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Research paper

Mobility Management in Cognitive Radio Vehicular Cellular Networks

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Abstract

There is a growing interest in enhancing cellular network support for vehicular communication. Cellular networks based on cognitive radio (CR) technology offer a promising solution for both improving the network capacity in areas facing high customer density and achieving matching between costs and demand in areas of low customer density. In this paper, we propose a mobility management technique for CR cellular network in vehicle-to-infrastructure (V2I) scenarios. The management scheme consists of intercellular resource allocation, and spectrum and user mobility management techniques. In the intercellular resource allocation, each cell selects an extended area band to support the mobility of high-speed users and improve cell capacity. Through the spectrum mobility management, both user and target cell selections are decided based on spectrum availability and user mobility. The user mobility management determines the handoff mechanism at different boundaries of the cell that supports good and reliable communications for high speed mobile users. Simulation results show that our scheme outperforms classical handoff schemes in supporting the mobility and the reliable communications in CR cellular networks.

Keywords: *cognitive radio; handoff; secondary user; spectrum pool; vehicle-to-infrastructure*

1. Introduction

Intelligent transportation systems (ITS) have been attracting increasing interest from automakers, and road operators [1]. They are expected to improve the road safety and support in-vehicle entertainment by utilizing vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) communications. V2I communication can be deployed either as vehicle-to roadside (V2R) communication or through cellular networks. Cellular networks offer a good solution for supporting vehicular communications as they provide highly mobile voice and data connections. However, they suffer from two challenges: cellular spectrum congestion in large cities and the lack of cellular coverage in rural areas and highways [2].

Recently, cellular networks have been exploiting opportunistic spectrum usage with cognitive radio (CR) technology [3]to face these challenges. In CR networks the unlicensed devices utilize the licensed spectrum without interfering with the transmission of primary users (PUs). Hence, if a band is occupied by an authorized client, the secondary user (SU) moves to another spectrum hole, which is referred to as spectrum mobility. Many researchers have focused on spectrum mobility schemes [4] [5] [6] [7]. In [8] [9]timing-based handoff schemes are proposed. [10] [11]investigate the spectrum handoff strategy for graded secondary connections that have different delay requirements and different priorities in accessing to spectrum. In [12] a mobility management scheme for CR cellular networks in urban areas was proposed.

Around 70% or more of TV bands are unused in small cities and rural areas. Thus, CR-technology is particularly applicable for highways since most portions of a highway are located in rural areas, where the spectrum is quite clean and CR network (CRN) is able to find large number of idle spectrum channels [13]. In addition, most portions of highways and rural areas have low user density, so a CR-based network that doesn't require dedicated spectrum can be a solution for service providers in terms of saving the cost of getting a spectrum's license. Additionally, the opportunistic usage of (VHF/UHF) TV bands can achieve large network coverage due to the favorable propagation condition in the VHF/UHF bands where the signal can reach long distance which makes this technology particularly suitable for rural and highways deployment [14].

Few works in the literature have discussed mobility management in the context of cognitive radios [15]and fewer have discussed it for cellular networks that is based on CR technology despite its good coverage and sufficient security [16]. Both spectrum and user mobility must be considered in designing a mobility management scheme for CR cellular networks. Therefore, this study aims to bridge the gap in knowledge in mobility management for CR Cellular networks in highways through proposing mobility management scheme for CR Cellular networks in highway scenarios, while handling different mobility scenarios in CRNs in order to improve the quality of service. Firstly, we adopt a spectrum pool-based CR cellular network architecture to face the heterogeneity in the available spectrum [12]. Based on this architecture, a mobility management scheme consists of intercellular resource allocation, spectrum mobility management, and user mobility management schemes are proposed. For intercellular resource allocation we adopt the proposed method in [12]. The spectrum mobility management determines both user and target cell selections based on time-varying spectrum availability and user mobility. The user mobility management

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determines the HO mechanism at different boundaries of the cell that supports good, seamless, and reliable communications for SUs. This paper is organized as follows: Sections 2 present the network architecture and HO modelling in the proposed scheme, respectively. Mobility management schemes and technique for CR networks are presented in Section 3. In Section 4, results and discussion are presented. Finally, we conclude this paper in Section 5.

2. Network architecture and handoff modeling

We adopt an infrastructure-based CRN. Each spectrum band is licensed to various primary networks which are located in different zones, denoted as the PU activity regions (Fig. 1). We assume that the length of busy (ON) and idle (OFF) periods at PU activity region r in a band b is exponentially distributed with means $1/\alpha(b,r)$ and $1/\beta(b,r)$, respectively. To face the discontinuous spectrum distribution over a wide frequency range, we adopt a spectrum pool-based network architecture. In order to improve the mobility of SUs move to their adjacent cells an extended coverage area (EA) is introduced.

HO techniques in CR cellular networks are related to various mobility events (i.e. user mobility and spectrum mobility). We adopt various HO strategies considering these mobility events.

- Proactive or soft HO strategy in the case of SU mobility.
- Reactive or hard HO strategy in the case of PU appearance. This strategy is more suitable in the case of low PU traffic as in the case of highways[17] [18].

Based on these strategies and the network architecture, the HO schemes can be modeled as follows:

2.1. Intracellular/intrapool HO

A reactive-HO occurs when a PU is detected and SU is required to move to a spectrum band in the same spectrum pool. The delay time for intracellular/intrapool HO (Type 1) is denoted as T_1.

2.2. Intracellular/interpool HO

If the base station (BS) has multiple spectrum pools and the current spectrum pool does not have enough spectrum resources, upon detection of PUs activities, the SU switches to a new spectrum pool in the same cell using a reactive-HO (Type 2). The HO latency in this case is denoted as T_2.

2.3. Intercellular/interpool HO

Both mobility scenarios can initiate this HO scheme. When SU moves to an adjacent cell this HO is initiated. In this case, the HO delay is T_3 .Moreover, PU appearance can start this HO in two scenarios. First, if all spectrum pools in the serving cell are overloaded, the BS forces SUs to move to adjacent cells which requires T_2 delay time. Secondly, when a PU appears in the extended band, SUs in EA have to switch to the adjacent cells but they lose a control channel so the current BS sends HO information to a selected BS. In this case, SU makes one or more RF front end reconfigurations till it can hear the advertisement message from the selected BS and, in every reconfiguration, SU monitors the control channel for a certain time. Therefore, this scenario has the largest HO delay T_4.

2.4. Intercellular/intrapool HO

A proactive-HO occurs when mobile SUs in EA switch to the extended neighbors. The delay time for this HO scheme is T_5.

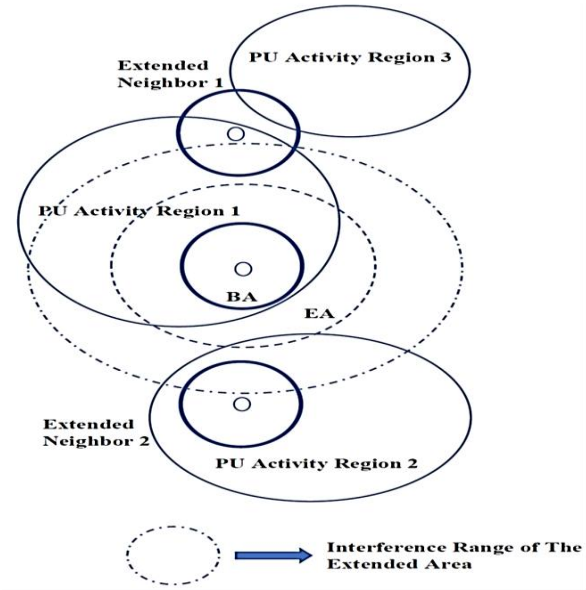


Fig .1: The primary user (PU) activity regions.

3. Mobility management scheme

To improve the mobility of high speed SUs and the cell capacity each cell determines its extended spectrum band based on the expected capacity gain through the intercellular resource allocation proposed in[12] . Then, for a mobility management, two main management functionalities which are initiated by user mobility or spectrum mobility are proposed as follows:

3.1. Spectrum mobility management

If a PU appears in the cell, and there are enough spectrum resources for all SUs that need new spectrum bands, the HO (Type 1) is performed for all of them. Otherwise, some of SUs are selected to move to the neighbor cells based on user selection metrics introduced in [12] . If the PU is detected in the EA, all SUs in EA perform HO (Type 4) to find a new cell because we consider only one extended band in EA. For target cell selection we use a network-controlled method where the current BS selects the new cell with the highest total connectivity P_i^T that can be obtained according to both connectivity and spectrum utilization as follows [12]:

$$P_i^T = (1 - \prod_{b\in B_i} (1 - P_i^c(b))).(1 - \frac{N_i^{BA} + \rho N_i^{EA}}{\sum_{b\in B_i} N_i^{max}(b)}), \quad (1)$$

here, N_i^{BA} and N_i^{EA} are the number of channels used in the basic area (BA) and EA of cell i, respectively, $N_i^{max}(b)$ is the maximum number of channels in the band b at the BA of the cell i , ρ is the channel gain ,and $P_i^c(b)$ is the connection probability of spectrum b in pool i which can be expressed as follows[19]:

$$P_i^c(b) = \Pr[p_{t,dB} - PL_{0,dB} - 10\gamma \log_{10} d - X_\sigma \geq p_{min,dB}], \quad (2)$$

here, $p_{min,dB}$ is the minimum detectable signal, $p_{t,dB}$ is the transmission power, $PL_{0,dB}$ is the average path loss at the reference distance, d is the distance to the BS, γ is the path loss exponent, and X_σ is the shadowing factor.

3.2. User mobility management

The SU mobility is another reason for HO initiation, which can be initiated at the boundary of either BA or EA. Unlike the urban scenario of [12], the behavioral characteristics of vehicles movement on a highway are continuous motion with infrequent changes in direction and speed [20]. Thus, the user mobility in highway scenarios is strongly predictable as the user traverses the successive neighboring cells in almost direct path with high velocity[21]. For high speed mobile users, larger cell coverage is more advantageous as it reduces the number of HOs. However, in CRNs the large coverage is not desirable for mobile SUs as it is more likely to include more PU activity regions (Fig.1).

Unlike the more complicated user mobility management introduced in [12] which need much calculations , we propose an appropriate user mobility management for SUs in highways that aims to improve the mobility support for them.

As explained before, The PU activity in EA causes a long switching latency. Additionally, since SUs in BA have a higher priority in channel access, cell overload also affects the use of extended band.

Due to these reasons and the predictable SU's movement in highways, BS decides the intercellular/interpool HO (Type 3) for mobile SUs at the boundary of BA by choosing a cell having a different spectrum pool. The HO timing is based on the candidate cells' connectivity and it is generated when:

$$[P_{i_c}^{c} \le \max_{i\in C} P_i^{c}], \qquad (3)$$

where P_i^c is the connection probability of cell i, C is a set of candidate cells, and i_c is the current cell.

If the adjacent cell is not available, the SU stays in the EA of the current cell by performing the intracellular/intrapool HO.

When SUs approach the boundary of EA, first they check the feasibility of intercellular/intrapool HO by measuring the signal strength from other BS directly as classical HO schemes. If SUs cannot find a target cell for this HO (Type5), they need to perform the intercellular/interpool HO by choosing a cell having a different spectrum pool (Type 3).

4. Simulation Results And Discussion

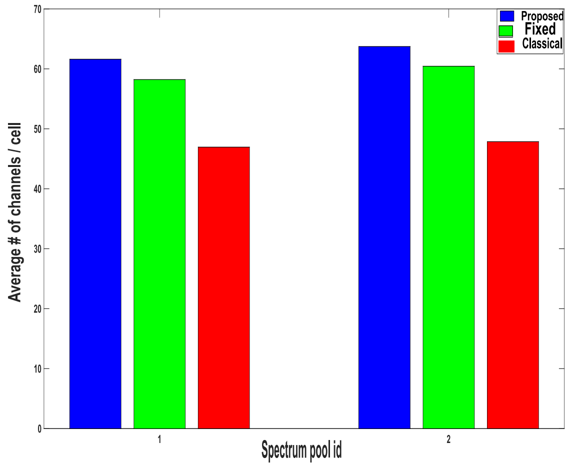
We assume a network topology that consists of 17 cells. The transmission range of the cell is 2 Km while the interference range is 4 Km. The transmission range of the extended spectrum band is 4 Km. We consider two spectrum pools; each pool consists of 8 spectrum bands. The basic band support 10 channels for users in BA. In addition, each band has 3 to 5 PU activity regions that have different activities, $\alpha(b,r)$ and $\beta(b,r)$ uniformly distributed in [0.03, 0.05] and [0.01, 0.03], respectively. The HO delay components T_1, T_2, T_3, T_4, and T_5 are set to 0.2, 0.5, 0.4, 0.8, and 0.1 sec, respectively.

For the radio propagation model, a channel gain is set to -31.54 dB, and γ is 2.5 [22]. Shadow fading standard deviation σ of the bands in each cell are randomly distributed in [6, 9] dB. The BS uses 28 dBm transmission power on average for the basic spectrum band and 37 dBm for the extended band. The receiver sensitivity is -102 dBm. Finally, the proposed mobility management is evaluated under various constant user velocities of 70, 90, and 110 Km/h.

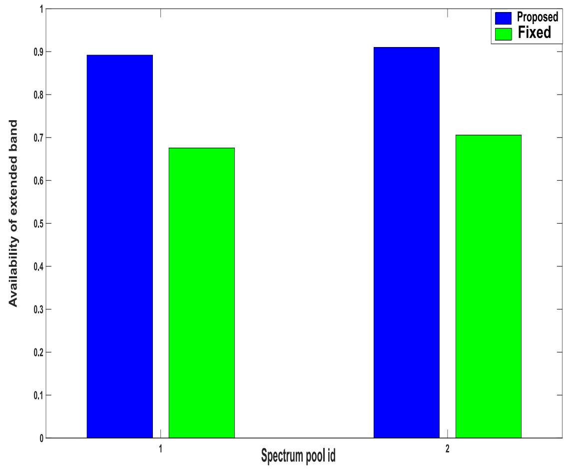
4.1. Performance of the intercellular resource allocation method for extended spectrum bands

We evaluate the performance of the adopted intercellular resource allocation in comparison it with classical HO scheme[12] which only has basic bands and does not support the extended band. In addition, we compare it to the fixed allocation scheme[12] where the extended band is also selected based on the expected capacity gain, but unlike the proposed scheme it is not changed even if it is lost due to PU activity.

In Figure 2, we investigate the average number of channels per cell in the case that all the SUs who use the extended band are situated on the BA, and the availability of the extended bands or the ratio of the time that the extended band is usable by BS to total simulation time for each scheme.



(a)



(b)

Fig. 2: Intercellular resource allocation: (a) cell capacity ,and (b) availability of extended spectrum bands.

In Figure 2(a), the proposed method shows higher channel availability than the classical scheme through using the extended spectrum band that supports more channels for SUs in BA.In addition,the proposed method shows higher availability of the extended spectrum and the cell capacity than the fixed scheme by using the dynamic allocation technique for extended spectrum allocation.

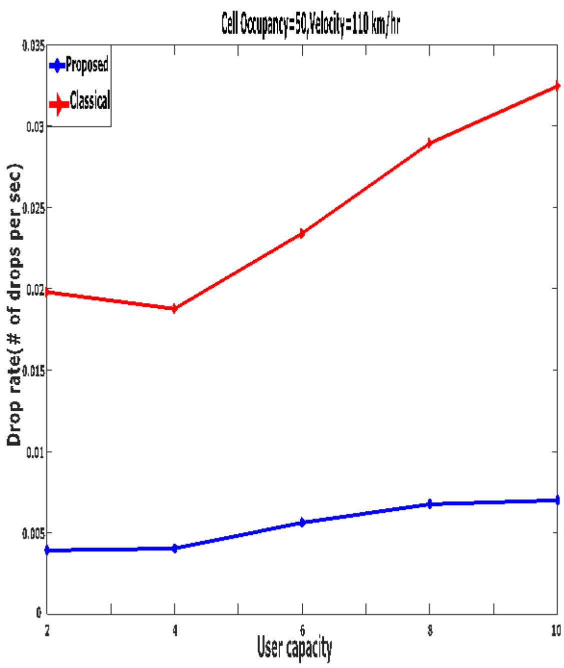
4.2. Performance of the proposed spectrum and user mobility management schemes

We investigate the transmission performance in mobile SUs under various network scenarios to estimate the performance of both user and spectrum management methods. (i.e., SU's QoS requirement, the number of channels currently occupied by other SUs, and SU's velocity). Here, the experiments are carried out by 30 half-hour-simulations for each scenario and the average values are obtained.

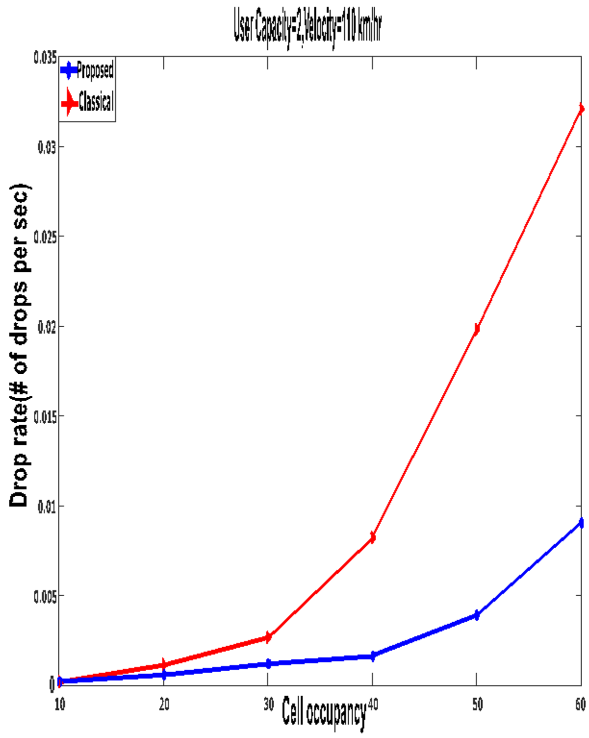
One of the most significant metrics in mobility management is the call drop probability. The call drop takes place when a mobile SU with an ongoing call cannot find any other free channels in both serving and target cells. In Figure 3, the proposed scheme shows lower drop rate than classical. As shown in Figure 3(a), even though SU's QoS requirement increases, the proposed technique can preserve a specific level of drop rate using the spectrum mobility management. In Figure 3(b), if the cell occupancy increases, a drop rate increases as the available spectrum resources decrease, but it is still lower than classical scheme by using the extended band that improves the cell capacity and by choosing the HO type adaptively to cell's conditions. Moreover, as shown in Figure 3(c), the proposed technique achieves the optimal usage of EA that reduces the number of intercellular/interpool HOs through the user mobility management scheme. Therefore, the proposed scheme keeps a lesser drop rate although a mobile SU traverse across wider areas and more cells with higher velocity. Figure 4 shows the link efficiency, in other words, the transmission time over the whole simulation time. The classical scheme shows lower link efficiency than the proposed scheme due to the multiple intercellular/interpool HOs resulting from the lower of network capacity and cell coverage area of the classical scheme. Morever, when the current cell is overloaded, some of the SUs cannot find spectrum resources until spectrum availability changes or they move into a new target cell, which causes quality degradation. On the contrary, the proposed scheme achieves higher link efficiency by intelligently determining the HO types and exploiting the extended area to reduce the latency as well as the drop rate.

5. Conclusion

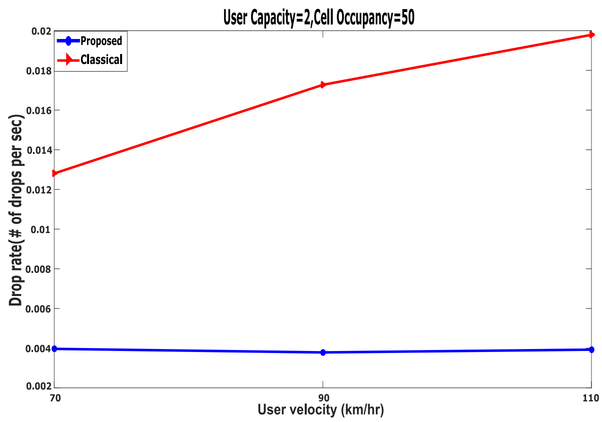
In this paper, we present a mobility management technique for vehicular CR cellular networks in highway scenarios. In order to face the discontinuous spectrum distribution over a wide frequency range, we adopt a spectrum pool network architecture. Extended bands are used to support the mobility of SUs as well as to improve network capacity. In addition, a mobility management scheme is presented to handle both spectrum and user mobility in CR cellular networks in highways. The proposed scheme consists of intercellular resource allocation, spectrum mobility management scheme and user mobility management scheme. Simulation results show that the proposed scheme can support mobility for high speed SUs, maximizes cell capacity, provides better QoS to the high-speed SUs, and achieves high actual transmission opportunity.



(a)

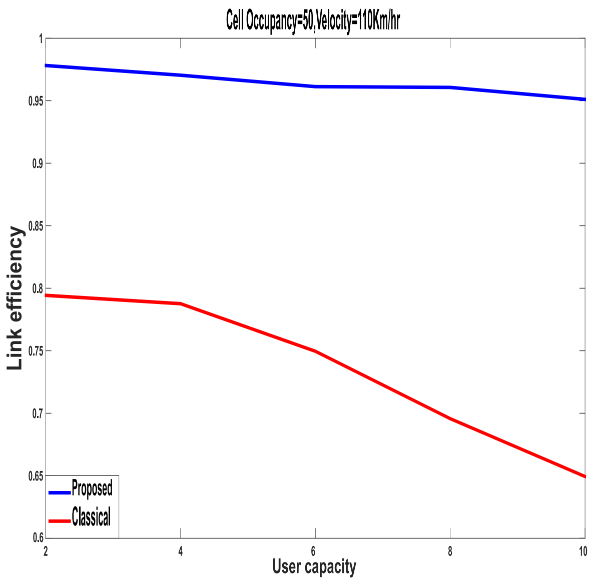


(b)

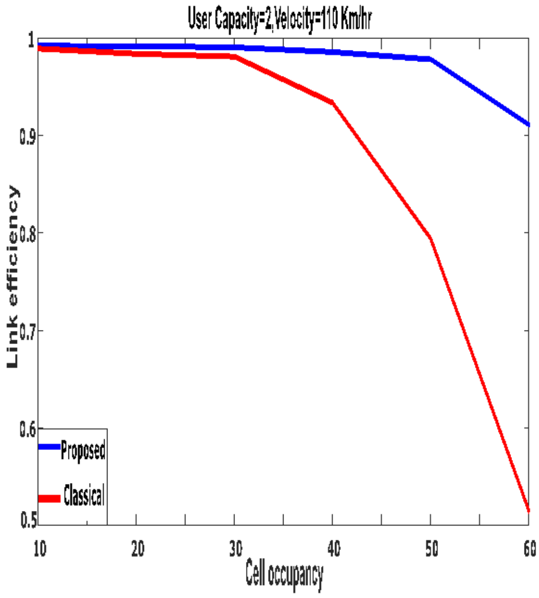


(c)

Fig. 3: Drop rate: (a) user capacity, (b) cell occupancy, and (c) user velocity.



(a)



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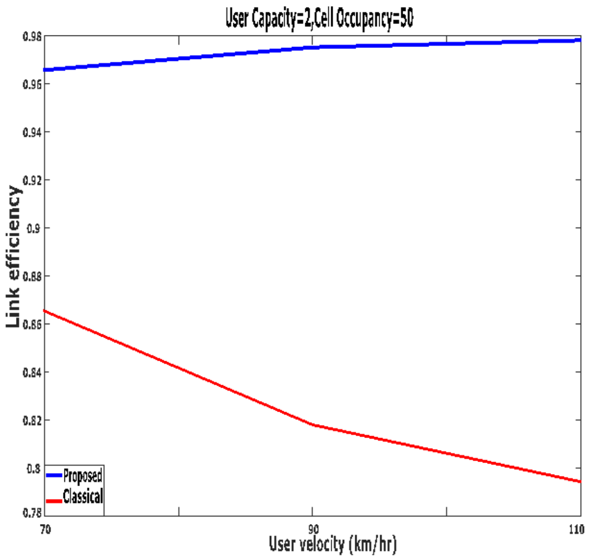

(c)

Fig.4: Link efficiency: (a) user capacit, (b) cell occupancy, and (c) user velocity.

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