Spectrum Sensing and Spectrum Allocation Algorithms in Wireless Monitoring Video Transmission

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Abstract. Video monitoring system is an important measure to guarantee people's safety. Wireless video monitoring system has been widely used with advantages of simpler construction and higher flexibility compared with traditional wired video monitoring system. Cognitive radio network is introduced into the wireless video monitoring system in this paper to improve the spectrum utilization. Cognitive radios have enabled users to utilize licensed bands opportunistically without harmful interference to licensed users. The basic concept of wireless video monitoring system is recalled in this paper first. Then we analyze the system model of the cognitive radio network based video monitoring system. We provide a centralized cooperation spectrum sensing algorithm and a priority and channel ranking based spectrum allocation algorithm. Simulation results show that our algorithms have better performance than algorithms without the consideration of priority or channel ranking.

Keywords: Cognitive radio · Video monitoring system · Cooperation spectrum sensing · Spectrum allocation

1 Introduction

With the rapid development of national economy and the improvement of our living standard, there are increasingly stringent requirements for the improvement of security facilities. As a major component of security system, video monitoring system can provide real-time surveillance video for us to find and deal with emergencies in time as well as record and store the event process, which makes great contribution to the safety, property and social stability. Therefore, video monitoring system has been gradually applied to all walks of life.

Traditional video monitoring system is a wired video system, where transmission is realized by prepositioned cables. Despite the advantage of wide bandwidth and small interference, wired video surveillance system has lots of flaws which cannot be ignored. Monitory points have to be set within the scope of the cable network, which reduces the

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flexibility of the system. Construction and installation have to take the cable pipes into consideration, which increases the cost and operating time of the system as well as the difficulty to rapidly maintain the system when failure occurs [1, 2]. Due to the existence of these defects, the access mode of video surveillance system is gradually turned into wireless. With the development of wireless communication technology, wireless video monitoring system with high flexibility and strong extendibility has increasingly broad application prospects.

However, spectrum resources are quite limited in wireless communication. The wireless spectrum is mainly allocated by a stationary policy so far. The government unifies the spectrum resources and allocates specific frequency bands to particular communication services. Spectrum resource allocation is imbalanced due to the fixed strategy. Lots of unauthorized spectrum is overloaded with some licensed spectrum being idle at the same time. A research from Federal Communications Commission (FCC) shows that the spectrum utilization of authorized frequency bands is from 15% to 85% with temporal and geographical changes [3]. Another measurement report from National Radio Network Research Test-bed (NRNRT) indicates that the average spectrum utilization below 3 GHz spectrum band is just 5.2% [4].

Wireless video monitoring system usually works in the ISM band without permission to pre-allocated frequency bands. The realization of the system has been limited because of the finite available spectrum resources and the need of ensuring not to cause interference to other users. Hence, we propose the cognitive radio network based wireless video monitoring system in this paper to improve spectrum utilization to get more efficient and extensive applications [5].

The rest of this paper is arranged as follows. A brief introduction of the cognitive radio network and the framework of cognitive radio based video surveillance system are provided in Sect. 2. A centralized cooperation spectrum sensing algorithm and a priority and channel ranking based spectrum allocation algorithm are proposed in Sects. 3 and 4, respectively. The performance of the algorithm is verified in Sect. 5. Section 6 concludes this paper.

2 System Model

2.1 Cognitive Radio Network

The traditional fixed spectrum allocation scheme has been unable to satisfy the increasing needs for high quality communication with the rapid growth of wireless communication services. Therefore, dynamic spectrum access technology arises to provide more wireless spectrum for cognitive radio users, resulting in cognitive radio network.

The cognitive radio technology is the most important part in cognitive radio network, which allows the secondary users (SUs) to detect idle spectrum bands and share them with other users without causing harmful interference to primary users (PUs), thus improving the average utilization of spectrum resources. Cognitive radio can help the secondary users with the following functions [3, 6]: Determine available spectrum bands and discover the occupation of licensed bands by original authorized users timely (Spectrum Sensing), select the optimal idle channel (Spectrum Management), share the available spectrum bands with other cognitive users fairly (Spectrum Sharing), move out of current channel immediately when a primary user is detected or the channel quality becomes unacceptable (Spectrum Mobility).

The relationship between the above four functions can be concluded as a basic cognitive cycle [7, 8], as shown in Fig. 1. Secondary users detect the radio environment by spectrum sensing to estimate the channel occupancy of primary users and other secondary users. The spectrum quality report will be given in the spectrum analysis step with the help of spectrum sensing results. Spectrum decision helps to assign best available channel to cognitive users on the basis of channel quality and different user requirements [9, 10].

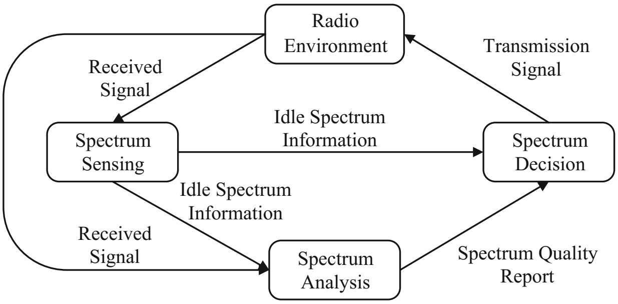

Fig. 1. The basic cognitive cycle [7, 8].

2.2 Framework of Cognitive Radio Based Wireless Video Monitoring System

The cognitive radio network based video monitoring system proposed in this paper mainly consists of front end video capture system with cognitive radio devices, wireless transmission system, sensing data fusion center and monitoring center. The system structure diagram is given in Fig. 2.

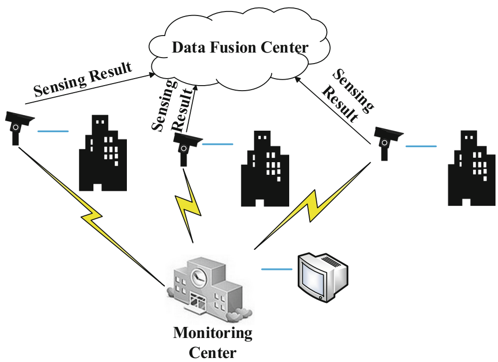

Fig. 2. The structure diagram of the cognitive radio based wired video monitoring system.

The video capture system is composed of a plurality of capturing front, which capture and process real time video signals by preset cameras. Cognitive radio equipment detect the radio environment and send spectrum sensing results to the fusion center. Available channels are allocated to different capturing front according to fusion results as well as the priority of users. Compressed encoded video stream is transmitted through the assigned channels to corresponding monitoring center to be decoded and displayed on the monitoring interface.

3 Centralized Cooperative Spectrum Sensing Algorithm

Spectrum sensing enables SUs to identify radio environment and detect spectrum holes, which is a crucial technique in cognitive radio network. Spectrum sensing algorithms can be classified into non-cooperative detection and cooperative detection. Each SU selects their own sensing method such as energy detection, match filter detection and cyclostationary feature detection and makes their own spectrum decision in non-cooperative spectrum sensing, which is easy to implement. Cooperative spectrum sensing can reduce the uncertainty of single SU caused by interference and noise, thus improving the accuracy of spectrum decision. We use centralized cooperative spectrum sensing algorithm in this paper where all users transmit their sensing data to the fusion center, who makes global spectrum decision according to all sensing data and assigns channels to users.

The users need to process the sensing signal to build a Bayesian model before sending to the fusion center. We will use the same sensing signal acquisition model as in our previous work [11, 12], which is summarized as follows.

We choose $Y(k)$ to be our observations of channel k, which obeys exponential distribution, as expressed in Eq. (1):

$$Y(k) \sim Exponential(\lambda_k) \; = Gamma(l = 1, \lambda_k) \tag{1}$$

$$\lambda_k \triangleq 1/\sigma_k^2 + \sigma_0^2 \tag{2}$$

λ_k is the parameter of the exponential distribution, where σ_k^2 and σ_0^2 are the variance of Gaussian distribution of signal variable and noise variable, respectively. Detailed derivation process is provided in [11]. We use Gamma distribution as the conjugate prior of λ_k to build a Bayesian model, that is:

$$\lambda_k \triangleq Gamma(a_k, b_k), p(\lambda_k) = \frac{b_k^{a_k}}{\Gamma(a_k)} \lambda_k^{a_k - 1} e^{-\lambda_k b_k} \tag{3}$$

The posterior distribution of λ_k can be represented as in Eq. (4) giving n observations according to the Bayesian theory:

$$p(\lambda_k | \{Y(k)\}_n) = Gamma(a_k + nl, b_k + n\overline{Y(k)}) \triangleq Gamma(a'_k, b'_k) \tag{4}$$

$$\widehat{(1/\lambda_k)}|\{Y(k)\}_n = E[(1/\lambda_k)|\{Y(k)\}_n] = \frac{b'_k}{a'_k - 1} \tag{5}$$

where $\overline{Y(k)}$ is the main value of n observations and $\widehat{(1/\lambda_k)}$ represents the Bayesian estimation of channel state parameter.

Our previous work [11] focus on large-scale cognitive radio network where we need to group the users with the same channel state distribution parameters and fuse the sensing data within each group in a distributed manner. In this paper, we discuss a small-scale cognitive radio network where all video monitoring users share the same channel conditions. The fusion center obtains the global channel state parameter based on Eq. (4) according to the observations from all users by updating parameters (a'_k, b'_k).

4 Priority Based Spectrum Allocation Algorithm

High-definition real-time video monitoring system can restore event scenarios accurately after an emergency to ensure the safety of people's life and property. However, large amount of transmission data has brought great challenges to the limited spectrum resources. Limited bandwidth may not be able to meet the HD video transmission requirements for all video surveillance users in practical applications.

Prioritizing the users according to the urgent degree of emergency events is a good solution to above problem. Add intelligent analysis module to video monitoring system to discover unexpected events, determine the emergency degree of the incident and set higher priority for users with more urgent events. Under normal circumstances with no emergency, users with lower priority can sacrifice video clarity to reduce data transmission rate and save resources for other users. In case of an emergency, alarm and improve the priority of corresponding user immediately to provide greater bandwidth to achieve real-time transmission and storage of high-definition video, thus ensuring timely tracking and accurately recording emergencies.

We combine wireless video monitoring system and cognitive radio network with centralized cooperative spectrum sensing algorithm in Sect. 3, where the data fusion center processes the sensing data of all users to obtain globally consistent spectrum decision results and allocates channels according to the priority of user events. The specific steps of the algorithm are shown in Table 1.

We will realize the algorithm and analyze simulation results in the next section.

5 Simulation Result

In our simulation scenarios, we considered a cognitive radio network in a 15 km × 15 km square area which is further divided into 9 grids with the size of 5 km × 5 km. Each PU works on one of 32 channels located in the middle of one grid randomly. It can be considered as a PU works on multiple channels if multiple PUs happen to be in the same location. The probability of the channel occupancy of each PU is 1/3 and transmission signals go through a Rayleigh channel and attenuate according to the free

Table 1. The channel allocation algorithm

1) All video monitoring users with cognitive radio equipment in the same network detect the radio environment at the same time and send their sensing results, the observations $Y(k)$ of channel k mentioned in Section 3, to data fusion center.
2) Data fusion center uses observations of all users to update the distribution parameters (a'_k, b'_k) of the state parameter λ_k of each channel according to Equation (4) and utilizes the updated distribution parameters to estimate the channel state parameter according to Equation (5).
3) For each channel k, compare λ_k with a preset threshold. Channel k is considered unavailable when λ_k is larger than the threshold, and vice versa.
4) All available channels from step 3 will be ranked according to the large of λ_k . Channels with larger λ_k will be considered to have better conditions than those with smaller state parameters.
5) Data fusion center assigns the available channels to users based on their event priority by providing more channels with better conditions for users with higher priority.

space propagation model. Video monitoring users are located randomly in the middle grid. We considered a channel unavailable if the received signal from corresponding PU is larger than the noise power according to the interference temperature model proposed by FCC [13]. The noise threshold is set to be −90 dBm.

We compare three algorithms in this paper. The first one is the channel ranking and priority based spectrum assignment algorithm proposed in the previous section where all channels are ranked based on their channel state parameter and users with higher priority will get more and better channels. Instead of sorting the channels first, we will compare the channel state parameter with a preset threshold to determine channel availability in second and third algorithms. We will take user priority into consideration in second algorithm where high priority users will get more available channels randomly selected from spectrum pool. In the third algorithm, each user will get the same number of available channels.

There are 32 channels which can be allocated to 10 cognitive video monitoring users if available. The probability of a user to have the highest priority, lower priority and lowest priority is 0.3, 0.2 and 0.5, respectively. Each of them will get three, two and one channel. We use the total “benefits” that all users can get to measure the performance of each algorithm. If a channel assigned to a user is actually available, the user will obtain certain benefits. The benefits each user can obtain from each idle channel are set to be 1.5, 1.25 and 1 for the highest priority, lower priority and lowest priority users, respectively.

The comparison of the performance of three algorithms is shown in Figs. 3 and 4, with receiver SNR being set to be 10 dB and 20 dB, respectively. The abscissa represents decision threshold. As we can see, the performance of the two priority based algorithms is much better than the third algorithm without considering the user priority. Furthermore, the performance of the algorithm without channel ranking changes with the decision threshold and is poorer than the first channel ranking based algorithm under most thresholds. All channels are sorted and allocated to users based on their channel state parameter in the first algorithm without comparing to a threshold, so its performance doesn't vary with threshold.

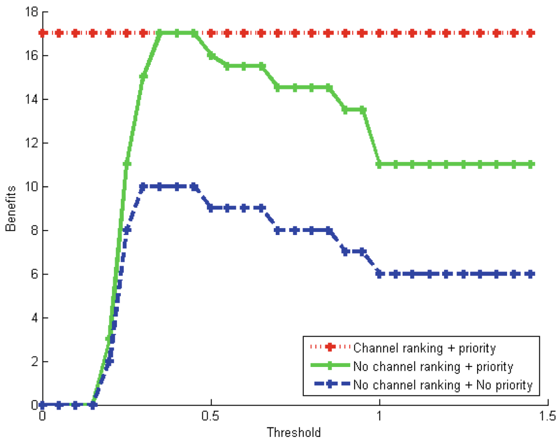

Fig. 3. The comparison of the three algorithms (SNR = 10).

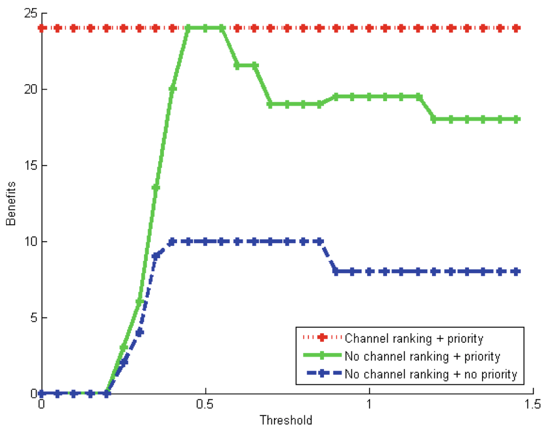

Fig. 4. The comparison of the three algorithms (SNR = 20).

We can also see from Figs. 3 and 4 that receiver SNR will influence algorithm performance. Figure 5 shows the effect of receiver SNR on the performance of our algorithm. The receiver SNR will influence the spectrum sensing accuracy, thus affecting algorithm performance. We can see that algorithm performance gets better when SNR increases.

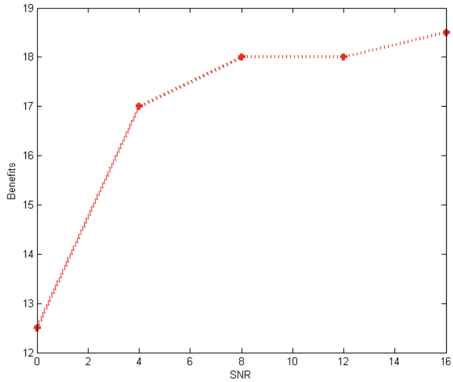

Fig. 5. The effect of receiver SNR on the performance of our algorithm.

Figure 6 compares the accuracy of cooperative and non-cooperative spectrum sensing algorithms. The correct detection probability of cooperative spectrum sensing algorithm is apparently higher than non-cooperative spectrum sensing algorithm under the same false alarm probability. Figure 7 shows the effect of user number on the performance of our algorithm. The number of users who can get the channels is fixed on 10 while the number of users who participate in cooperative spectrum sensing changes. We can see from the two figures that the uncertainty of single-user spectrum sensing reduces and the algorithm performance gradually reaches the optimal when the number of cooperative spectrum sensing users increases.

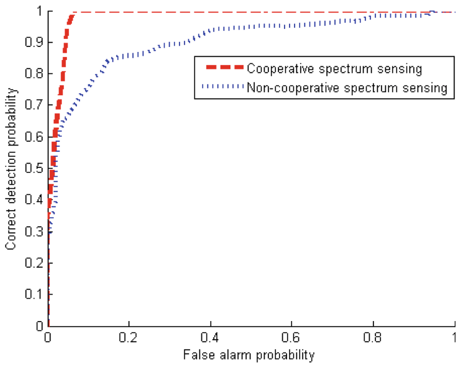

Fig. 6. The comparison between cooperative and non-cooperative spectrum sensing.

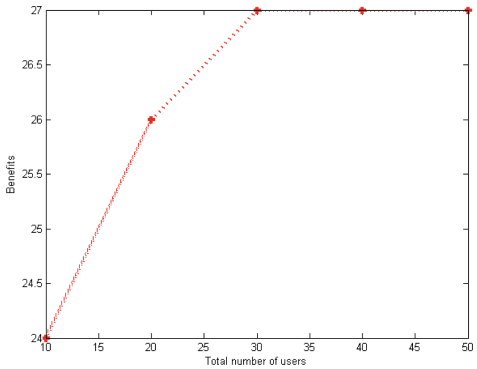

Fig. 7. The effect of user number on the performance of the algorithm.

6 Conclusion

In this paper, we first introduced cognitive radio network into wireless video monitoring system to increase spectrum efficiency. Then we proposed a centralized cooperation spectrum sensing algorithm and a priority and channel ranking based spectrum allocation algorithm where we sort the channels to provide more and better channels to higher priority users. Our simulation results proved that compared with algorithms without consideration of priority or channel quality, the performance of our channel assignment algorithm is much better.

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