Cooperative caching and coordinated beamforming technique for cognitive radio networks

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Abstract
Scarcity of frequency spectrum is one of the main issues in wireless communications. Cognitive radio networks (CRNs) have been considered as an effective way of improving the spectrum efficiency by opportunistically using the spectrum resources through appropriate cooperation between primary and secondary networks. Exploitation of content caching in CRNs can enhance the system performance and reduce the backhaul cost and delay. In this paper, we propose a combined caching strategy and base station coordination in CRNs to achieve a proper balance between the signal cooperation gain and the content diversity gain. Depending on the availability and placement of the requested content, we propose a zero-forcing coordinated beamforming technique to simultaneously transmit the most popular contents that are cached in every secondary base station and achieve the signal cooperation multiplexing gains, also we propose a maximum ratio transmission technique to deliver the less popular contents which are cached in different secondary base stations and achieve the caching diversity gain. Enumeration of the solution space search is used to obtain the optimal cache solution. Numerical results show that our proposed solution outperforms the cooperative caching and transmission solution proposed where only a maximum ratio transmission technique is used.

KEYWORDS
cognitive radio, content caching, multiplexing gain, zero-forcing coordinated beamforming

1 | INTRODUCTION

The cooperative cognitive radio network (CCRN) is emerging as a new paradigm to tackle the problem of spectrum scarcity in cognitive radio systems. The main idea is that primary and secondary systems cooperate in such a way that mutual benefit can be achieved. Unlike traditional wireless networks, cognitive radio networks (CRNs) allow dynamic allocation of spectrum resources. This enables the system to fully exploit unused spectrum band and significantly enhance system performance.

In the existing literature, the focus has been on addressing the issue of improving radio resource efficiency. Various optimization techniques have been used to formulate the problem of maximizing the usage of spectrum resources. For example, the authors in [1] proposed an optimization technique to maximize spectrum resource usage for centralized and decentralized CRNs. Self-organization approaches and optimization schemes were proposed in [2] as an effective way to achieve a network paradigm that can facilitate spectrum sensing, spectrum mobility, spectrum management, and sharing in large-scale network configurations and management in which the spectrum is continuously fluctuating. Cooperation in CRNs has been an active research topic in the last few years for improving spectrum efficiency and data transmission throughput. In this win–win strategy for both systems, the secondary users (SU) act as relays for the primary users (PU) when channel conditions between the primary transmitter and
PU$_s$ are poor, and in return, the secondary system exploits the unused spectrum of the primary system to serve its users. The work in [3] investigated the cooperative multi-relay in CRNs and proposed a resource allocation strategy to accelerate data transmission. The work in [4] studied the problem of spectrum sharing together with adaptive user cooperation in a heterogeneous cognitive relay system. In [5], the authors proposed a power-optimized approach of cooperative spectrum sensing in CRNs. In this approach, a group of secondary nodes can share the tasks of spectrum sensing to detect any gaps in the spectrum band that are underutilized by the primary nodes. The authors in [6] studied optimal power allocation in decode and forward relaying for CRNs to maximize energy efficiency. Joint information and energy cooperation was investigated in [7] and shown to substantially enhance system performance.

Wireless edge caching has been recognized as a solution to reduce the backhaul capacity requirement and delay. For example, the work in [8] presented a framework to minimize the average download delay in a wireless caching network accounting for caching capacity constraints and base station cooperation. A joint beamforming and admission control technique for a cache-enabled cloud radio access network with limited backhaul capacity was developed in [9]. The objective was to minimize the total network cost including power cost and backhaul cost while admitting as many users as possible under certain constraints such as backhaul capacity. A better transmission data throughput in wireless edge caching networks can be achieved by a joint design of caching strategy along with transmission technique. The authors in [10] suggested that some popular content files can be stored at the edge base stations to serve nearby users to increase the transmission rate. In [11], a joint cache placement in small-cell base stations equipped with limited caching capabilities was studied. As a proper balance between caching strategies is required to achieve cooperative and diversity gains that help boost the system performance, a cooperative transmission via cache helper was investigated in [12] to obtain an optimal caching placement balancing and a trade-off between diversity and cooperation gains. A hybrid caching approach for collaborative relaying was optimized in [13] to achieve the desired trade-off between cooperation and diversity gains. The authors in [14] proposed a cooperative caching and transmission in cluster-centric small-cell networks to balance transmission and content diversity. In [15], the authors proposed distributed caching of contents in small cells and cooperative transmission from nearby base stations to maximize system throughput. An optimal caching scheme was designed in a cache-enabled wireless dense small-cell network by simultaneously considering coordinated multi-point joint transmission and interference to minimize system spectrum resource consumption in [16].

Caching in CRNs was studied in [17], where the data retrieval probability was derived and analysed but the primary–secondary cooperation was not considered. The authors in [18] studied joint optimization of caching and scheduling of secondary base stations (SB$_s$) to maximize the utility of the SB$_s$. Joint optimization of content placement and bandwidth allocation for CRNs was investigated in [19] by formulating the optimization problem to maximize the SUs' average successful transmission probability under the quality-of-service constraint of the PU. The authors in [20] presented joint optimization of content caching capacity and power allocation in CRNs to maximize SB$_s$ utilization and obtain optimal solutions.

Although the issues of caching in CCRNs have been explored in several studies, our main contribution is to propose a combined caching strategy and base station coordination in CCRNs that attains a proper balance between the signal cooperation and content diversity gains achieved by caching most popular contents (MPCs) and caching largest content diversity (LCD), respectively. We classify the content files into three different groups according to content popularity and adopt different caching strategies that accommodate secondary base station storage capacity limits. We employ a group-based caching strategy to balance the cooperation and content diversity gains. We consider caching the same copies of MPC files at each secondary base station and use a zero-forcing coordinated beamforming (ZFCB) technique to simultaneously transmit the requested contents and achieve multiplexing gain. We formulate the problem as maximizing the average sum of successful transmission probabilities for SU$_s$ while satisfying a target successful transmission probability for PU$_s$. We optimize the number of the MPC files stored in all SB$_s$. The performance of the proposed caching and transmission solution is also studied in terms of the sum of successful transmission probabilities and is shown to outperform the caching and transmission solution proposed in [19] where a maximum-ratio transmission (MRT) technique is used in either a centralized or a distributed manner.

The rest of the paper is organized as follows. Section 2 presents the network model and problem formulation. The cooperative caching and transmission techniques with the optimal solution are proposed in Section 3. In Section 4, simulation results are provided followed by conclusions in Section 5.

**Notations:** Boldface upper-case and boldface lower-case letters denote matrices and vectors, respectively. R and C respectively denote the sets of real and complex numbers. The conjugate transpose of a vector is denoted $(\cdot)^H$. $E[\cdot]$ denotes the expected value of a random variable. $CN(\mu, \sigma^2)$ represents the complex Gaussian distribution with mean $\mu$ and variance $\sigma^2$.

## 2 | NETWORK MODEL AND PROBLEM FORMULATION

### 2.1 | System model

We consider a downlink transmission for the CCRN that includes both the primary and the secondary system. The primary system consists of $K$ PU$_s$ denoted PU$_1$, PU$_2$, ..., PU$_K$ and served by a single antenna primary base station (PB). $M$ SU$_s$ are denoted SU$_1$, SU$_2$, ..., SU$_M$ and served by $N$ SB$_s$ equipped with single antennae denoted SB$_1$, SB$_2$, ..., SB$_N$, as
shown in Figure 1. The SBs are ordered by the distance to PB, that is, SB1 is the closet one to PB. We denote the transmit power limit of the primary and secondary base stations as $P_P$ and $P_s$, respectively. We assume that each SB is equipped with local storage to cache content files for both the PUk and the SUn. We consider the SBs capable of sensing the spectrum environment so that when the PUk are not served by PB, the secondary system can share the primary system licensed spectrum. We assume that PUk are far from PB and closer to SBr, and hence, their communication channels to the PB are poor. This will motivate the SBs to serve the PUk to achieve its target data rate. To ensure that the received signals are decoded successfully at the receiver, perfect channel state information at the SBs is assumed.

We consider $\mathcal{F} = \{1, 2, \ldots, F\}$ as a library of $F$ contents. All the contents are of the same normalized size. These content files are sorted according to their popularity $f_i$, $1 \leq i \leq F$, $f_1 > f_2 > \ldots > f_F$, $\sum_{i=1}^{F} f_i = 1$. Each SB can store only $U$ files in its cache and $U \ll F$. We consider that the PUk and SUj are interested in the same content files. It is assumed that the popularity distributions are known a priori. We adopt Zipf law to represent the content popularity distribution [10] $f_i = \frac{1}{i^\epsilon}$, $i \in \mathcal{F}$, where $\epsilon$ is the content popularity concentration. Storing the same content files at different SBs will allow them to cooperatively transmit the content, while storing different files at different SBs will maximize the hit probability that a file can be found at the SBs.
2.2 Problem formulation

We aim to benefit both the primary and the secondary systems. We consider a combination of caching strategy and base station coordination at the SBs to serve the edge PU, to achieve their target transmission data rate in return for the secondary system gaining access to the licensed spectrum to serve its users. We formulate the optimization problem as maximizing the average sum of successful transmission probabilities for the SUs (\(p_V\)) while satisfying a target successful transmission probability for the PU, (\(p_U\)) to obtain the optimal threshold caching (V) for MPC as follows:

\[
P_1 : \max \quad p_V
\]

\[
s.t. \quad p_V \geq p_U,
\]

\[
0 \leq V \leq U,
\]

where, \(p_U\) is the target successful transmission probability for the primary system.

3 | COOPERATIVE CACHING AND TRANSMISSION TECHNIQUES

3.1 Cache model

Based on the idea of using MPC and LCD approaches, we propose a group-based caching strategy to balance cooperation and diversity gains. We divide the content files into three different groups. We exploit the threshold-based caching strategy to cache the MPC files from 1 to a threshold value V in all SBs. This threshold value is a design parameter, and 0 \(\leq V \leq U\). We cache only one copy of the files from \(V + 1\) to \(U + (N - 1) \cdot (U - V)\) in one of the SBs. Precisely, for the \(j^{th}\) secondary base station SB\(_j\), \(j \in N\), the corresponding cached files are from file \(U + (j - 2) \cdot (U - V) + 1\) to \(U + (j - 1) \cdot (U - V)\). The remaining files from \(U + (N - 1) \cdot (U - V) + 1\) to \(F\) are stored in the server, which is connected to the PB through a backhaul link.

3.2 User request model

3.2.1 Primary users

We associate K PUs with K different time slots. We group the users into three different groups based on their file requests. We denote the first group size as \(K_1\), which includes the users who request files in the MPC range, i.e. their popularity order \(f_i\) is between 1 \(\leq i \leq V\) and cached in all SBs. The users who request files in the LCD range, i.e. their popularity order \(f_i\) is between \(V\) and \(+1 \leq i \leq U + (N - 1) \cdot (U - V)\), are in the second group with size \(K_2\). All remaining users who request files cached in server, i.e. their popularity order \(f_i\) is between \(U + (N - 1)\) and \((U - V) + 1 \leq i \leq F\), are in the last group with size \(K_3\), where \(K_3 = K - K_2 - K_1\). We define the cumulative distribution function (cdf) of the file popularity distribution as \(p_i = \sum_{j=1}^{F} f_j, l = 1, \ldots, F\). Because each PU generates a content request independently but in a statistically identical manner, a user would be in the first group with probability \(p_U\) and would be in the second and third groups with probabilities \(p_{U+1} \cdot \sum_{j=1}^{N-1} (U-V) - p_U\) and \((1 - p_{U+1} \cdot (U-V))\), respectively. The multinomial probability when there are \(i\) users in the first group, \(j\) users in the second group, and \(N - (i + j)\) users in the third group is

\[
\frac{K!}{i!j!(N-i-j)!} \cdot (p_U \cdot \sum_{j=1}^{N-1} (U-V) - p_U)^i \cdot (1 - p_{U+1} \cdot (U-V))^{(N-i-j)}.
\]
3.3.1 Transmission model for PUs

a) When a PU of the first group (group size $K_1 = t$) requests a file, the requested file is cached in all SBs. A ZFB technique is used to allow all SBs to transmit the file to the requested user without causing any interference. Because each PU has a time slot allocated, serving $t$ number of users simultaneously using ZFB during $t$ time slot will create a multiplexing gain of order $t$ [15]. Because there is no closed-form expression to obtain the transmission data rate when the ZFB technique is used under individual base station power constraints, we adopt the optimization problem in [23] that maximizes user throughput as follows:

$$\max_{\{Q_i\}} \log_2 |1 + \text{diag}\{h_{k}^H Q_{n} h_{k}\}|$$

s.t. $h_{k}^H Q_{n} h_{k} = 0, \forall k \neq j,$

$$\sum_{k} |Q_{k}|_{n,n} \leq \beta P_{3n},$$

$$Q_{k} \geq 0, \forall k,$$

where $h_{k} = [b_{1,k}, \ldots, b_{N,k}]^T$ is the channel vector between the $k^{th}$ PU and $N$ SBs, and $Q_{k} \in \mathbb{C}^{N \times N}$ is the beam-forming matrix for the $k^{th}$ PU. The constraint (2b) means that there is no interference from other user transmissions. The constraint (2c) ensures that the total transmit power of SB is below the maximum transmit power. The problem in (2) is a convex optimization problem and can be solved efficiently using a numerical optimization method. We employ the successful transmission (non-outage) probability to express the performance metric [15], so the probability of successful transmission for $k^{th}$ PU is expressed as follows:

$$\bar{p}_{p,k} = \Pr\left(\log_2 \left(1 + \frac{|h_{k}^H Q_{k} h_{k}|}{N_{0}w}\right) \geq R_{k}\right),$$

where $R_{k}$ is the required transmission rate for $k^{th}$ PU, and $N_{0}$ is the noise power spectral density. Because each PU may have a different data rate and appears in the first group in different combinations, we need to consider the probability of successful transmission for all PUs, and the resulting group sum is therefore

$$\bar{p} = A \sum_{i=1}^{V} \sum_{k=1}^{K} \bar{p}_{k},$$

where $A = \frac{C_{K-1}^{K-i-1}}{K!(i-1)!}$ represents the probability of a PU appearing in the first group among $K!/(i-1)!$ combinations.

b) When a PU in the second group (group size $K_2 = j$) requests a file, it is assumed to be contained in only one SB (the SB that stores the requested file). The corresponding SB will deliver it directly through its dedicated time slot. Hence, an MRT scheme will be used. We express the probability of successful transmission for $k^{th}$ PU as follows:

$$\bar{p}_{n,k} = \Pr\left(\log_2 \left(1 + \frac{\beta P_{s}|h_{n,k}|^2}{N_{0}w}\right) \geq R_{k}\right).$$

Because each PU has a different probability of successful transmission and appears in the second group in different combinations, the resulting group sum is

$$\bar{p} = B \sum_{n=1}^{N} \sum_{i=U+(n−1)(U−V)}^{U+(n−2)(U−V)+1} \sum_{k=1}^{K} \bar{p}_{n,k},$$

where $B = \frac{C_{K-1}^{K-i-1}}{K!(i-1)!}$ denotes the probability of a PU appearing in the second group among $K!/(i-1)!$ combinations.

c) When a PU in the third group requests a file that is stored in the server (not cached), the requested file will be fetched from the server and delivered by the PB to the PU in its dedicated time slot. Similarly, an MRT scheme will be used to evaluate the probability of successful transmission for $k^{th}$ PU as expressed below:

$$\bar{p}_{p,k} = \Pr\left(\log_2 \left(1 + \frac{P_{p} |y_{p,k}|^2}{N_{0}w}\right) \geq R_{k}\right),$$

where $R_{k}$ is the required transmission rate for $k^{th}$ PU, and $N_{0}$ is the noise power spectral density. Because each PU may have a different data rate and appears in the first group in different combinations, we need to consider the probability of successful transmission for all PUs, and the resulting group sum is therefore

$$\bar{p} = D \sum_{i=U+(N-1)(U-V)+1}^{F} \sum_{k=1}^{K} \bar{p}_{p,k},$$

where $D = 1 - A - B$ indicates the probability of PU appearing in the third group among $K!/(i-1)!$ combinations. The average sum of successful transmission probabilities for the $K$ PUs in the three groups $p_{d}(V)$ can be formulated as
\[
\begin{align*}
\mathbb{P}(V) &= \frac{1}{K} \sum_{i=0}^{K} \sum_{j=0}^{K-i} \frac{K!}{i!j!(K-i-j)!} \\
\hat{p}_U^t &\left( \mathbb{P}_{U+(N-1)(U-V)} - \mathbb{P}_U \right) \left( 1 - \mathbb{P}_{U+(N-1)(U-V)} \right)^{K-i-1} \\
& \left[ \hat{p} + \tilde{p} + \overline{p} \right].
\end{align*}
\]

### 3.3.2 Transmission model for SUs

For the SU, we consider a model similar to that of the PU; however, the SB will assign the power ratio \((1 - \beta)\) to serve SU using the remaining bandwidth \((W - w)\).

a) In this case, an SU in the first group (group size \(M_1 = i\)) requests a file, the file exists in all SBs, that coordinate their transmissions to serve those \(i\) number of users simultaneously in the users' dedicated time slots using the ZFBC technique. Simultaneous transmissions will create \(i\) spatially isolated channels and achieve a multiplexing gain of order \(i [15]\). Again, we adopt optimization problem (2) to evaluate the transmission data rate for each SU as follows:

\[
\begin{align*}
\max_{\{X_m\}} & \quad \log_2 \left| 1 + \text{diag} \{g_m^H X_m g_m \} \right| \\
\text{s.t.} & \quad g^H_j X_m g_j = 0, \forall m \neq j, \quad (10a) \\
& \quad \sum_m |X_m|_{n,n} \leq (1 - \beta)P_n, \quad (10b) \\
& \quad X_m \succeq 0, \forall m, \quad (10d)
\end{align*}
\]

where \(g_m = [g_{1,m}, \ldots, g_{N,m}]^T\) is the channel vector between the \(m^{th}\) SU and \(N\) SBs, and \(X_m \in \mathbb{C}^{N \times N}\) is the beamforming matrix for the \(m^{th}\) SU. The probability of successful transmission for \(m^{th}\) SU can be calculated as follows:

\[
\hat{p}_m^i = \text{Pr}(i(W - w)\log_2 (1 + \frac{|g^H_m X_m g_m|}{N_0(W - w)}) \geq R_z),
\]

where \(R_z\) is the required transmission rate for \(m^{th}\) SU. Because each SU has a different data rate and appears in the first group in different combinations, we need to consider the data rate for all SUs, and the resulting group sum is therefore

\[
\hat{p}_m^i = \Phi \sum_{i=1}^{V} f_i \sum_{m=1}^{M} \hat{p}_m^i,
\]

b) In this case, a requested file in the second group (group size \(M_2 = j\)) appears only in one SB (the SB that stores the requested file), and the \(m^{th}\) SU will be served by the corresponding SB in its dedicated time slot. The MRT scheme will be used. The probability of successful transmission for the \(m^{th}\) SU is expressed as

\[
\hat{p}_{n,m} = \text{Pr}(W - w)\log_2 (1 + \frac{(1 - \beta)P_n |g_{n,m}|^2}{N_0(W - w)}) \geq R_z). \quad (13)
\]

As a requested file in the second group appears only in one SB and could be any one of them, we use the probability of the cached file to express the data rate. Because each SU has different data rate and appears in the second group in different combinations, we need to consider the data rate for all SUs.

The resulting group sum is therefore

\[
\hat{p} = \Psi \sum_{n=1}^{N} \sum_{i=U+(n-1)(U-V)}^{U+(n-2)(U-V)+1} f_i \sum_{m=1}^{M} \hat{p}_{n,m},
\]

where \(C_{M,i}^{M-1,j} \Phi^{M-1} C_{M-1,j}\) represents the probability of an SU appearing in the second group \((M_2)\) among \(M/|M-i-j|\) combinations.

c) In this case, when an SU in the third group (group size \(M_3 = M - i - j\)) requests a file not cached in SBs, the file will be fetched from the server via backhaul links. The transmission of the requested files to the SU will not occur until all the SBs receive them. Once the files are received, the SBs will cooperate and transmit the requested content files simultaneously to the SU using the ZFBC technique. Simultaneous transmissions can occur in their dedicated time slots, thus causing a multiplexing gain of order \((M - i - j) [15]\). As the ZFBC technique is also used in this case, we adopt the optimization problem (10) to evaluate the data rate for each SU as follows:

\[
\begin{align*}
\max_{\{X_m\}} & \quad \log_2 \left| 1 + \text{diag} \{g_m^H X_m g_m \} \right| \\
\text{s.t.} & \quad g^H_j X_m g_j = 0, \forall m \neq j, \quad (15a) \\
& \quad \sum_m |X_m|_{n,n} \leq (1 - \beta)P_n, \quad (15b) \\
& \quad X_m \succeq 0, \forall m. \quad (15d)
\end{align*}
\]
The optimization problem in (15) is convex and can be solved using the interior point method to obtain the optimum solution. The probability of successful transmission for the $m^{th}$ SU is expressed as

$$\bar{P}_m^{(M-i-j)} = \Pr((M - i - j)(W - w) \log_2(1 + \frac{|g_m^H x_m g_m|}{N_0(W - w)}) \geq R_z).$$  \hspace{1cm} (16)$$

Because each SU has a different data rate and appears in the third group ($M_3$) in different combinations, we need to consider the data rate for all SUs. The resulting group sum rate is therefore

$$\bar{P}_m^{(M-i-j)} = \Theta \sum_{i=U+(N-1)(j-V)+1}^{F} \sum_{m=1}^{M} \bar{P}_m^{(M-i-j)}. \hspace{1cm} (17)$$

FIGURE 2 Average of successful probability of secondary users (SU) versus the caching capacity when $\epsilon = 0.3$

FIGURE 3 Average of successful probability of secondary users (SU) versus the caching capacity when $\epsilon = 1.5$
The probability of the SU appearing in the third group among $M_i/M! \cdot (M - i - j)!$ combinations is 

$$\Theta = 1 - \Phi - \Psi$$

The average sum of successful transmission probabilities of the SU, $p_s(V)$ in the three groups can be formulated as

$$p_s(V) = \frac{1}{M} \sum_{i=0}^{M} \sum_{j=0}^{M-i} \frac{M!}{i! \cdot (M - i - j)!}$$

with

$$p_s^i(V)(p_{U+(N-1)(U-V)} - p_V)^{(1 - p_{U+(N-1)(U-V)})^{M-i-j}}$$

$$[p^i + p + b^{(M-i-j)}].$$

The objective function (1a) is the average of sum successful transmission probability for the SU, to be maximized. Constraint (1b) ensures that the successful transmission probability for PU, is greater than the target successful transmission probability $p_t$. Constraint (1c) ensures that $V$ is an integer value and $1 \leq V \leq U$. By substituting (18) and (9) in (1), the optimization problem has only one optimization variable $V$. Hence, a one-dimensional exhaustive search method is used to obtain the optimal caching threshold ($V^*$) by enumeration of the solution space $V = 1, \ldots, U$, which is linear in the cache size $U$ and easy to compute in practice with $O(C)$ computational complexity.

### 4 | SIMULATION RESULTS

We present simulation results of the proposed caching cooperation scheme for CRNs. The primary system consists of $K = 5$ PU, and one PB with transmit power $P_p$ is 40 dBm. The secondary system consists of $M = 5$ SU, and $N = 5$ SB, with transmit power $P_s$ of 37 dBm. Each SB has a cache capacity of $U = 60$. We assume a library of files $F = 1000$. In addition, we assume the power spectral density $N_0$ as $-144$ dBm/Hz. Furthermore, we consider power ratio $\beta$ and utilized bandwidth $\omega$ for PU as 0.75 and 4 MHz, respectively. The licensed bandwidth $W$ is 10 MHz. The path loss exponent $a$ is 4. The users are assumed to be at different distances and fixed during the optimization process. The PU and SU content requirement rates, $R_k$, $R_z$ are 4 Mbps and 2 Mbps, respectively. The target successful transmission probability for the primary system $p_t$ is 70%. For benchmark comparison, we choose the caching and transmission solution proposed in [19] where collaborative beamforming using the MRT principle in either a centralized or a distributed way has been considered.

Figure 2 compares the average of successful transmission probability of SU, and the caching threshold when the Zipf distribution parameter $\epsilon$ is 0.3. The results show that our proposed system achieves a higher successful transmission probability of SU, when a low Zipf distribution parameter $\epsilon$ is applied. It is observed that our proposed caching and transmission solution outperforms the caching and transmission solution proposed in [19]. To evaluate the impact of the Zipf distribution parameter on our proposed system, we investigate the system performance when the Zipf distribution parameter $\epsilon$ is 1.5. As shown in Figure 3, our proposed caching and transmission solution achieves the same performance as the caching and transmission solution proposed in [19].

Figures 4 and 5 depict the impact of various numbers of SU, on the average of successful transmission probabilities of $SU$, at Zipf distribution parameter $\epsilon = 0.3$ and caching.
capacity of SB $U$ of 60 and 80, respectively. The average of successful transmission probabilities of SU$_i$ increases as $M$ increases because of multiplexing gain. The performance of our proposed caching and transmission solution is consistently better than the caching and transmission solution in [19] when the number of SU$_i$ is less than 10. To assess the impact of various caching capacities $U$, we evaluate the system performance at different values of $U$ in Figure 6. Our proposed system achieves better performance as the caching capacity decreases when the Zipf distribution parameter $\epsilon$ is 0.3.

5 | CONCLUSIONS

We studied a cooperative caching and transmission technique in cache-enabled CRNs aimed to balance the cooperation and diversity gains achieved by caching the MPCs and LCD, respectively. We proposed the MPCs with ZFCB transmission technique to achieve the multiplexing gain and LCD with MRT technique to enhance system performance. We optimized the caching threshold for the MPC strategy by formulating the problem as maximizing the average sum of successful transmission probabilities for SUs while satisfying a target
successful transmission probability for the PUs. The optimal cache threshold was obtained by enumeration of the solution space search. The system performance of the proposed cooperative caching and transmission techniques was verified by numerical results and compared with the caching and cooperative caching and transmission techniques was verified by numerical results and compared with the caching and transmission solution proposed in [19]. Simulation results indicate that the performance of our proposed solution is better than that of the one proposed in [19].

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