Improving Reliability in Cognitive Radio Networks Using Multiple Description Coding

Abdelaali Chaoub[1] and Elhassane Ibn Elhaj[2]

[1] Electronic and Communication Laboratory,
Mohammadia School of Engineers,
Mohammed V-Agdal University, Rabat, Morocco
chaoub.abdelaali@gmail.com
[2] Department of Telecommunications,
National Institute of Posts and Telecommunications, Rabat, Morocco
ibnelhaj@inpt.ac.ma

Abstract. This paper looks at the problem of multimedia traffic transmission over Cognitive Radio networks in a delay sensitive context and under lossy network conditions. Secondary Users are allowed to share the vacant subchannels using the Time Division Multiple Access method based on the Opportunistic Spectrum Sharing. Each Secondary User is assigned one time slot where it habitually transmits with a certain probability. The given model allows each Secondary User to transmit opportunistically in the remaining slots. Accordingly, the reasons for packets to be discarded are threefold: primary traffic interruptions, collisions between the competing secondary users and erasures due to subchannels fading. To mitigate the collision effects, an innovative idea is to exploit the Multiple Description Coding technique. More particularly, a specific packetization framework derived from the Priority Encoding Transmission is used to deal with the packet loss pattern. Numerical simulations, in view of Message Error Probability and Spectral Efficiency, show that the system still exhibit good secondary traffic robustness despite of the presence of primary reclaims, secondary collisions and subchannel errors.

Keywords: Cognitive Radio, multimedia transmission, TDMA, Collision, Multiple Description Coding, Priority Encoding Transmission, SPIHT.

1 Introduction

Last decades have witnessed an enormous proliferation of services and applications which has increased the need for more bandwidth leading to a real spectrum availability crisis. However, real measurements underline a low and discontinuous usage of the licensed spectrum in time and space [1] [2]. As a result, Cognitive Radio (CR) [3] brings a concept shift as a new paradigm to find strategies for enhancing and sustaining the growth of multimedia and wireless networks with limited spectrum.

Characterizing reliability in Opportunistic Spectrum Sharing (OSS) [4] based CR networks is one of the major bottlenecks in the performance evaluation of multimedia

V.V. Das and J. Stephen (Eds.): CNC 2012, LNICST 108, pp. 99–108, 2012.

traffic transmission under secondary use constraints regarding the multiple interactions between primary (PUs) and secondary users (SUs) and between the SUs themselves.

To overcome the problem of packet loss incurred by lossy CR environments, lost packets are modeled as erasures and error correcting codes could be employed [5]. This approach comprises two axes: channel coding and/or source coding. The channel coding is used to compensate for the corrupted packets and source coding permits recovering the secondary content up to a certain quality commensurate to the number of packets received. In this work and like in [6], we adopt a Multiple Description Coding (MDC) method which is among the most appropriate techniques widely used to communicate multimedia content over lossy packets network.

1.1 Previous Works

There exist little research efforts on the problem of secondary traffic transmission over Cognitive Radio networks using Multiple Description Coding. In [5], Kushwaha, Xing, Chandramouli and Subbalakshmi have studied the coding aspect over CR networks. Principally, the paper has given an overview of the multiple description codes as source coding well suited for use in CR networks. For simulation results, the paper has adopted the LT codes to combat the secondary use losses under the CR architecture model defined in [7]. This study was an attempt to give a general analyze of MDC applications on CR networks and no numerical results have been presented for this specific coding scheme. In [8], Husheng has investigated the use of MDC in cognitive radio systems to overcome the losses caused by the primary traffic arrival on the secondary applications that are delay sensitive with some tolerable quality degradation. Using a Gaussian source, he has proposed an algorithm to turn the selection of rates and distortions into an optimization problem for the expected utility. The primary users' occupancy over each frequency channel was modeled as a Markov chain. Numerical results have been presented for real time image coding. However, this study has not considered the sharing aspect of CR networks due to the opportunistic spectrum access feature and consequently there is an additional packets loss average due to collision effects which degrades considerably the system Spectral Efficiency. Moreover, this study has considered only the Gaussian sources and need to be generalized to more sources types. Recently, in the paper [6], the issue of multimedia transmission over CR networks using MDC has been treated, but OSS conflicts have been omitted.

1.2 Novelty of this Article

The current work is addressing the multimedia transmission problem through opportunistic CR Systems in lossy environments. To solve this issue, the paper [9] has examined the possibility of using fountain codes under different subchannel selection policies in a noisy environment. Primary traffics are assumed to evolve following a Poissonian process. Herein and instead of LT codes, the MDC approach is considered. A Bernoulli distribution with parameter p_a is used to modelize the arrival of the primary user. As in [7], one packet is sent per subchannel. The network topology providing the infrastructure for the multimedia communication in a secondary use scenario is depicted and discussed. Particularly, our main attention is paid to multimedia applications that are delay constrained with a targeted distortion measure. So, the secondary stream delivery has a predetermined delay not to exceed, under some allowed distortion. Time Division Multiple Access (TDMA) method has been adopted as a mean for sharing the same CR infrastructure among multiple cognitive devices (SUs). Meanwhile, we have opted for an efficient time slot allocation. In fact, secondary users transmit one after the other, each principally using its specific time slot i with some probability q . Nevertheless, as far as the secondary transmission is opportunistic, the same secondary user could utilize the other slots if it has data to transmit out of its own slot like urgent packets or prioritized data, let p be the probability that this SU convey its packets in the remaining slots $j \neq i$ (Fig. 1) [9]. Realistic CR contexts are distinguished by their complexity and the multitude of factors involved in shaping their performance. Thus, for ease of exposition we are going to be concerned only with three chief factors influencing the reliability of the cognitive transmission: first, primary traffic interruptions causing harmful interferences to the secondary signal. Second, cognitive transmissions may collide with one another due to the fact that each secondary peer attempts to transmit opportunistically in the remaining slots reserved for the other secondary peers. Last, data packets may be disrupted because of subchannel characteristics like shadowing. In the present CR network model, collision occurs when two or more secondary users attempt to deliver a packet or many packets across the same Secondary User link (SUL) at the same time, in other words the dynamics between the competing secondary users where accessing the available secondary user links is the root cause of secondary mutual collisions. So it is clear that the occurrence of collisions may impede the performance of the CR network. Multiple Description Coding technique has been employed as a join source channel coding to cope with the specific pattern of loss examined, namely: primary traffic interruptions, packet collisions and subchannel fading. In deed, the media stream is progressively encoded using a scalable compression algorithm like the well known SPIHT [13]. The paper make use of a specific source coding structure that implements the Priority Encoding Transmission (PET) packetization technique of Albanese et al. [10] (Fig. 2). Different amounts of Forward Error Correction (FEC) are allocated to different message fragments according to their contribution to the image quality. The used FEC can be Reed Solomon codes [11] or any error correcting codes like Fountain codes [12]. Making use of the MDC in conjunction with the PET based packetization scheme in CR networks enables recovering the multimedia data content up to a certain quality commensurate to the number of received descriptions and provides reliability in various secondary applications against the resulting erasures.

The remainder of this paper is organized as follows: In Section 2 the analytic expression of the Message Error Probability which considers primary traffic interruptions, TDMA collisions and subchannel characteristics is computed. Then, the Spectral Efficiency expression is derived. Section 3 evaluates the influence of the proposed model parameter settings on the secondary traffic transmission performance in view of the Spectral Efficiency and finally Section 4 draws some conclusions.

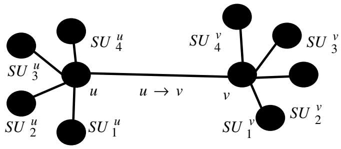

Fig. 1. Shared Cognitive Radio network

2 Proposed Network Model

2.1 General Analysis

Consider an infrastructure based CR network collocated with a licensed network. The primary traffic evolves following a Binomial distribution and Secondary Users $(SU_i)_{1 \le i \le M}$ share the temporarily unoccupied spectrum holes using the TDMA method (Fig .1). In particular, we aim at discussing the efficiency of the secondary multimedia service provision under delay constraints. Time is slotted into frames. The frame consists of M slots each of the same time duration T .

The practical model of the opportunistic spectrum access defined in [9] will be reused here. Each Secondary user SU_i always transmits in its assigned slot i with probability q and transmits with probability p in the remaining time slots ($M-1$ slots). At the start of every slot i, a SUL is formed by selecting a set of S subchannels from different PU bands of the spectrum pool, let T_{sens} denotes the SUL setup time. Then, SU_i starts conveying its packets over this SUL during the data duration T_{data} . So, $T = T_{sens} + T_{data}$. For simplicity of analysis and without loss of generality, data time should be confused with time slot [6]: $T \approx T_{data}$.

The probability of PU appearance on any subchannel is given by p_a . p_a is assumed to be independent for different subchannels. Let π be the subchannel fading and noise probability supposed to be the same for all the subchannels. In a specific time slot, several SUs could be actives and using this slot for transmission or reception at the same time and over the same subchannel. Hence, collisions could occur on the network.

To cope with unreliability in the proposed CR network model, MDC features are exploited to enable the provision of multimedia service to a meaningful degree.

2.2 Problem Formalization

The Multiple Description Encoded message is divided into L descriptions $(D_l)_{1 \le l \le L}$ and consists of N packets. Stream 1 is the first stream (most important data), and stream L is the last stream (least important data). In fact, the SPIHT compression scheme [13] generates progressively a scalable bit stream from the initial image. Then, the bit stream source is partitioned into L fragments $(N_l)_{1 \le l \le L}$ indexed in order of decreasing importance and each fragment is blocked into K_l source blocks. Some redundancy amount (FEC) is added to each message fragment such that the sub stream N_l and the FEC form a description D_l (Fig. 2). Let FEC_l be the length of FEC assigned to the $l'th$ stream where $l \in \{1,\dots,L\}$. We state that $N = N_l + FEC_l$. Unlike [6], the question of how much FEC amount to assign to each layer will not be addressed in this contribution.

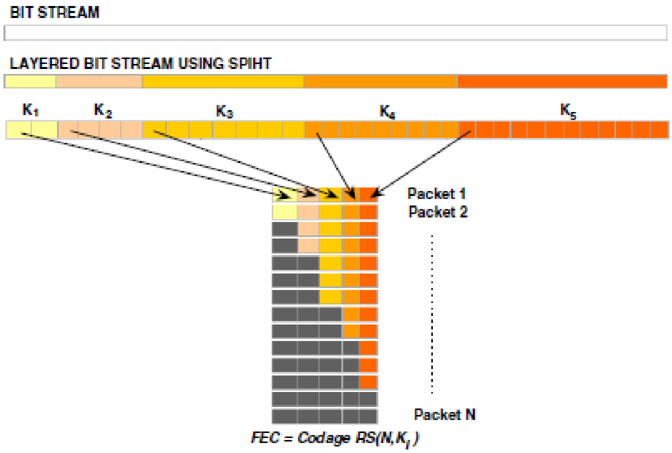

Fig. 2. Multiple Description Coding framework based on Priority Encoding Transmission

The use of MDC on CR networks permits to improve the spectrum efficiency by sending only some descriptions instead of sending the whole stream. Thereby, the involved spectrum resources are minimized and service provision is ensured as long as packet losses did not reach a certain threshold corresponding to the FEC_l protecting the given description D_l.

Under a targeted level of quality given by a certain description D_{l_0} where $l_0 \in \{1,\dots,L\}$, let u and v be two active secondary users (Fig. 1). The objective is to study the Spectral Efficiency of the communication $u \to v$ for the given description D_{l_0}. Define P_{err,l_0} as the message error probability of the transmission $u \to v$ (Fig. 1). In the given scheme for secondary use, the message error probability P_{err,l_0} is introduced as the probability that the active cognitive user v could not reconstruct the stream D_{l_0} sent by u. In other words, if (1) $FEC_{l_0} + 1$ or more subchannels got jammed due to the arrival of PUs, or (2) the transmission $u \to v$ is subject to collisions affecting at least $FEC_{l_0} + 1$ packets, or (3) the corrupted packets, due to fading and noise, overcome the FEC average FEC_{l_0}, the $l'th$ description of the message can not be successfully reconstructed at the receiver.

Then, P_{err,l_0} is computed as:

$$P_{err,l_0} = P_{reclaim,l_0} + P_{collision,l_0} + P_{fading,l_0} . \quad (1)$$

$P_{reclaim,l_0}$ is the probability that the active Cognitive user v fails to receive N_{l_0} packets over the selected SUL due to primary traffic interruptions. $P_{collision,l_0}$ is the probability that there is at least $FEC_{l_0}+1$ secondary communications that coincide at the same time slot over the same subchannels in the selected SUL. P_{fading,l_0} is the probability that at least $FEC_{l_0}+1$ subchannels are subject to fading and noise.

2.3 An Analytical Expression for $P_{reclaim,l_0}$

This communication will succeed only if at most FEC_{l_0} subchannels are claimed by their associated licensed users. Hence, the message error probability for the secondary users, which takes into consideration only the Primary traffic interruptions, is given by:

$$P_{reclaim,l_0} = \sum_{n=1}^{N_{l_0}} \binom{N_{l_0}+FEC_{l_0}}{FEC_{l_0}+n} p_a^{FEC_{l_0}+n} (1-p_a)^{N_{l_0}-n} . \tag{2}$$

2.4 An Analytical Expression for $P_{collision,l_0}$

Let i be the time slot assigned to the active Cognitive user u and Deg_v defined as the number of neighbors of the active cognitive user v ($\left(SU_i^v\right)_{1\le i\le 4}$ in Fig. 1).

Let P_c be the probability that there is some collisions perturbing the transmission $u \to v$ on a given subchannel. As shown in [9], P_c can be written as:

$$P_c = 1 - \frac{q(1-p)+(M-1)p(2-p-q)}{M}(1-p)^{Deg_v-1} . \tag{3}$$

The description D_{l_0} is considered useless if the collisions occur on at least $FEC_{l_0}+1$ subchannels. Hence, using (3), the total average probability of collisions for the description D_{l_0} is:

$$P_{collision,l_0} = \sum_{i=1}^{N_{l_0}} \binom{N_{l_0}+FEC_{l_0}}{FEC_{l_0}+i} P_c^{FEC_{l_0}+i} (1-P_c)^{N_{l_0}-i} . \tag{4}$$

2.5 An Analytical Expression for P_{fading,l_0}

π is assumed to be the subchannels shadowing coefficient. Then,

$$P_{fading,l_0} = \sum_{i=1}^{N_{l_0}} \binom{N_{l_0}+FEC_{l_0}}{FEC_{l_0}+i} \pi^{FEC_{l_0}+i} (1-\pi)^{N_{l_0}-i} . \tag{5}$$

From (2), (4) and (5), P_{err,l_0} is completely defined.

The spectral efficiency of the given description l_0 could be written as:

$$Eff_{l_0} = \frac{\left(1 - P_{err,l_0}\right) \times L \times N_{l_0}}{S \times W \times T_{data}} \quad . \tag{6}$$

Where W is the subchannel bandwidth and L is the packet length.

3 Numerical Results

For these experiments, we used Lenna image compressed with SPIHT using a bit rate of $r = 0.146\ bit/pixel$ for data and FEC bytes. We consider an ATM transmission. ATM Packets consist of 48 bytes where 1 byte is reserved for sequence number. Therefore, a total of $N = 100$ packets are needed. The image needs to be transmitted over a TDMA CR network in a maximum delay of $T_{data} = 1ms$. Subchannel bandwidth is $W = 100kHz$ and the estimated traffic average on the assigned slot i is $q = 98\%$. p_a and π has been fixed respectively at 0.08 and 0.02.

Fig. 3 depicts the impact of the average traffic in the remaining slots $j \neq i$ on the message error probability P_{err,l_0} . Deg_v and M values has been fixed respectively at 1 and 5. As it is seen and according to what was theoretically expected, the message error probability performs good results where increasing the number of FEC packets. In deed, at a specific time slot, as long as the number of subchannels that will carry the FEC packets increases, it become very unlikely that two Secondary Users transmits over the same subchannel and consequently more chance to avoid collisions. It is also interesting to note that, for some FEC values, there is an optimal p value that minimizes the message error probability. Carefully designing the opportunistic transmission plays a critical role in cognitive radio systems to reach a good compromise between efficient sharing of licensed spectrum and reliability.

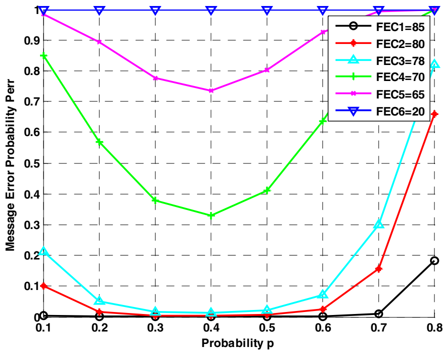

Fig. 3. Message Error Probability for $Deg_v = 1$ and $M = 5$

Fig. 4 illustrates the achieved Spectral Efficiency over Cognitive Radio network shared by several SUs using TDMA technique plotted against the probability p . Here, the impact of the FEC on the traffic transmission performance is analyzed. The following settings $Deg_v = 1$ and $M = 5$ are fixed. Thus, on one hand we find an optimal p value $(p \approx 40\%)$ that maximizes the system Spectral Efficiency and on the other hand, the quantity Eff_{l_0} attains another maximum at a specific value of FEC $(FEC \approx 78)$. For large number of FEC, i.e. a big amount of protection, transmission is reliable and consequently the probability of messages error is small which increases the Spectral Efficiency. However, large number of FEC results in a reduced number of information symbols N_{l_0} which degrades the Spectral efficiency.

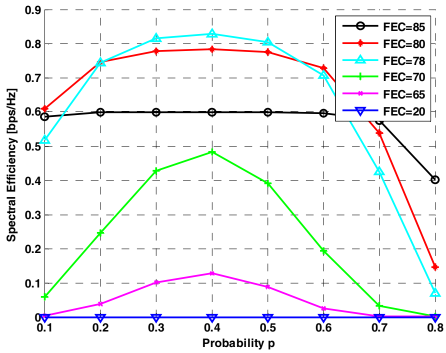

Fig. 4. Achieved Spectral Efficiency for $Deg_v = 1$ and $M = 5$

In Fig. 5, the computed Message Error probability is given versus the probability p ; simulations were run for several FEC values, $M = 5$ and $Deg_v = 3$. It can be observed that high traffic performance in view of P_{err,l_0} is attained where increasing FEC_{l_0} values. Nevertheless, where increasing Deg_v for 1 to 3, the message

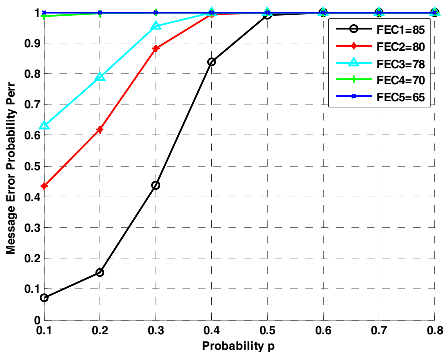

Fig. 5. Message Error Probability for $Deg_v = 3$ and $M = 5$

error probability has been increased. It is obvious that where increasing the number of neighbors, the chance that this SU interferes with the other active cognitive users get increased. On the other hand, it is noticed that there is no optimal value of the probability p maximizing the system Spectral Efficiency.

Fig. 6 represents the Spectral Efficiency against the probability p for several values of FEC_{l_0} . The slots number has been fixed at 5 and Deg_v has been increased to 3. The Spectrum Efficiency has been degraded by increasing the number of neighbors of the active CR user v . The reason is obvious, more neighbors means more active SUs which will arouse more collisions. Where increasing the amount of FEC, the Eff_{l_0} improves and there is no local maximum of the graph which means that increasing the traffic p decreases the efficiency of the spectral resources for those specific system parameter settings.

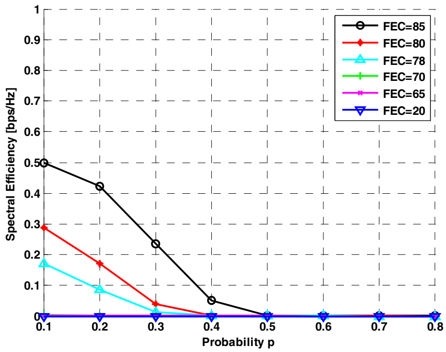

Fig. 6. Achieved Spectral Efficiency for $Deg_v = 3$ and $M = 5$

4 Conclusion

In this paper, the issue of delay constrained multimedia transmission over Cognitive Radio networks is examined. In deed, the TDMA frame is opportunistically shared by several SUs. We have suggested the use of MDC approach to improve the efficiency of CR networks against the unreliability caused by primary traffic reclaims, opportunistic collisions and subchannels shadowing. The numerical simulations have been presented in terms of the Message Error Probability and the Spectral Efficiency. The achieved results prove the effectiveness of the given solution to achieve a good balance between several system parameters and the packet loss pattern.

References

1. Shared Spectrum Compagny. Spectrum occupancy measurement, `http://www.sharedspectrum.com/measurements/`
2. NTIA, U.S. frequency allocations, `http://www.ntia.doc.gov/osmhome/allochrt.pdf`

3. Mitola III, J.: Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio. Ph.D Thesis, KTH Royal Institute of Technology (2000)
4. Cabric, D., Mishra, S.M., Willkomm Foster, D., Broderson, R.W.: A Cognitive Radio approach for usage of virtual unlicensed spectrum. In: Proc 14th IST Mobile and Wireless Communication (2005)
5. Kushwaha, H., Xing, Y., Chandramouli, R., Subbalakshmi, K.P.: Erasure Tolerant Coding for Cognitive Radios. In: Mahmoud, Q.H. (ed.) Cognitive Networks: Towards Self-Aware Networks. Wiley, Chichester (2007)
6. Chaoub, A., Ibn Elhaj, E., El Abbadi, J.: Multimedia Traffic Transmission over Cognitive Radio Networks Using Multiple Description Coding. In: Abraham, A., Lloret Mauri, J., Buford, J.F., Suzuki, J., Thampi, S.M. (eds.) ACC 2011, Part I. CCIS, vol. 190, pp. 529–543. Springer, Heidelberg (2011)
7. Willkomm, D., Gross, J., Wolisz, A.: Reliable link maintenance in cognitive radio systems. In: First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Baltimore, pp. 371–378 (2005)
8. Li, H.: Multiple description source coding for cognitive radio systems. In: 2010 Proceedings of the Fifth International Conference on Cognitive Radio Oriented Wireless Networks & Communications (CROWNCOM), Cannes, pp. 1–5 (2010)
9. Chaoub, A., Ibn Elhaj, E., El Abbadi, J.: Multimedia traffic transmission over TDMA shared Cognitive Radio networks with Poissonian Primary traffic. In: International Conference on Multimedia Computing and Systems, Ouarzazat, pp. 378–383 (2011)
10. Albanese, A., Blömer, J., Edmonds, J., Luby, M., Sudan, M.: Priority encoding transmission. IEEE Transactions on Information Theory 42, 1737–1744 (1996)
11. Mohr, A.E., Riskin, E.A., Ladner, R.: Generalized multiple description coding through unequal loss protection. In: IEEE International Conference on Image Processing, Kobe, pp. 411–415 (1999)
12. MacKay, D.J.C.: Fountain codes. IEE Proceedings Communications 152, 1062–1068 (2005)
13. Said, A., Pearlman, W.A.: A new, fast, and efficient image codec based on set partitioning in hierarchical trees. IEEE Transactions on Circuits and Systems for Video Technology 6, 243–250 (1996)