0utage Performance of Spectrum Sharing Networks in Presence of Multiple Primary Users

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Abstract - Wireless communication technology has witnessed diverse and rapid advancement in the last few decades, which is because of its proliferating demands, capability and importance in day-to-day life. Subsequently, the field has attracted recent interest from research community to explore new techniques which are more promising in terms of throughput over limited spectrum. One of the important aspects of such techniques is to utilize the scarce bandwidth resource efficiently and reliably. Towards this end, cognitive relay network has come out as a potential technique, claiming to provide per- formance gain with efficient utilization of spectrum.

In this thesis, we investigate the outage performance of cognitive relay network con- sisting of multiple primary (those who have licensed the given spectrum) receivers and secondary (unlicensed) network which comprises a source, a destination and multiple relays. We consider a scenario in which information is transmitted from a source to a destination over the spectrum licensed to the primary users. There are K secondary relays from which a best relay is selected opportunistically, and is used to facilitate secondary communication using amplify-and-forward protocol. Opportunistic relay se- lection is carried out in such a way that it maximizes the instantaneous end-to-end signal-to-noise ratio (SNR) of the secondary communication and also satisfies the power constraints imposed by multiple primary receivers.

1. INTRODUCTION

Wireless communications have seen a remarkably fast rise in its applications and num- ber of users over the past few years. With each new generation, wireless technology introduces significant improvements in terms of data rate, power efficiency, applications and device size. The technological progress in this field follows that of many flagship technologies such as integrated circuits, antennas and energy storage. One of the un- derlying technologies contributing to this is digital signal processing. Following this technological progress, need of high quality and high speed services such as wi-fi, video calling, live streaming etc. are also rising, but evolution of these services requires large spectrum which eventually leads to raise in demands for radio spectrum. Table 1.1 shows the growth of mobile communication and its bandwidth requirement since its inception. As a consequence to this, radio spectrum has become the most valuable and scanty natural resource in wireless communication. Moreover, with the evolution of a large number of new applications, the demand for spectrum is expected to rise even more in the forthcoming years.

1.1 Cognitive Radio

Electromagnetic spectrum is viewed as a precious natural resource. To use a particular frequency band, licensing of the radio spectrum is done by the government regulatory bodies, which prohibits unlicensed users to use that spectrum. However, when spectrum is allocated to users for different applications, it has been observed that a larger portion of the assigned spectrum is used irregularly i.e. some frequency bands in the spectrum are unused most of the time, some other frequency bands are occupied partially and the other remaining bands are used heavily. The unused band at a particular time and specific geographic location is termed as spectrum hole or white space. Figure 1.1 shows how sporadically a particular frequency band is being utilized.

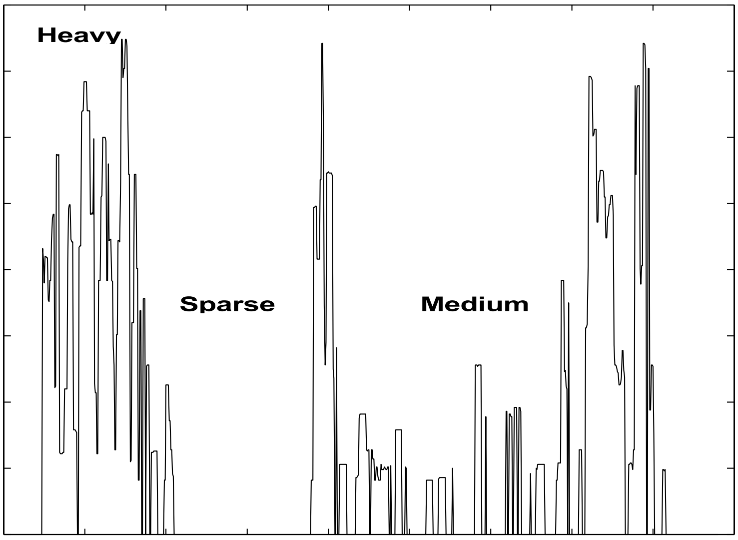


Figure 1.1: Spectrum Utilization

1.2 Spectrum Sharing Approach

A key question to be followed now is, how the secondary users are allowed to use the licensed spectrum of primary users, in a way that transmission quality of primary users is not compromised. Answer to that is proposed in form of some spectrum sharing approach, which are as follows

- Underlay Approach
- Interweave Approach

1.3 Cooperative Diversity

Cooperative diversity is a distributed MIMO technique which is used for maximizing or improving total network channel capabilities. In cooperative diversity, nodes in the network cooperate together for the distributed transmission and processing the infor- mation. The cooperating node acts as a relay node for the source node. So, instead of transmitting data directly to the destination, it is first send to the relay node, and then after some processing, it is further sent to the destination. Doing so generates independent paths between source and the destination, and as all paths fade independently from the direct path, they form a virtual MIMO channel between source and destination. A basic cooperation model is shown in Figure 1.3.

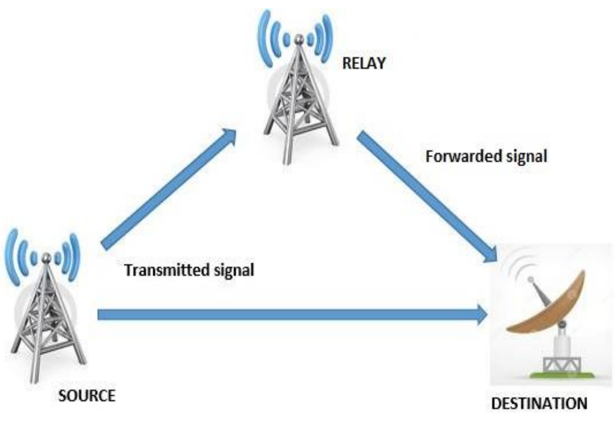


Figure 1.3: Cooperation Model

1.3 Relaying Protocols

Signal received at the relay from the source can be processed in different ways before sending it further to the destination. Depending on the processing at relay, different kinds of relaying protocols are employed as explained below.

1.3.1 Fixed Relaying

In this, the channel resources are distributed between source and relay in a fixed man- ner. Such protocols are easy to implement but they have drawback of low bandwidth efficiency. This is because of the fact that half of the channel resources are allocated for the relay, which reduces the overall rate. It especially happens when the channel between source and destination is not very bad, because in such cases most of the packets received at the destination from source can be received correctly and relay's transmission is futile. It is of two types

Amplify-and-Forward (AF):In AF relaying protocol, the relay simply amplifies the signal received from its part- ner/source and transmits it further to the destination. Then, receiver at the destination combines the information sent from both the source and the relay, using any of the di- versity combining techniques, to make final decision about the transmitted bits. Here, amplification is done essentially to combat the effect of the fading between the source and relay channel. In this process, the noise at the relay also get amplified by the relay, which is main drawback of this protocol. But reduced hardware complexity is advantageous over its DF counterpart.

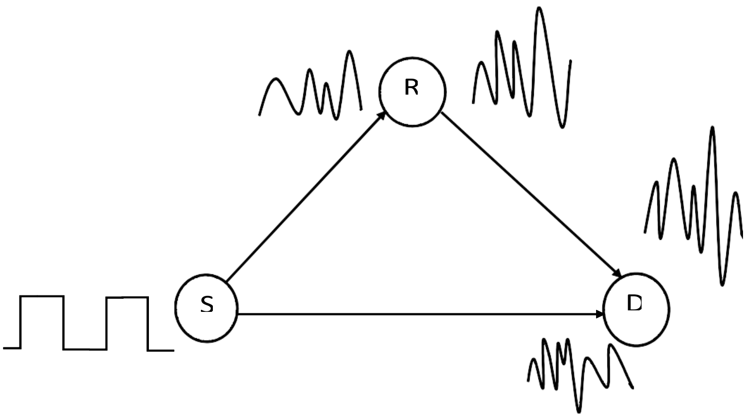


Figure 1.4 AF Relaying

b)Decode-and-Forward (DF): DF relaying is also known as regenerative relaying. In DF relaying protocol, relay decodes the signal received from its partner/source, re-encode it and then retransmit it to the receiver, and then receiver at the destination perform the same task as that of AF. While doing this, there is a possibility that relay decodes the signal incorrectly and forwards it resulting in an error propagation.

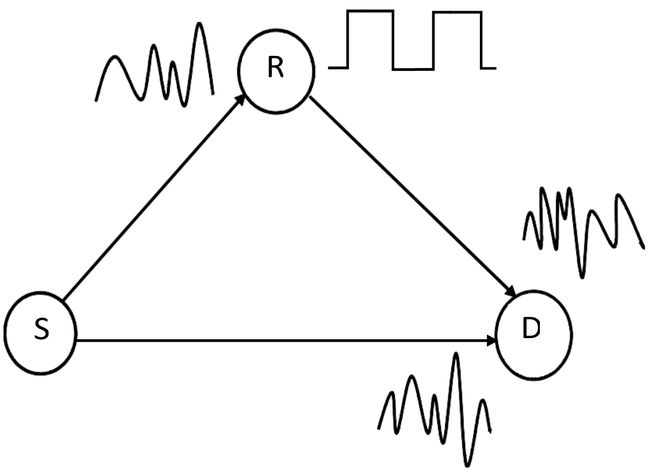


Figure 1.5: DF Relaying

1.4Diversity Combining Techniques

In an attempt to achieve the diversity, multiple independent copies of signal are received at the destination, and to retrieve the information from the received copies, the desti- nation needs to employ a combining technique to combine the diverse received signals. Based on the way signals are combined at the receiver, several kinds of diversity com- bining techniques are used. In our work, we have considered the Selection Combining (SC) and Maximal-Ratio-Combining (MRC) techniques only.

1.4.1 Selection Combining (SC)

Selection combining is a kind of diversity combining technique which is used to get the information from the multiple copies of signal at the destination. It does so by selecting the signal with highest instantaneous SNR using a switching or logic circuit. Since the output signal here is the output signal from any one of the channels, there is no need to add the individual channel output. Hence, SC presents the lower bound of the diversity that a system can achieve. Although this technique requires some information about the channel, but it results in bandwidth savings. This technique is simple but ineffective because all the antenna branches are not used effectively, hence wastage of hardware.

Mathematically, if there are K paths from source to the destination, SNR at the destination can be written as

$\Lambda D =$ max

$k \in \{1,...,K\}$

where Λk denotes the SNR for the kth path.

Figure shows how the technique works, here SNR from both relay and direct link are compared to determine the maximum SNR and then using the switch, corresponding link is selected to give output.

2. Cognitive Opportunistic Relaying System and Channel Models

2.1 Rayleigh Fading Channels

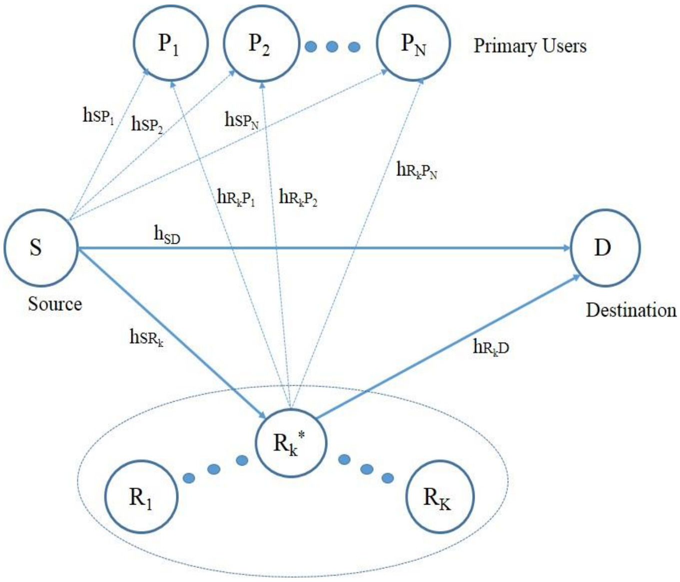
Wireless channels are characterized by fading. In our system, we have considered channel fading to follow Rayleigh distribution.

2.2 System Model Description

We consider a cognitive relay network, having one secondary user (SU) source S, K relays Rk (k = 1, • • • , K), one SU destination D and N primary user receivers (PU) Pn (n = 1, • • • , N), as shown in Figure 2.2. The primary transmitters are assumed to be located far from the secondary nodes and hence their interference on the secondary communication is neglected. Secondary users are communicating over the spectrum licensed to primary users but with certain restrictions.

Signals transmitted in channels are prone to fading because of several disturbing factors present in the wireless channel. This fading can be modeled using distribution functions like Nakagami-m, Rayleigh and Rician, etc. depending upon the communi- cation environment. In our case, we consider fading to follow Rayleigh distribution, which is quite popular and widely used for modeling the typical wireless channels. The channel coefficient between any two arbitrary nodes

i and j (i, j ∈ {S, Rk, D}, i ƒ= j) is denoted by hij. All pertinent channel coefficients {hij} in the network are considered to experience independent and identically distributed Rayleigh fading. While transmis- sion over the wireless channel, noise severely affects the signal.



2.3 SNR Expressions

To proceed further, we need to obtain the expressions for the instantaneous Signal-to- Noise-Ratio (SNR), which is given as the ratio of received signal power to noise power.

Mathematically, it can be formulated as

$$k^* = \arg\max_{k \in \{1 \ldots k\}} \{\Lambda_k\}$$

where k∗ is the index for best selected relay.

3. System Performance Analysis with MRC and SC Schemes

we analyze the performance of the cognitive opportunistic relaying system, as discussed in previous chapter, in presence of multiple primary receivers over Rayleigh channels.

3.1 With Maximal-Ratio-Combining Scheme

we conduct mathematical analysis for the outage performance and asymptotic behavior as follows

3.1.1 Outage Probability

To achieve the acceptable communication performance for a system, a minimum strength of the signal level is required. But if the signal drops below that level, then outage oc- curs. Thus, the outage probability (OP) can be defined as the probability that a given rate will not be supported because of instantaneous channel condition.

$$P_{out}(\Upsilon_{th}) = P_r[\Lambda_D < \Upsilon_{th}]$$

$$P_{out}^{MRC}(\Upsilon_{th}/W) \approx \int_0^{\Upsilon_{th}} f\Lambda_{kk^*}(u/W)du \int_0^{\frac{\Upsilon_{th}}{2}} f\Lambda_0(v/W)dv +$$

$$\int_0^{\frac{\Upsilon_{th}}{2}} f\Lambda_{k^*}(u/W)du \int_{\frac{\Upsilon_{th}}{2}}^{\Upsilon_{th}} (v/W)dv,$$

which can be further written as

$$P_{out}^{MRC}(\Upsilon_{th}/W) = F_{\Lambda_{k^*}}(\Upsilon_{th}/W)\, F_{\Lambda_0}(\tfrac{\Upsilon_{th}}{2}/W) + F_{\Lambda_{k^*}}(\tfrac{\Upsilon_{th}}{2}/W) \times (F_{\Lambda_0}(\Upsilon_{th}/W) - F_{\Lambda_0}(\tfrac{\Upsilon_{th}}{2}/W)$$

3.2 With Selection Combining Scheme

The outage performance and asymptotic outage behavior by employing SC receiver at the destination will be discussed.

3.2.1 Outage probability

The outage probability with SC at destination can be expressed mathematically as

$$P_{out}^{SC}(\gamma_{th}) = \Pr[\max(\Lambda_0, \Lambda_{k^*}) < \gamma_{th}]$$

After performing required integration, the outage probability with SC can be given as

$$P_{out}^{SC}(\gamma_{th}) = \frac{N}{\Omega_{th}} \sum_{t=0}^{K} \sum_{k=0}^{N-1} \sum_{\mu=0}^{1} (-1)^{(t+\mu+k)} \binom{K}{t} \binom{N-1}{K} (F_{\Lambda_{RD}}^{c}(\gamma))^{t} \times \frac{1}{\frac{t\gamma}{\Omega_{SR_Q}} + \frac{\mu\gamma}{\Omega_{SD_Q}} + \frac{k+1}{\Omega_{SP}}}$$

4. Results and Discussion

We also corroborate the analytically obtained results by Monte Carlo simulations and use them to provide valuable insights into the system performance.

4.1 Numerical Plots and Discussion

This section illustrates the performance of considered system by depicting numerical plots of outage probability (OP) versus SNR for various cases based on number of PUs, number of relays, and position of PUs.

we analyze the performance of our system, based on the following three cases under Rayleigh fading channels.

Table : Different parameters and their values.

Parameter	Value
γ_{th}	3dB
Pathloss exponent (α)	4
Position of relays	[0.5, 0.5]
Position of SU source	[0,0]
Position of SU destination	[1,0]

Case 1: For fixed number of primary users and their location

In first case, number of primary users present is fixed as N = 2 and their cluster is located at coordinate [0.5,0.5]. Figure plots the OP versus SNR for both MRC and SC schemes for different values of K.

We can see that the analytical curves are in well agreement with the exact simula- tion results. The asymptotic curves are also aligned with the exact results in the high SNR regime, validating our analysis. Moreover, there is apparent difference between the curves of MRC and SC which suggests that MRC outperforms the SC in terms of coding gain, while both schemes achieve the same diversity gain of $K + 1$. We can further observe that as K is increasing from 1 to 3, the OP curve is shifting downward signifying the improvement in outage performance. This is owing to the increase in the diversity gain of the system.

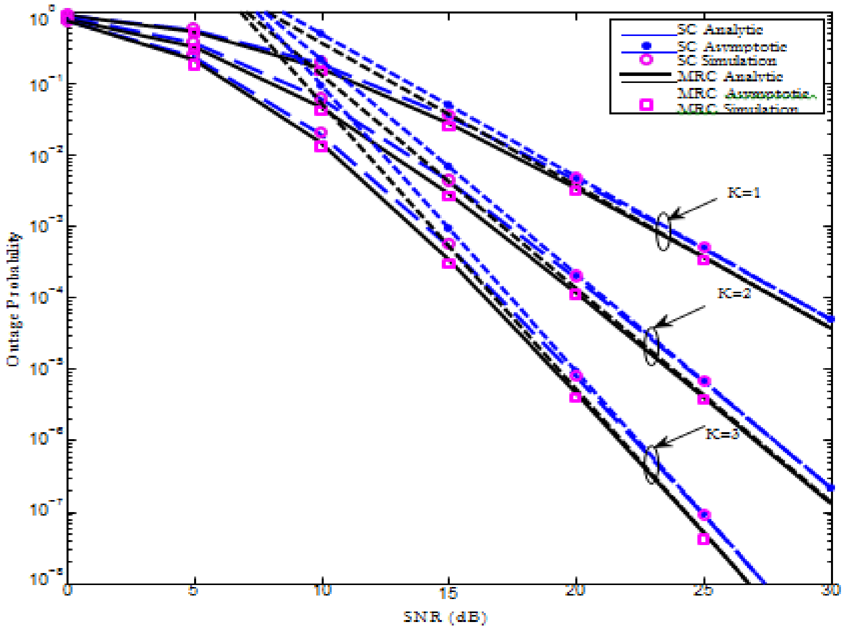


Fig Outage Performance for Fixed PU Position and N = 2 with Varying K

Case 2: For fixed number of relays and primary users' location

In this case, number of relays is fixed as K = 3 and cluster of the primary users is located at [0.5,0.5]. Figure 4.4 plots the OP versus SNR for both MRC and SC schemes for different values of N .

Here, we observe that as N increases from 1 to 3, performance of the system for both the schemes degrades. This is expected due to increase of the interference constraint on the secondary user. It should be noted here that slope of all the curves is same, which reveals that increasing the number of primary users does not affect the diversity gain of the system. It only affects the coding gain, which contributes to the performance improvement. Moreover, as apparent from the asymptotic curves, we can see that the performance gap (at high SNR) between MRC and SC remains unaffected with the variation in number of primary users.

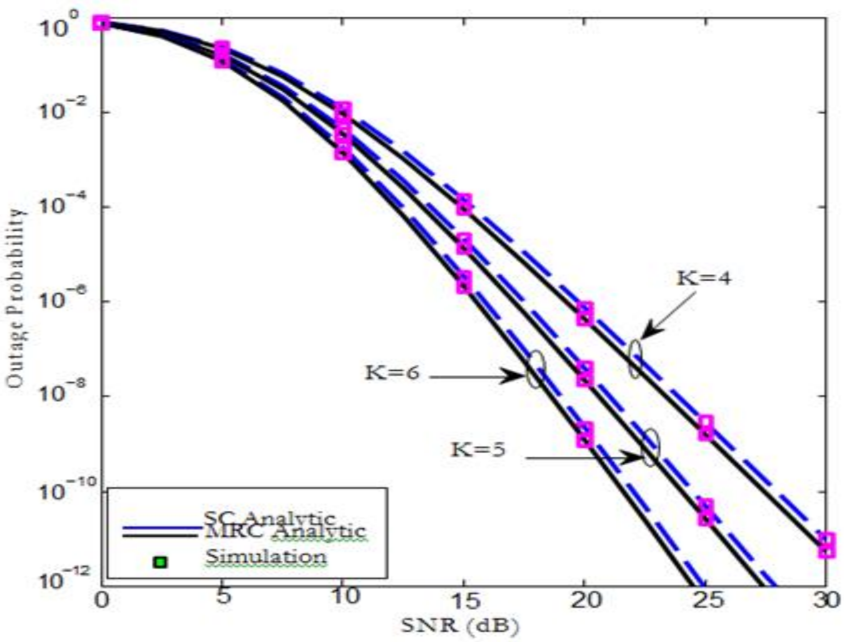


Fig: Outage Performance for Fixed PU Position and N = 3 with Varying K.

Case 3: For fixed number of relays and primary users

For this case, the number of relays and number of primary users are fixed fixed as K = 3 and N = 2 respectively. show the impact of variation in position of the primary users on the outage performance for both MRC and SC schemes.

We can observe that the increase in the distance of primary users from the SU source causes improvement in the system performance. This is owing to the fact that, as the distance of primary users from secondary source increases, the interference restriction on secondary user decreases. It is evident from the figure that position of primary users only affects the coding gain of the system, which is derived from the fact that slope of all the curves remains same for different position of primary users.

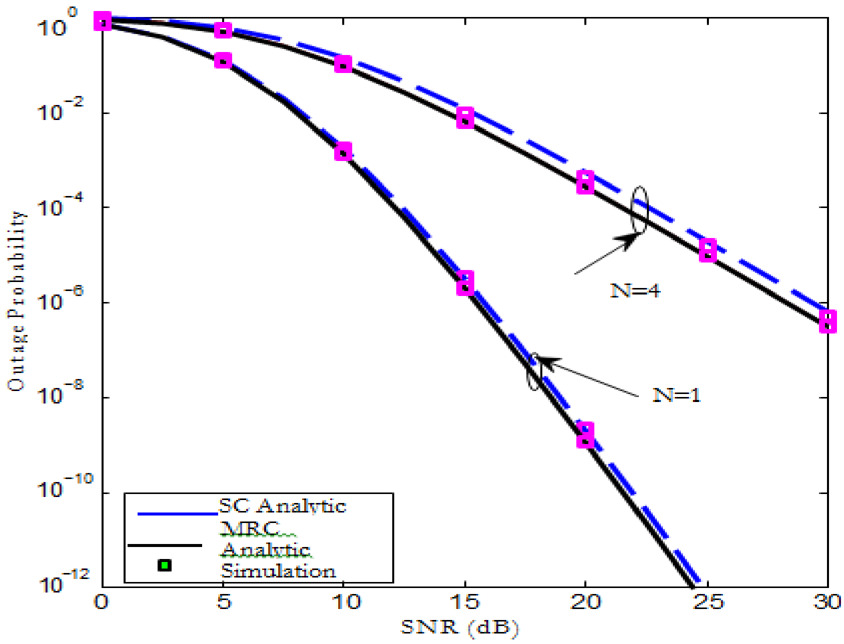


Fig: Outage Performance for Fixed PU Position and K = 2 with Varying N

5. Conclusions

We conclude our thesis work with possible extensions and scope for further research in the field.

Unified outage analysis has been conducted for MRC and SC schemes in cognitive multi-relay networks with a direct link. We have employed opportunistic relay selection strategy in the presence of multiple primary receivers. For Rayleigh fading, we derived outage probability and asymptotic outage expressions in the high SNR region. Finally, analytical results are validated through extensive simulations. From these results, we deduce some valuable remarks which are as follows:

•It has been inferred that outage performance of MRC is better than SC i.e. outage probability in case of MRC is less than that of SC, which is evident from the broader integral region in case of SC compared to MRC.

•We further observe that both MRC and SC achieve the same diversity gain (i.e. equal to number of relays+1), which is independent of primary network. However, it depends on the number of relays due to the use of opportunistic relaying.

Results also revealed that variation in number and position of primary users affects the coding gains.

Moreover, the performance gap between the MRC and SC schemes depends on their coding gains which can be quantified by the ratio of coding gains.

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