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Robust Frequency Synchronization in OFDM for MIMO Based Cognitive Radio Systems

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ABSTRACT: Cognitive Radio (CR) is a novel concept for improving the utilization of the radio spectrum. It is a software controlled radio that senses the unused frequency spectrum at any time from the wide but congested wireless radio spectrum. This promises the efficient use of scarce radio resources. Orthogonal Frequency Division Multiplexing (OFDM) is a reliable transmission scheme for Cognitive Radio Systems [3] which provides flexibility in allocating the radio resources in dynamic environment. It also assures no mutual interference among the CR radio channels which are just adjacent to each other, making it one of the best schemes to be used in CR systems. Allocation of radio resources is a major challenge in cognitive radio systems. In a dynamic environment, many parameters and situations have to be considered which affect the total data rate of the system. A Secondary users (CRUs/SUs) may coexist with the Primary user (PU) either on Conservative basis or on a more aggressive basis which allows secondary transmissions as long as the induced interference to the PU is below acceptable level.
Keywords: Cognitive Radio, OFDM, Primary user,CSI.

I. INTRODUCTION

The electromagnetic radio spectrum is one of the most precious and scarce natural resource. Wireless networks today follow a fixed spectrum assignment strategy, the use of which is licensed by government agencies. This results in a large portion of assigned spectrum being used only intermittently or not at all due to various factors such as amount of traffic load on licensed users or geographical variations [1]. Actual measurements by FCC [2] support this fact by showing a severe underutilization of the licensed spectrum by the licensed or primary user (PU). Due to limited availability of radio spectrum and high inefficiency in its usage, new insights into the use of spectrum have challenged the traditional approaches to spectrum management. This necessitates a new communication paradigm to harness the underutilized wireless spectrum by accessing it opportunistically. This new communication technology is referred as Dynamic Spectrum Access (DSA) or Cognitive Radio (CR). Derived from J.Mitola's doctoral thesis [4], a cognitive radio is an intelligent wireless communication system that relies on opportunistic communication between unlicensed or secondary users (SU)s over temporarily unused spectral bands that are licensed to their PUs. The FCC suggests that any radio having adaptive spectrum awareness should be referred to as Cognitive Radio [5].

In this we have considered Uplink cognitive radio system heaving one PU coexists with M SUs and A Downlink of an Multi User Orthogonal Frequency Division Multiplexing CR system with one base station (BS) serving one PU and K SUs. We focused on the design on the design and analysis of subcarrier and power allocation scheme under imperfect CSI for cognitive OFDM systems. A two –step Algorithm for bit rate is proposed to obtain the (1) subcarrier allocation to secondary users and (2) bits, power allocation on subcarriers.The algorithms attempt to maximize the total throughput of the CR system (secondary users) subject to the total power constraint of the CR system and tolerable interference from and to the licensed band (primary users).

II. COGNITIVE RADIO FEATURES

Cognitive Radio systems has been seen as a promising solution to improve the current spectrum underutilization while accommodating the increasing amount of services and applications in wireless networks [6]. Cognitive radio technology could potentially allow a complete SU system to simultaneously or opportunistically operate in the same frequency band as the PU. However, the development of cognitive radio is still at a conceptual stage due to a number of challenges it faces in how the it learns and adapts to the local spectral activity at each end of the link.

The inherent feature of these CR systems would be their ability to recognize their communication environment and adapt the parameters of their communication scheme to maximize the quality of service for the SUs while minimizing the interference to the PUs. Nevertheless, CR systems need to have a high degree of flexibility in order to overcome high variation in channel quality and interference. It will be build over software defined radio (SDR) due to implicit realization of these characteristics in SDR technology, which is already in production and is now available. The key features of CR transceivers are awareness of the radio environment (in terms of spectrum usage, power spectral density of transmitted/received signals), dynamic adaptability (adaptive tuning to system parameters such as transmit power, carrier frequency, modulation strategy etc.) and highly efficient cooperative or non-cooperative behavior (when there is competition between multiple CR transceivers).For a CR network to be deployed for practical usage a number of new technologies have to be developed. Of particular interest are the challenges involved in the design of physical and link layers. A number of new mechanisms within these layers such as measurement of network parameters, reliable spectrum sensing (detecting un used spectrum), spectrum mobility (maintaining seamless transition to a new spectrum), coexistence (with PUs and other CR networks), spectrum management, reliability (in terms of QoS), resource allocation (such as transmit power allocation and dynamic spectrum sharing (DSS)) and so on, have to be designed for most efficient and practically harmless access and sharing of opportunistic radio spectrum. In addition, it is critical to best optimize these mechanisms for different situations in order to enhance network performance. Since PU channels have to utilized by secondary users in a CR network without causing any degradation in service to PUs, Orthogonal Frequency Division Multiplexing (OFDM) has been identified as an potential transmission technology for future CR systems. This is mainly due to its great flexibility in dynamically changing spectral environments and allocating unused spectrum among SUs, which allows for simple adaptation of sub-carriers to fast changing conditions in radio spectrum. Besides, OFDM allows for multi user diversity overcoming frequency selective fading which helps to enhance the spectrum utilization in general. A major challenge is to design efficient resource allocation algorithms (spectrum sharing and power allocation) that works well in OFDM based CR networks. we specifically look at these two problems of Sub Carrier Allocation, Bit Allocation and power allocation to CRUs and we then propose and design practical algorithms for them.

III. SYSTEM MODEL AND PROBLEM

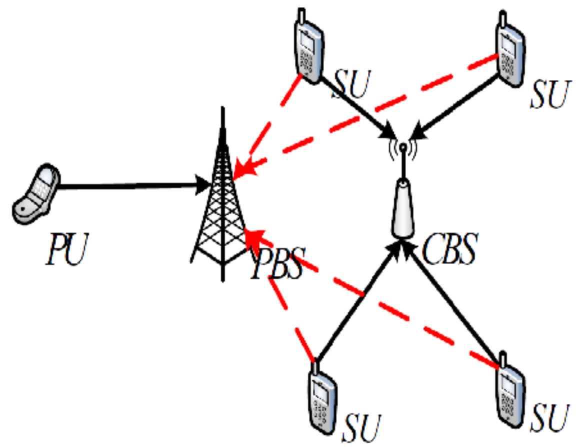

Fig. 1. Uplink CR system one PU with M SUs.

A. Channel, spectrum, and waveform based cognitive radio systems

The radio spectrum is becoming increasingly congested everyday with emerging technologies and with the increasing number of wireless devices. Considering the limited bandwidth availability, accommodating the demand for higher capacity and data rates is a challenging task, requiring innovative technologies that can over new ways of exploiting the available radio spectrum. Cognitive radio arises to be a tempting solution to the spectral crowding problem by introducing the notion of opportunistic spectrum usage. Because of its attractive features, orthogonal frequency division multiplexing (OFDM) has been successfully used in numerous wireless standards and technologies. We believe that OFDM will play an important role in realizing the cognitive radio concept as well by providing a proven, scalable, and adaptive technology for air interface. The goal of this dissertation is to identify and address some of the challenges that arise from the introduction of cognitive radio. Specically, we propose methods for obtaining awareness about channel, spectrum, and waveform in OFDM-based cognitive radio systems in this dissertation.

Parameter estimation for enabling adaptation, spectrum sensing, and OFDM system identification are the three main topics discussed. OFDM technique is investigated as a candidate for cognitive radio systems. Cognitive radio features and requirements are discussed in detail, and OFDM's ability to satisfy these requirements is explained. In addition, we identify the challenges that arise from employing OFDM technology in cognitive radio. Algorithms for estimating various channel related parameters are presented. These parameters are vital for enabling adaptive system design, which is a key requirement for cognitive radio. We develop methods for estimating root-mean-square (RMS) delay spread, Doppler spread, and noise variance As wireless communication systems are making the transition from wireless telephony to interactive Internet data and multi-media types of applications, the desire for higher data rate transmission is increasing tremendously. As more and more devices go wireless, future technologies will face spectral crowding and coexistence of wireless devices will be a major issue. Considering the limited bandwidth availability, accommodating the demand for higher capacity and data rates is a challenging task, requiring innovative technologies that can over new ways of exploiting the available radio spectrum.1 Cognitive radio over a solution to the spectral crowding problem by introducing the opportunistic usage of frequency bands that are not heavily occupied by licensed users [3]. It is a new concept in wireless communications which aims to have more adaptive and aware communication devices which can make better use of available natural resources [4]. Even though there is no agreement on the formal de¯nition, and hence capabilities, of cognitive radio as of now, the concept has evolved recently to include various meanings in several contexts [5]. One main aspect of it is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access. Other aspects include interoperability across several networks; roaming across borders while being able to stay in compliance with local regulations; adapting the system, transmission, and reception parameters without user intervention; and having the ability to under- stand and follow actions and choices taken by their users to become more responsive over time. Cognitive radios can be used as a secondary system on top of current allocation of users which are called primary (or licensed) users. In this case, secondary (cognitive) users need to detect the unused spectrum in order to be able to exploit it. Moreover, the radio should be able to shape its waveform so as to exploit only the unused part of the spectrum. OFDM is a multicarrier modulation technique that can overcome many problems that arise from high bit rate communications, the biggest of which is time dispersion. In OFDM, carrier frequencies are chosen in such a way that there is no impudence of other carriers when detecting the information bearing symbol stream is split into several lower rate streams and these streams are transmitted on deferent carriers. Since this splitting increases the symbol period by the number of non-overlapping carriers (sub carriers), multi path echoes affect only a small portion of the neighboring symbols. Remaining inter-symbol interference (ISI) is removed by cyclically extending the OFDM symbol. The length of the cyclic extension should be at least as long as the maximum excess delay (MED) of the channel. This way, OFDM reduces the effect of multi path channels encountered with high data rates and avoids the need for complex equalizers. Other advantages of OFDM include high spectral efficiency, robustness against narrow-band interference (NBI), scalability, and easy implementation by fast Fourier transforms (FFTs). OFDM is used as the modulation method for digital audio broadcasting (DAB) [6] and terrestrial digital video broadcasting (DVB-T) [7] in Europe, and in asymmetric digital subscriber line (ADSL) [8]. The wireless local area network (WLAN) [9{11], and wireless metropolitan area network (WMAN) standards [12] use OFDM as their physical layer transmission technique as well. OFDM is also a strong candidate for IEEE wireless personal area network (WPAN) standard [13], for fourth generation (4G) cellular systems (see *e.g.* [14]), and wireless regional area network (WRAN) standard which is known as cognitive radio standard [15]. Application of OFDM to cognitive radio brings about new aspects and challenges to system design. The cognitive OFDM conceptual Cognitive engine is responsible for making the intelligent decisions and conjuring the radio and physical layer (PHY) parameters. Spectral opportunities are identified by the decision unit based on the information from policy engine as well as local and network spectrum sensing data. Policy engine provides information to the cognitive engine concerning the current policies to be considered by the system depending on the location of the system. This ensures that cognitive radio does not use illegal waveforms or breach any policies. On the other hand, local spectrum sensing unit processes the spectrum information and identifies licensed users accessing to spectrum and their signal specifications such as their bandwidth and power level. It also detects spectrum opportunities that can be exploited.

IV. RESULTS

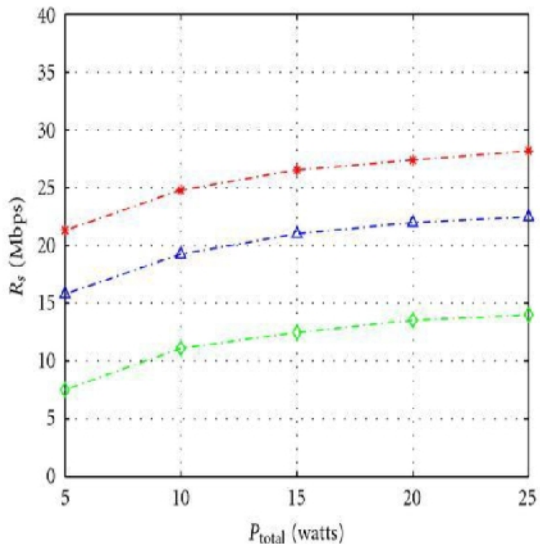

Fig. 2. Average total CRU Rs Vs total CRU transmit power for λ= [1 1 1 1] with different ρ .

The Fig. 2 shows the average total bit rate, , as a function of the total CRU transmit power, , for = 0.7, 0.9, and 1 with , = 0.02 W, and a PU transmit power, , of 5W. As expected, the average total bit rate increases with the maximum transmit power budget . It can be seen that the average total bit rate, , varies greatly with . AT = 5W, increases by a factor of 2 as increases from 0.7 to 0.9. This illustrates the big impact that inaccurate CSI may have on system performance. The , curves level off as increases due to the fixed value of the maximum interference power that can be tolerated by the PU. The graph shows the average total bit rate, , as a function of the total CRU transmit power, , for = 0.7, 0.9, and 1 with, = 0.02 W, and a PU transmit power, , of 5W. As expected, the average total bit rate increases with the maximum transmit power budget . It can be seen that the average total bit rate, varies greatly with (Fig. 3).

The Fig. 4 shows the average total bit rate, , as a function of the total CRU transmit power, for = 0.7, 0.9, and 1 with, = 0.02 W, and a PU transmit power, , of 5W. As expected, the average total bit rate increases with the maximum transmit power budget.

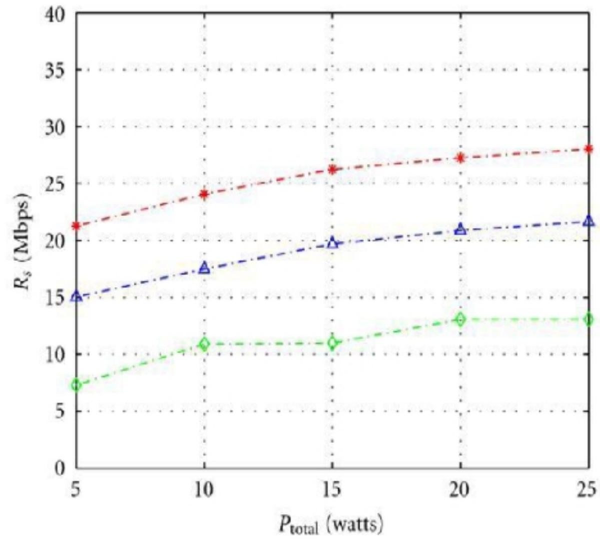

Fig. 3. Average total CRU Rs Vs total CRU transmit power for λ= [1 1 1 4] with different ρ.

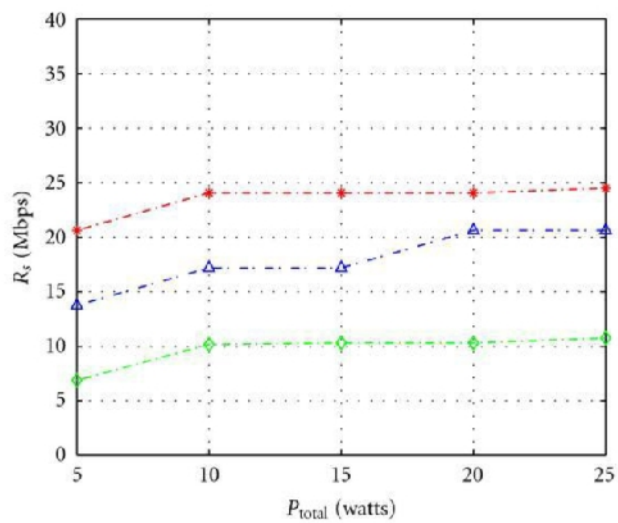

Fig . 4. Average total CRU Rs Vs total CRU transmit power for λ= [1 1 1 8] with different ρ.

It can be seen that the average total bit rate, varies greatly with . Corresponding results for **λ** = [1 1 1 4] and **λ** = [1 1 1 8] are plotted in Fig. 2 and 3, respectively. The Average total bit rate, decreases as the NBRW distribution becomes less uniform; the reduction tends to increase with.

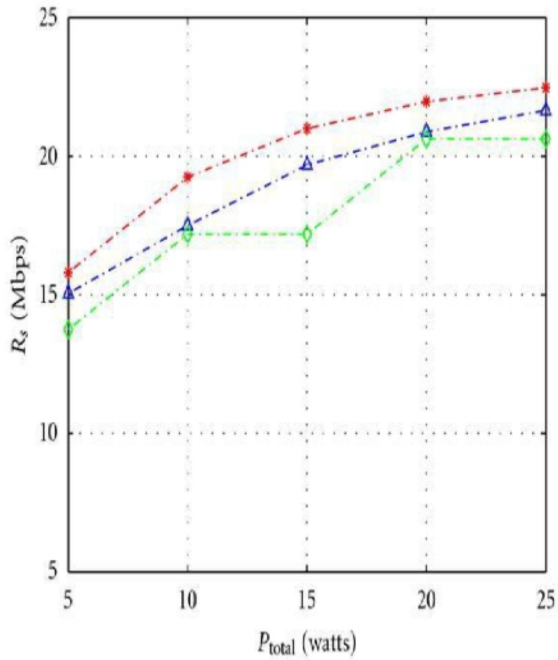

Fig. 5. Average total CRU Rs Vs total CRU transmit power for ρ = 0.9 with different λ

The above graph shows the three cases of different = [1 1 1 1], [1 1 1 4], [1 1 1 8] in the case = 0.9 .the average total bit rate, , as a function of the total CRU transmit power, , = 0.02 W, and a PU transmit power, , of 5W. As expected, the average total bit rate increases with the maximum transmit power budget . It can be seen that for **λ** = [1 1 1 1] is larger than for **λ** = [1 1 1 4], and for **λ** = [1 1 1 4] is larger than for **λ** = [1 1 1 8]. When the bit rate requirements for CRUs become less uniform, decreases due to a decrease in the benefits of user diversity. With = 15W, increases by about 30% when **λ** changes from [1 1 1 8] to [1 1 1 1].

The Fig. 6 shows the three cases of different = [1 1 1 1], [1 1 1 4], [1 1 1 8] in the case = 0.7 .the average total bit rate, , as a function of the total CRU transmit power, , = 0.02 W, and a PU transmit power, , of 5W.

As expected, the average total bit rate increases with the maximum transmit power budget .

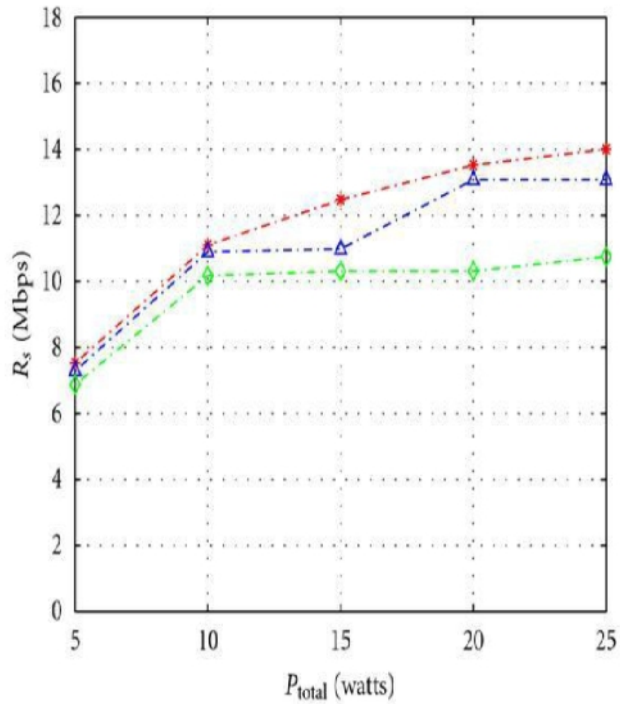

Fig. 6. Average total CRU Rs Vs. total CRU transmit power for ρ =0.9 with different λ.

It can be seen that for **λ** = [1 1 1 1] is larger than for **λ** = [1 1 1 4], and for **λ** = [1 1 1 4] is larger than for **λ** = [1 1 1 8].

When the bit rate requirements for CRUs become less uniform, decreases due to a decrease in the benefits of user diversity. With = 15W, increases by about 30% when **λ** changes from [1 1 1 8] to [1 1 1 1]. In order to get more insight of the impact of the other constraints on the average total bit rate ,we study the variety of under different maximum tolerable interference power. The average total bit rate, , is plotted as a function of the maximum PU tolerable interference power, , with = 25 W and of 5W for *ρ* = 0.9 in above graph respectively.

As expected, increases with and decreases as the CRU bit rate requirements become less uniform. The curves level off as increases due to the fixed value of the total CRU transmit power .

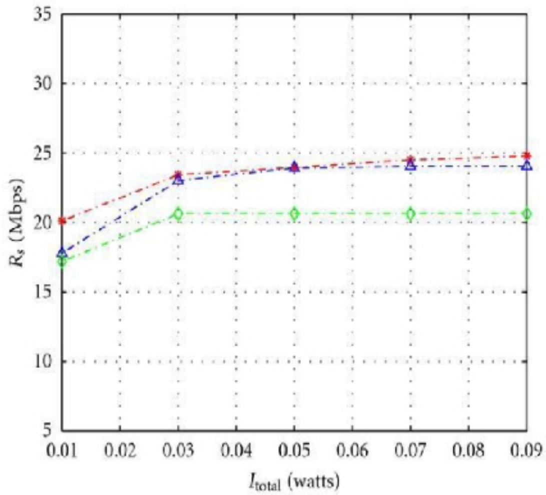

Fig. 7. Average total CRU Rs Vs. maximum PU tolerable interference power total for ρ = 0.9.

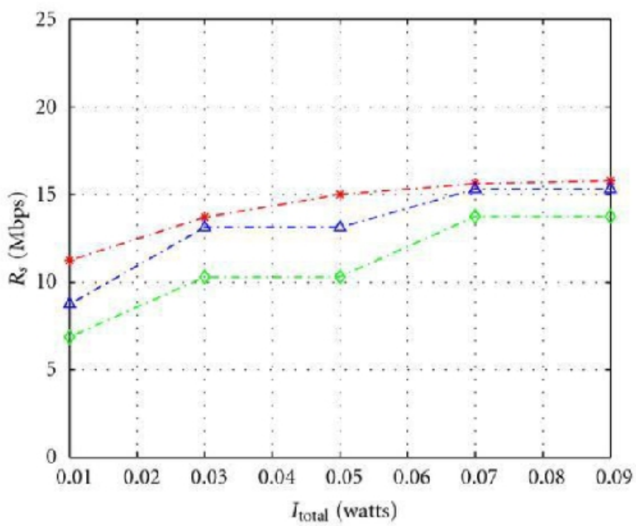

Fig. 8. Average total CRU Rs Vs. maximum PU tolerable interference power total for ρ =0.7.

The average total bit rate, , is plotted as a function of the maximum PU tolerable interference power, , with = 25 W and of 5W for ρ = 0.7 in above graph respectively. As expected, increases with and decreases as the CRU bit rate requirements become less uniform. The curves level off as increases due to the fixed value of the total CRU transmit power .

V. CONCLUSION

We have studied the sub carrier and power allocation problem with imperfect CSI in uplink cognitive radio systems. We have augmented the maximization formulation of this problem by taking into different constraints. We have proposed a two-step scheme with low computational complexity, in which sub carrier and power allocation are optimized separately. We have presented simulation results to show that when performing channel estimation with a larger number of training symbols, the sum capacity is largely increased. A realistic assumption is made on the special that all SUs have the same priority. Some algorithms were directly implemented from certain papers, which are the work done by esteemed engineers, and simply their behavior was studied. We used the system model where a primary band was operating side by side to the secondary band in a multi user system. The assumption that the transmitter always receives the channel state information perfectly is impractical for wireless systems .The system performance will degrade when the transmitter only has partial CSI. In order to maintain the system performance, an appropriate transmission schedule based on partial CSI is needed .However; the optimal resource allocation in MU-OFDM systems based on partial CSI is still an open issue. In this paper, we analyze the effects of partial channel state information on the resource allocation problem in MU-OFDM based cognitive radio systems. Based on obtained partial CSI at the transmitter, the average BER should satisfy the given BER target during transmission. As the function of average BER is to complex, we apply a Nakagami- distribution to approximate the original function. A simple function, which is close to the original function, is derived. The resource allocation problem in MU-OFDM based cognitive radio systems is computational complex. In order make the problem tractable, we solve the problem into two steps. Firstly, we apply a simple SA algorithm for sub carrier allocation. Then we apply a simple at efficient memetic algorithm to solve the bits allocation problem. Different cases of partial CSI and bit rate requirements are studied .simulation show that partial CSI has great impact on the wireless transmission. In addition, due to user diversity, the total bit rate decreases when the data the data rate requirements become less uniform.

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