth-based scheme. When the signal power of call is maximum, the SIR at low interference is higher than the SIR at high interference. So the proposed scheme can guarantee QoS of the call over the bandwidth-based scheme.

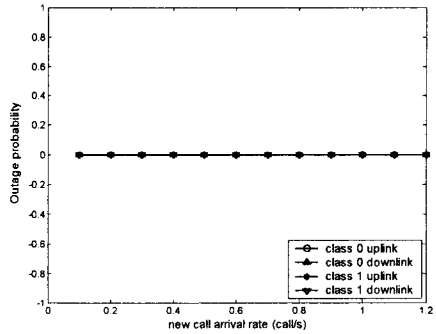

Fig. 4. Outage probabilities according to new call arrival rate for the proposed scheme.

Second, we compare the system performances between SB and AB strategies for the proposed scheme.

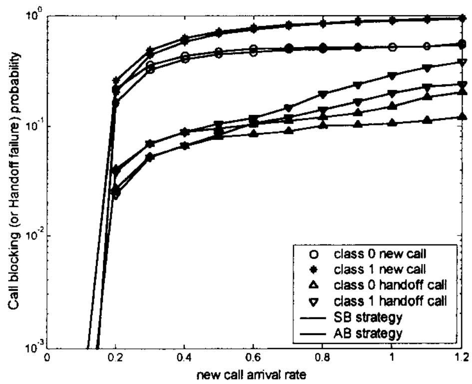

Fig. 5. Performance comparison between SB and AB strategies in the aspect of call blocking probability and handoff failure probability.

When traffic between uplink and downlink is asymmetric, the system with AB strategy will outperform that with SB strategy. Fig. 5 agrees with this expectation. That is, we can see in the figure that the handoff failure probability and new call blocking probability with AB strategy are lower than those with SB strategy.

The superiority of AB strategy over SB strategy can be found by observing the system utilization with the proposed CAC scheme. Fig. 6 shows the total utilization of the system with SB and AB strategies. The low utilization with SB strategy is caused by very low uplink utilization. With SB strategy, many call requests can be rejected by the lack of downlink fractional load even if there is sufficient fractional load in uplink. As a result, a large portion of uplink bandwidth may not be used. On the other hand, if the bandwidths of both links are properly allocated under AB strategy, the utilization of both links can be balanced regardless of the offered load. This results in an excellent performance in total utilization, as seen in Fig. 6.

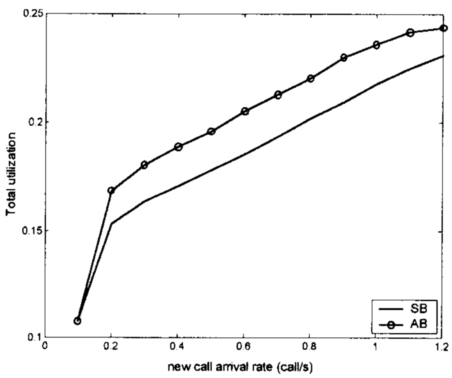

Fig. 6. Performance comparison between SB and AB strategies in the aspect of total utilization.

Let us compare the outage probability between SB and AB strategies. From Fig. 4 and Fig. 7, we can observe that system performance is similar even if the AB strategy gives better utilization than SB strategy. We use the same CAC scheme that considers the interference, so it can guarantee QoS of the ongoing calls before admitting the incoming call.

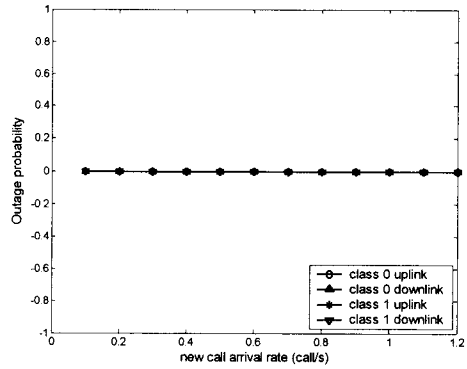

Fig. 7. Outage probabilities according to new call arrival rate for the proposed scheme in AB strategy.

5. Conclusion

We have proposed an advanced CAC scheme and demonstrated its performance. Since the call admission decision is based on the load factor values that consider interference, the proposed CAC scheme gives a better performance than the bandwidth-based scheme in the aspect of the guaranteed QoS of calls while it gives lower bandwidth utilization than the bandwidth-based scheme. However, the proposed scheme can achive nearly 0% outage probability independent the load level, but the outage probability of the bandwidth-based scheme increases dramatically as the load levels increase. Thus, the proposed scheme gives more advantages than disadvantages.

To handle the load asymmetry between both links, which is inherent in mobile multimedia communication environments, the proposed CAC scheme gives system performances better than those in the symmetric bandwidth system. So, the proposed CAC scheme in the asymmetric bandwidth system can be a solution for the CDMA mobile communications systems supporting multimedia services.

For further research, interference cancellation mechanism or adaptable Δ should be applied in order to increase the total bandwidth utilization and to be suitable for all environments.

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