Cognitive radio based efficient video multicast in TV white space

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Abstract
The wireless video multicast in TV White Space (TVWS) is a challenging task due to the characteristics of the wireless channels and the video streaming. This paper studies the optimized real-time video multicast in TVWS, and proposes a practical and bandwidth-efficient TVWS video multicast framework. First, a TVWS-based efficient quasi-static spectrum access scheme is employed to reduce the spectrum switch delay. Second, a cross-layer optimized resource scheduling scheme is proposed to further improve the multicast performance, which considers various cross-layer design factors, including scalable video coding, adaptive modulation-coding, to maximize the overall received video quality. Finally, the proposed resource scheduling problem is formulated as a mixed-integer non-linear programming problem. Considering that the video streaming is delay-sensitive, the problem is addressed with a proposed sub-optimal but computational efficient algorithm. The simulation results demonstrate the effectiveness and superiority of the proposed scheme.

KEYWORDS
cognitive radio network, TV white band, video transmission

1 | INTRODUCTION

The TV White Space (TVWS) refers to a large portion of spectrums in the UHF bands, which becomes available on a geographical basis after digital switchover. Currently, research on TVWS mainly focuses on how to use cognitive radio technology to obtain available spectrum and how to access it under the FCC regulations. However, research on which applications can effectively utilize TVWS through reasonable protocol design is rarely mentioned. With the proliferation of cognitive wireless devices, as well as the surge of the demand on service varieties and qualities, there is a compelling need for enabling video multicast services in TVWS to fully harvest its potential.

However, carrying out video multicast services in TVWS is a challenging task due to the inherent characteristics of TVWS and the potential requirements of video multicast services. The difficulties mainly focus on the following three aspects. (1) Channel availability is varying over time due to external factors such as noise, interference, node movement etc. (2) The temporal variation and spectrum fragmentation of the TVWS further complicate the channel conditions. (3) The characteristics of high data rate and delay-sensitive in video transmission impose strong demands on multicast scheduling protocols.

Therefore, this paper mainly studies how to solve the above key problems and design an efficient multicast protocol. The research results of this paper can effectively reduce the service load of each mobile network and improve the efficiency of its network operation.

In our work, the main contribution is reflected in three aspects.

1. We consider TVWS-based for video multicast, and present a new CR video multicast framework. TVWS consists of several UHF bands, according to their characteristics, fixed bandwidth and time.
2. We adopt an efficient quasi-static spectrum access scheme, which avoids the disadvantages of low spectrum utilization of the static spectrum access scheme and high delay of the OSA scheme.
3. We further improve the overall video quality by cross-layer optimization subcarrier scheduling scheme and propose a low complexity binary particle swarm optimization algorithm.

The rest of this paper is organized as follows: Related works are given in Section 2 and the network model of this paper is explained in Section 3. The access scheme of the spectrum is
presented in Section 4 and the optimized subcarrier scheduling is presented in Section 5. In Section 6, the solution procedure is described. In Section 7, the spectrum access scheme and algorithm presented in this paper are evaluated, and the simulation results are analysed. Finally, the conclusion of this paper is drawn in Section 8.

2 RELATED WORKS

The shortage of spectrum resources is not only due to the growing demand for wireless data transmission, but also due to the traditional static spectrum allocation method. On the whole, the spectrum utilization of communication frequency band is not high. Cognitive radio has alleviated the shortage of spectrum resources to a certain extent. With the increasing scarcity of spectrum resources, spectrum switching for media access protocols has become a new topic.

In [1], a cognitive radio network simulation model composed of primary and secondary users has been studied. In [2], a MAC protocol based on cognitive radio to meet the high-performance requirements of wireless CRNs has been proposed. Considering the QoS requirement of a wireless CRN environment, an autonomous control strategy that can identify both the main network and the CRN environment has been proposed. In [3], a priority-based data communication approach has been proposed that utilizes the cognitive radio capabilities of sensor nodes in wireless terrestrial sensor networks (TSN).

Wireless video multicasting is also a hot topic currently and many schemes have been proposed for it, for example, Ad-Hoc based video multicast scheme [4], 4G based video multicast scheme [5], Wi-Fi-based video multicast scheme [6–8]. However, TVWS based video multicast is rarely mentioned.

The development of cognitive radio technology offers the possibility of opportunistic spectrum access [9]. TVWS provides a large number of UHF bands that can be sensed and accessed [10]. Their combination will certainly promote the development of wireless multimedia. Besides, signals in the TVWS bands are transmitted farther than WiFi and 4G signals and are more readily to penetrate buildings. And the wavelength of signals in TVWS bands is sufficiently short such that resonant antennas with a sufficiently small footprint can be used which are acceptable for portable mobile devices. Therefore, Europe and North America have allowed opportunists to visit TVWS [11, 12].

Spectrum database-based access is often used for spectrum access schemes in TVWS [13]. But the scheme still has some unsolved technical issues such as the problem of positioning wireless microphone signals [14]. A traditional “opportunistic” spectrum access scheme is assumed in many works [15–17]. However, from the real system’s point of view, the traditional "opportunistic" spectrum access (OSA) scheme is impractical for video multicast system. In the OSA scheme, the spectrum sensing phase and the channel reconstruction process in each round of data transmission will cause intolerable delay to the system (it is known that the video services are very sensitive to the delay) [18, 19]. And in the OSA scheme, one UHF channel is sensed each time and used for transmission if it is available, which will lead to a low bandwidth efficiency in TVWS and greatly restrict the services that ask for high speed such as wireless high-definition videos [20, 21].

Spectrum resource scheduling is also an important part of the video multicast scheme [22, 23]. Hu et al. proposed a scalable CR video multicast framework, and an optimal resource scheduling scheme [15]. Matthew proposed an optimization framework for power control and time-frequency resource scheduling and a new algorithm based on numerical solution and optimization problem analysis, but with higher complexity [24]. Liu et al. designed a graph-based resource allocation framework and proposed a new ant colony algorithm spectrum scheduling scheme. This scheme improves the solution speed and avoids local optimization. However, it does not consider the proportional fairness of resource scheduling [25, 26].

3 SYSTEM MODEL

We consider a centralized network, which consists of a primary user and a CR network. And the CR network includes set $N$, composed of several groups of CR multicast users, and a CR base station. CR base station can sense idle UHF spectrum resources and decide its mode of allotment. We assume that the base station is equipped with $\delta$ widely tunable Omni-directional antennas accessing different bands without interfering with each other. Each user is also equipped with an antenna that matches the UHF band of user-desired video source allocated by the base station.

CR base station simultaneous multicasts $G$ real-time videos to the multicast groups. According to the received video, the user set $N$ can be further divided into $G$ subset, denote as $N_g$, $g = 1, 2, \ldots, G$. Obviously, $\cup N_g = N$. Considering that different types (standard-definition or high-definition) of videos have different data rates, we assume that the video $g$ has a data rate $R_g$.

Assuming $C$ UHF channels (each with the bandwidth of $B$) are the potential candidates for opportunistically accessed by the CR system. Within a certain time, a CR user $i$ can access a subset of the UHF channels potentially depending on its current location. This information is concisely represented by a binary channel accessibility vector $S_i = \{S_{i1}, \ldots, S_{iC}\}$, given as:

$$S_{ic} = \begin{cases} 
1, & \text{if CR user } i \text{ can access UHF channel } c \\
0, & \text{otherwise}.
\end{cases}$$

(1)

Additionally, multiple CR systems can access the same channel if they simultaneously perceive that the channel is available, which is called secondary interference. This type of interference can seriously affect the quality of communication. Hence, we introduce a special channel metric to prevent this interference, which is the expected signal to interference plus noise ratio (ESINR), given as:

$$U_{ic} = 10 \log \frac{P_i}{I_{ic} + N_0}$$

(2)

In Equation (2), $P_i$ represents the received power of CR user $i$. $I_{ic}$ is the secondary interference that user $i$ sensed in
channel $c$ and $N_0$ is the power spectral density of the additive white Gaussian noise.

For each CR user $u_i$, it should maintain a channel accessibility vector $S_i$ and an ESINR vector $U_i = \{u_1, \ldots, u_C\}$. This information is obtained by energy detection technology [27]. The CR users should periodically update this information and transmit them to the CR base station as part of a control message.

To improve transmission efficiency, adaptive modulation coding (AMC) is adopted in the PHY layer. In AMC, different modulation coding schemes (MCSs) have different bandwidth utilization ratio (BUR), for example, QPSK & FEC 1/2 (code rate) has the BUR 1 $\text{bit/s Hz}^{-1}$, 16-QAM & FEC 3/4 has the BUR 3. We consider $N$ unique MCSs in this paper, and sort them according to their BUR in the increasing order, assuming the sorted list is $\{MC_1, MC_2, \ldots, MC_M\}$, and the BUR of entry $MC_m$ in this list is set $\lambda_m$.

As shown in Figure 1, scalable video coding (SVC) is adopted in our framework to adjust the video rate commensurate with the channel conditions, in which each video is encoded into the base layer and enhancement layer. The base layer ensures basic video quality and the enhancement layer heightens the quality of the video [28].

Since the base layer carries the most important data in SVC, the most reliable MC scheme should be used. Without loss of generality, assume that the base layer is always transmitted by $MC_1$. If a user’s channel is so poor that it cannot decode the $MC_1$ signal, we consider it disconnected from the system. For users, denoted by $\mathcal{R}_g$, to determine the set of UHF channels available for all the bitwise AND of all its received channel accessibility vectors, to determine the set of UHF channels available for all users, denoted by $\mathcal{R}_g = \{\mathcal{S}^1, \ldots, \mathcal{S}^C\}$, where $\mathcal{S}^C = 1$ represents that the channel $c$ is available for all CR users, and $\mathcal{S}^C = 0$ otherwise.

**FIGURE 1** Scalable video multicast scheme

Notice the base station is equipped with $S$ antennas. In spectrum access scheme, we must select $S$ spectrums, denoted as $F = \{F_1, F_2, \ldots, F_S\}$. Considering one UHF channel (with the bandwidth 6 MHz) may not enough to support high-definition videos, we require that one spectrum can include multiple consecutive UHF channels. However, the greater the spectrum span, the greater the probability that the system will be interrupted by the primary user. Hence, we set an attenuation factor $\delta \in (0, 1)$ to limit the spectrum span. To evaluate the quality of multiple continuous channels, we define a multichannel evaluation metric called multichannel quality metric (MCQM), denoted by $M_F$ which is given as

$$M_F = \delta^{\frac{L_F}{N_F}} \sum_{c=1}^{C} \pi_c^g$$

where $L_F$ denotes the number of UHF channel spanned by $F$, binary variable $\pi_c^g = 1$ represents that the UHF channel $c$ is spanned by spectrum $F$, and 0 otherwise, and $\pi_c^g$ is the global evaluation of the channel $c$ for group $g$, given as

$$\pi_c^g = \begin{cases} 0 & \text{if } \pi_c^g = 0, \\ \frac{1}{N} \sum_{g \in N_g} \pi_c^g, & \text{otherwise}. \end{cases}$$

Remark 1: The spectrum with the maximum width (the number of UHF channels spanned by the spectrum) may not be the best candidate for access. Since the more the number of channels spanned by a spectrum, the higher probability it will be interrupted by “primary attacking” (the sudden appearance of a primary user on a UHF channel that the system is using for communications, requiring that a channel must be vacated, we call it “primary attacking”). Taking this into consideration, we introduce an attenuation factor in multichannel quality evaluation to avoid the appearance of the extra-wide spectrum.

### 5 OPTIMIZED SUBCARRIER SCHEDULING

To further improve the overall received video quality, we introduce a cross-layer optimized subcarrier scheduling mechanism for the TVWS video multicast system. The subcarrier scheduling should be implemented when new spectrum sensing data arrived. In this section, the principle of optimal subcarrier scheduling is described. Then, optimal subcarrier scheduling is implemented.

#### 5.1 Preliminaries

We consider the orthogonal frequency division multiplexing (OFDM) at the PHY layer. Assuming each subcarrier has the identical bandwidth $\Delta f$ hence there are $K = \frac{BW_F}{\Delta f}$ subcarriers which are available for the CR system, where $BW_F$ is the
bandwidth of the working spectrum $F$. Let $k = 1, 2, \ldots, K$ be
the index of the subcarrier sequence. For each subcarrier $k$ and user $i$, we first estimated SINR $\gamma i,k$. Assume that subcarrier $k$ is
spanned by the UHF channel $i$, then,

$$\hat{\gamma}_{i,k} = 10^{\log\beta i}.$$  

(5)

We consider $M$ unique MCSs in the PHY layer. Given a cer-
tain bit error ratio (BER) $P_{err}$, the SINR can be partitioned into
$M$ consecutive non-overlapping intervals with boundary points
denoted by $\gamma_m (m = 1, 2, \ldots, M)$ [29]. These boundary points are
independent of users and subcarriers are given as:

$$\gamma_m = \frac{2^{m-1} \ln(5P_{err})}{-1.5}$$  

(6)

Then, for each multicast group $g$, we can get the users set who receive till modulation-coding $MCM$ in subcarrier $k$, denote it as $L_{g,m,k}$, where each user in $L_{g,m,k}$ satisfies the condition $\gamma_m < \gamma_{m+1} (\forall i \in N_g)$.

### 5.2 Optimization criteria

In the subcarrier scheduling process, we attempt to determine the mapping relationship between the subcarrier sequence and
layers in each video accompanied by the consideration of different modulation-coding combinations. We consider the criterion which determines the received video quality for different users, and the goal is to ensure that subcarrier scheduling is “fair” across all multicast users. Hence, the concept of proportional justice is introduced in subcarrier scheduling [30]. Intuitively, proportional fair scheduling ensures that the aggregate of propor-
tional changes between a proportional fair scheduling and
any other subcarrier scheduling is always negative. Proportional fair scheduling ensures that the aggregate of pro-
portional justice is introduced in subcarrier scheduling [30]. Intuitively

$$\sum_{g=1}^{G} \sum_{m=1}^{M} l_{g,m,k} \leq 1, \forall k$$  

(9)

Packing constraint: packing constraint ensures that the total subcarriers allocated cannot exceed $K$, that is:

$$\sum_{g=1}^{G} \sum_{m=1}^{M} \sum_{k=1}^{K} l_{g,m,k} \leq K.$$  

(10)

Layer integrity constraint: layer integrity constraint ensures that if the layer $m$ in group $g$ be transmitted, the PHY layer must provide enough subcarrier resource to support rate $R_{g,m}$. Mathematically,

$$\hat{R}_{g,m} = \lambda_m \Delta f \sum_{k=1}^{K} l_{g,m,k} \geq R_{g,m} \forall g, \forall m$$  

(11)

2. Lower layer priority constraint: in some circumstances, the working spectrum may not enough to support all the layers being transmitted. Notice that in SVC, a high layer could be decoded only if all lower layers are correctly decoded. We require that the lower layer has the priority to transmit. Mathematically, if $\hat{R}_{g,m} > 0$, then for all $n < m$, $\hat{R}_{g,n} > 0$.

3. Minimum rate constraint: to ensure a minimum quality of transmission for each group. We require the transmission of the base-layer, that is $\hat{R}_{g,1} > 0, \forall g$.

### 5.4 Problem formulation

Given an allocation matrix $A$, we can obtain the number of users in group $g$ who can receive only till modulation-coding $MCM$, denote it as $n g,A, m$, which is given as:

$$n^g_{A,m} = \left| \left\{ i \in \{ k | l_{g,m,k} = 1 \} \right\} \right|$$  

(12)

where the operator $| \cdot |$ represents the number of members it contains.

By grouping the users for every group according to the highest MCSs they can receive, we can rewrite Equation (7)
as:

\[ U = \sum_{g=1}^{G} \sum_{m=1}^{M} n_{g,m}^{L} \log(Q_{g}^{(m)}) \]  

(13)

where \( Q(m) \) represents the PSNR of the received quality and can be given as:

\[
Q_{g}^{(m)} = \begin{cases} 
Q_{g}^{\bar{R}} & \text{if } m = 1, \\
Q_{g}^{\bar{R}} + \beta \sum_{s=2}^{m} R_{s,m}, & \text{if } m \geq 2
\end{cases}
\]

(14)

In problem formulation, we consider the optimal subcarrier schedule problem (SSOP) with the following two cases.

1. The working spectrum can support all the layers transmit: in this case, \( K \geq \sum_{g} \sum_{m} \left[ R_{g,m}^{\bar{R}} \right] \Delta f \), this means that we don’t need to consider the lower layer priority constraint and the minimum rate constraint in the problem formulation. The corresponding problem can be given as (SSOP1)

\[
\max_{L} U = \sum_{g=1}^{G} \sum_{m=1}^{M} n_{g,m}^{L} \log(Q_{g}^{(m)}) \\
s.t. \sum_{g=1}^{G} \sum_{m=1}^{M} l_{g,m,k} \leq 1, \forall k \\
G \sum_{g=1}^{G} \sum_{m=1}^{M} \sum_{k=1}^{K} l_{g,m,k} \leq K. \\
R_{g,m} = \lambda_{g} \Delta f \sum_{k=1}^{K} l_{g,m,k} \geq R_{g,m}
\]

(15)

2. The working spectrum is not enough to support all the layers transmit: in this case, \( K < \sum_{g} \sum_{m} \left[ \frac{R_{g,m}^{\bar{R}}}{\Delta f} \right] \), we need to consider all the constraints defined in the problem formulation. The corresponding problem can be given as (SSOP2):

\[
\max_{L} U = \sum_{g=1}^{G} \sum_{m=1}^{M} n_{g,m}^{L} \log(Q_{g}^{(m)}) \\
s.t. \sum_{g=1}^{G} \sum_{m=1}^{M} l_{g,m,k} \leq 1, \forall k \\
G \sum_{g=1}^{G} \sum_{m=1}^{M} \sum_{k=1}^{K} l_{g,m,k} \leq K. \\
R_{g,m} = \lambda_{g} \Delta f \sum_{k=1}^{K} l_{g,m,k} \geq R_{g,m} \\
\text{if } R_{g,m} > 0, \text{ then for all } n < m, R_{g,n} > 0 \\
R_{g,1} > 0, \forall g
\]

(16)

Considering that the video service has the characteristic of delay-sensitive, the solution for SSOP should be high-efficiency and lower-complexity. In the next section, we will show a desirable algorithm for solving the SSOP.

### 6 | SOLUTION PROCEDURE

The SSOP is combinatorial in nature, and the best solution can be found by an exhaustive search algorithm (ESA). However, it is computationally prohibitive to find the global optimum, since there are \( 2^{GMK} \) possible subcarrier allocation schemes to be considered. In this paper, we suggest a heuristic algorithm called binary particle swarm optimization (BPSO) for getting the suboptimal solution of the SSOP.

#### 6.1 | Overview of BPSO

The PSO suggested by Kennedy and Eberhart [32], is a population-based parallel search algorithm using a group of particles (assume the particle’s number \( NP \)). It is based on the behavior of individuals of a swarm and its roots are in the zoologist’s modelling of the movement of individuals within a population. It has been noticed that members of a group seem to share information among them, a fact that leads to increased efficiency of the group. In PSO, each potential solution is represented as a particle. Two properties (position and velocity) are associated with each particle. In a D-dimensional search space, the position and velocity of the \( i \)-th particle are represented as \( X_i = [x_{i1}, \ldots, x_{iD}] \), \( V_i = [v_{i1}, \ldots, v_{iD}] \), where each element has real values. Let \( P_{best,i} = [p_{i1}^{b}, \ldots, p_{iD}^{b}] \) and \( G_{best} = [g_{i1}^{b}, \ldots, g_{iD}^{b}] \) be the best position (with the best fitness value) of the \( i \)-th particle and the group’s best position so far, respectively. The velocity and position of each particle are updated as follows:

\[
\begin{align*}
\dot{v}_{id}^{t+1} &= \omega \dot{v}_{id}^{t} + c_1 r_1 (p_{id}^{b} - x_{id}^{t}) + c_2 r_2 (g_{id}^{b} - x_{id}^{t}) \\
\dot{x}_{id}^{t+1} &= \dot{x}_{id}^{t} + \dot{v}_{id}^{t+1}, \quad i = 1, \ldots, NP : d = 1, \ldots, D
\end{align*}
\]

(17)

(18)

where \( \omega \) is called the inertia weight that controls the impact of the previous velocity of the particle on its current one, \( c_1, c_2 \) are positive constants, called acceleration coefficients, \( r_1, r_2 \) are random numbers that are uniformly distributed in \([0,1]\), and \( t \) represents the iterative index.

Applying a high inertia weight at the start of the algorithm and making it decay to a low value through the BPSO execution, which makes the algorithm search globally, at the beginning of the search, and search locally at the end of the execution. The following weighting function \( \omega \) is used in Equation (17):

\[
\omega_{t} = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}}
\]

(19)

Equation (19) shows how the inertia weight is updated, considering that \( \omega_{max} \) and \( \omega_{min} \) are the initial and final weights, respectively. \( iter_{max} \) is the maximum iteration number.
To prevent particles from leaving the searching space (the solution space) in the iteration process, particle’s velocity is usually limited within a certain range, such as $V_{id} \in [-V_{max}, V_{max}]$, where $V_{max}$ represents particle's velocity limitation.

BPSO is also introduced in [33], enables the PSO to operate in binary spaces. The structure of BPSO is effectively the same as that of the real-valued PSO, but the position vector of a particle is a binary one. The velocity of the $d$-th element in the $i$-th particle is related to the possibility that the position of the particle takes a value of 1 or 0. It is implemented by defining an intermediate variable $S(v_{it}+1 | d)$ called the sigmoid limiting transformation:

$$S(v_{it}+1 | d) = \frac{1}{1 + e^{-(v_{it}+1 | d)}}$$

(20)

The value of $S(v_{it}+1 | d)$ can be interpreted as a probability threshold. If a random number $r$ selected from a uniform distribution in [0, 1], is less than the value of $S(v_{it}+1 | d)$. The position of the $d$-th element in the $i$-th particle at iteration $k+1$ (i.e., $x_{id}$) is set to 1, otherwise, set to 0. In BPSO scheme, Equation (18) for modifying the position vector is replaced as follows:

$$x_{id}^{t+1} = \begin{cases} 1, & \text{if } r < S(v_{it}+1 | d); \\ 0, & \text{otherwise}. \end{cases}$$

(21)

The procedure of the proposed BPSO algorithm can be summarized as the following pseudo-code

| Algorithm 1: Pseudo-code of the BPSO algorithm |
|------------------------------------------------|
| Initial the parameters $c_1, c_2, \text{iter}_m$, $\omega_{\text{max}}, \omega_{\text{min}}, V_{\text{max}}$, the particles number $NP$, and the position and the velocity of them. Set iteration index $t = 1$. |
| Set initial $P_{\text{best}}$ for all particles and $G_{\text{best}}$. |
| While $t \leq \text{iter}_m$, do |
| Update $\omega$ via Equation (19). |
| Update $v_{id}$ and $x_{id}$ via Equation (17) and Equation (18). |
| Calculate the fitness of each particle. |
| Update $P_{\text{best}}$ for all particles and $G_{\text{best}}$. |
| Update $t = t+1$. |
| End while |

6.2 BPSO for SSOP

The structure of a population of the proposed BPSO is depicted in Figure 2, in which $x_{g,m,k}^{i}$ denotes that in particle $i$, the subcarrier $k$ is allocated to the $m$ layer in the group $g$, and 0 otherwise. We now give the detailed procedures of BPSO for SSOP as follows.

1. Population initializing: in the initialization process, we first give the initial position of the particles, and the initial velocity of each particle $v_{0}^{i} \in [-V_{max}, V_{max}]$. Then we set the initial $P_{\text{best}}$ and $G_{\text{best}}$.

2. Velocity update: after setting the inertia weight by Equation (19), the $i$-th particle's velocity is updated by:

$$v_{i}^{t+1} = \omega_{1} v_{i}^{t} + c_1 r_1 (p_{c_1}^{i} - x_{i}^{t}) + c_2 r_2 (g_{c_2}^{i} - x_{i}^{t})$$

(22)

3. Modification of position of particles: the position vector of the $i$-th particle at iteration $t$ is modified as follows:

$$x_{i}^{t+1} = \begin{cases} 1, & \text{if } r < S(v_{it}+1 | d); \\ 0, & \text{otherwise}. \end{cases}$$

(23)

4. Update of $P_{\text{best}}$ and $G_{\text{best}}$: If $X_{t} + 1$ yields a bigger fitness value than $P_{\text{best}}^{t+1}$, then $P_{\text{best}}^{t+1}$ is set to $X_{t} + 1$. Otherwise, $P_{\text{best}}^{t}$ retained:

$$P_{\text{best}}^{t+1} = \begin{cases} X_{t}^{t+1}, & \text{if } f(X_{t}^{t+1}) > f(P_{\text{best}}^{t}), \\ P_{\text{best}}^{t}, & \text{otherwise}. \end{cases}$$

(24)

5. Stopping criteria: the BPSO algorithm is terminated if the iteration reaches a pre-specified maximum iteration. Finally, we set the optimal solution $L^{*}$ for SSOP as $G_{\text{best}}^{\text{iter}_{\text{max}}}$.

7 SIMULATION RESULTS

This section mainly evaluates simulation results by comparing them with another prevalent method. The simulation platform is jointly built by C, MATLAB and SVC layered video special tool JSVM. The MATLAB part is mainly used for wireless channel simulation, video sequence coding and decoding work is mainly completed by C programming language. JSVM is used to encode video sequences into SVC stream.

7.1 Network environment and simulation parameter

We consider three multicast groups, corresponding to three different videos. Each multicast group contains 30 multicast nodes that are subject to a quasi-static mobile model. In this model, nodes can move freely, but they tend to stay in a fixed position for a long time, with an active radius of 1.5 Km and the
Figure 3 shows the total throughput of the two spectrum access schemes. It can be found from the figure that the throughput of the traditional OSA scheme (about 10 Mbps) is much smaller than the proposed spectrum access scheme (about 40 Mbps). This is because the OSA scheme only accesses one channel at a time, while the proposed scheme can access multiple channels at a time. The 10 Mbps bandwidth can only support up to three 480P video multicast programs, while the 30 Mbps bandwidth can support fourteen 480P video multicast programs. In the case where the number of program sources is the same, the proposed spectrum access scheme can greatly increase the received video quality.

Figure 4 shows that the OSA scheme performs a large number of spectrum switch operations during the video transmission process. Excessive spectrum switch operation will result in a higher cumulative switch delay. In Figure 4, the cumulative spectrum switch delay is much higher than the proposed scheme. As mentioned earlier, when a primary user becomes active on an operating channel or CR base station detects a serious performance drop on its current channel, the proposed spectrum access scheme will perform spectrum switch, which is the reason for its low cumulative switch delay. In the simulation time of 440 s, the OSA scheme cumulative switch delay is about 80 seconds, which is unacceptable for delay-sensitive video transmission services. The cumulative spectrum switch delay of the proposed spectrum access scheme is only about 30 s. Therefore, the proposed spectrum access scheme is more suitable for actual network deployment.

### Evaluation of the proposed BPSO algorithm

To evaluate the performance of the proposed algorithm including computational overhead and video quality, we compared the

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**TABLE 1** Simulation parameters

| Parameter                        | Value                                      |
|----------------------------------|--------------------------------------------|
| Number of multicast group        | 3                                          |
| Number of multicast nodes in one multicast group | 30                                         |
| Migration rate of the multicast node | [0,20 m/s]                                |
| Radius of the community          | 1.5 km                                     |
| Transmitting power of the base station | 36 dBm                                     |
| Power of the user node           | 20 dBm                                     |
| AWGN noise power spectral density | −174 dBm/Hz                                |
| UHF channels                     | #21 to #51 (except for channel #37)        |
| OFDM spectrum reuse factor       | 1                                          |
| The bandwidth of a subcarrier    | 15 kHz                                     |

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movement rate randomly distributed in [0, 20 m/s]. Multicast nodes obey a quasi-static mobility model, in which nodes can move at will, but they tend to stay in a fixed position for a long time [34]. The transmit power of the base station is set to 36 dBm, and the node power is set to 20 dBm. The AWGN noise power spectral density is set to −174 dBm Hz⁻¹. We consider the UHF channels from #21 to #51 (except for channel #37). The Hata–Okumura model is employed to simulate path fading. The Jake model is employed to simulate the short-term Rayleigh fading of mobile users. The attenuation factor is set to 0.8, the OFDM spectrum reuse factor is set to 1, and the bandwidth of a subcarrier is set to 15 kHz.

Three standard SVC test video sequences (CIF, 352 × 288) are used in the simulation as video sources, including Bus, Football, and City sequences. We use the JSVM9.15 reference software to encode three video sequences into an SVC stream containing one base layer and two enhancement layers. In the process, the encoding method adopts the MGS scheme, and the GOP size is set to 16. During the simulation time (440 s), all video sequences are repeatedly sent multiple times. The important simulation parameters are lists in Table 1.
proposed BPSO algorithm with the Greedy algorithm (it has lower complexity) and the ESA (it can achieve global optimal solutions).

Figure 5 shows the computational overhead for different algorithms. It can be seen that the computational overhead of BPSO is 108 ms, the computational overhead of Greedy is 220 ms, and ESA has a higher computational overhead (it is not fully drawn in the figure). It shows that the BPSO algorithm has a shorter computational overhead than the Greedy and ESA. We know that for real-time video transmission, less computational overhead can reduce latency and improve user experience.

In Figure 6, we plot the average PSNR among all users in each multicast group. For all groups, the average PSNR obtained by BPSO is 0.2 dB lower than ESA, which is higher than Greedy 1.1 dB. It shows that BPSO is not inferior to the performance of ESA. Although it does not reach the global optimal solution, it is only slightly lower than the global optimal solution, and it is higher than the performance of Greedy.

We increase the number of channels from 3 to 15 and their impact on the quality of multicast video is shown in Figure 7. It can be seen that as the number of channels increases, the quality of multicast video continues to increase, but this increase is disproportionate. This is because we limited the number of the channel by an attenuation factor &. The figure also shows that as the number of channels increases, the average PSNR obtained by BPSO still approximates the optimal solution obtained by ESA. However, as the number of channels increases, the number of subcarriers also increases. When the number of iterations is insufficient, the BPSO algorithm deviates from the optimal solution, and Greedy behaves more clearly. This result proves that as the number of channels increases, the BPSO algorithm requires less iteration than Greedy, which means that it has a better performance when the number of video transmission spectrum increases.
7.4 Evaluation of multicast scheme

To evaluate the proposed multicast scheme, we mark three reference users who come from three multicast groups and compare the PSNR of the video that they received under the different multicast schemes. We select one frame from the video sequences decoded by the three reference users to calculate the PSNR (the eleventh frame of the bus sequence, the ninth frame of the football sequence, the tenth frame of the city sequence).

Figure 8 shows the video decoding quality. It can be seen that the PSNR of the three reference users is 30.9467, 31.9343, 31.9198 dB, respectively by the traditional opportunistic spectrum multicast scheme. And the PSNR of the three reference users is 35.6733, 37.0565, 36.6396 dB by the proposed multicast scheme. By comparing the PSNR of the reference users under different multicast schemes, we can see that when the proposed multicast scheme is adopted, the user’s decoding quality is about 5 dB higher than that of the traditional multicast scheme, which proves the superiority of the proposed multicast scheme.

Remark 2: In the problem SSOP1, the spectrum resources are rich, and each video layer is transmitted, that is, the transmission rate of each video source can be regarded as a fixed value. Therefore, we have not shown the solution process of the problem in this paper.

8 CONCLUSIONS

In this paper, we study the TVWS-based video multicast. To improve the video quality of the overall user, an efficient TVWS video multicast framework is proposed. We consider a quasi-static spectrum access scheme that overcomes the drawbacks of previous solutions that can only access one UHF channel at a time. Then, a cross-layer optimized subcarrier scheduling scheme is proposed to solve the resource allocation problem, which is formulated as an MINLP problem. To solve this NP-hard problem, we proposed a lower complexity BPSO to obtain the suboptimal solution with lower computational overhead. Finally, the simulation results show the effectiveness of the proposed algorithm and prove the superiority of the proposed scheme in TVWS based video multicast. In the future work, we can combine the scheme proposed in this paper with relay technology and cellular technology to further improve the performance of the scheme in video multicast based on TVWS.

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