Proceedings of the World Congress on Engineering and Computer Science 2008
WCECS 2008, October 22 - 24, 2008, San Francisco, USA

Dynamic Channel Switching based on Rank Accounting in IEEE 802.22 WRAN System with Fast Channel Switching Technology

Harumasa Kinoshita*, Takuji Tachibana†, and Kenji Sugimoto‡

Abstract— **In this paper, we propose dynamic channel switching based on rank accounting so that WRAN systems can utilize channels effectively without strict coordination. In the proposed method, a base station in each WRAN cell has a ranking database where each rank denotes the usage frequency of channels. When the rank of a channel is high (low), the channel is (is not) used frequently for data transmission. Based on the ranking database, each WRAN cell utilizes an unused channel whose rank is high. Moreover, the proposed method utilizes the number of failures for channel switching in order to avoid the collision. By using the proposed method, it is expected that WRAN cells can perform channel switching with a small number of channels effectively. We evaluate the performance of the proposed method by simulation, and we investigate the effectiveness of the proposed method. Numerical examples show that the failure probability of channel switching for the proposed method is almost zero. In addition, it is shown that the proposed method uses a small number of channels effectively.**

Keywords:* *cognitive radio, IEEE 802.22, WRAN, channel switching, rank information

1 Introduction

Recently, wireless communication technologies such as Wireless LAN, 3G cellular system, and WiMAX are widely utilized for several types of services, and then a wide range of radio frequencies is assigned for these technologies. In especial, because frequencies below the 6 GHz band are suitable for mobile communication systems, many wireless communication systems have utilized these frequencies in Japan [1]. In the future, a shortage of these radio frequencies will occur and it is indispensable to utilize radio frequencies effectively.

Cognitive radio is one of the most promising technologies for the effective utilization of wireless resources [2, 3]. Here, cognitive radio is an extension of software defined radio [4, 5]. In cognitive radio, channels are utilized without harmful interference to the incumbent licensed services by using spectrum sensing.

Currently, IEEE 802.22 wireless regional area networks (WRAN) has attracted attention as the first worldwide standard based on the cognitive radio [6, 7]. IEEE 802.22 WRAN system provides a fixed point-to-multipoint wireless broadband networks and utilizes the channels allocated to TV broadcast services (from 41 MHz to 910 MHz). Therefore, it is indispensable to prevent the in-use channel from interfering with the incumbent services. For this end, cognitive radio technology is used in IEEE 802.22 WRAN.

As an intelligent interference avoidance method, in [8], dynamic frequency hopping (DFH) has been proposed. In DFH, each WRAN cell uses an in-band channel for data transmission and performs spectrum sensing on out-of-band channels simultaneously, which is called simultaneous sensing and data transmission (SSDT) [9]. After a WRAN cell uses its own in-band channel for at most two seconds, the WRAN cell selects a channel among out-of-band channels which has not been used by incumbent services. Then, the WRAN cell uses the selected channel to transmit data and performs spectrum sensing on out-of-band channels again.

Moreover, in order for multiple WRAN cells to perform DFH effectively, a phase-shifting DFH has been proposed [9]. In this method, each WRAN cell shifts its own DFH operation phase by small time. This method can reduce the number of used channels significantly. However, the phase-shifting DFH operation requires strict coordination for WRAN cells [9], and hence it is not simple to operate phase-shifting DFH among multiple WRAN cells.

In this paper, we propose dynamic channel switching based on rank accounting so that WRAN systems can utilize channels effectively without the strict coordination. In the proposed method, a base station in each WRAN

*Graduate School of Information Science, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan. Email: harumasa-k@is.naist.jp

†Graduate School of Information Science, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan. Tel/Fax: +81-743-72-5352/5359 Email: takuji-t@is.naist.jp (Corresponding author) This research was supported in part by Kinki Mobile Radio Center.

‡Graduate School of Information Science, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan. Email: kenji@is.naist.jp

cell has a ranking database, and the rank of each channel denotes its usage information. Based on the ranking database, each WRAN cell uses a channel with a high rank for data transmission among channels which have not been utilized by other services. By using a channel with a high rank, the number of used channels decreases and hence, limited number of channels are utilized effectively. In addition, when each WRAN cell selects a channel, the number of failures for the channel switching is utilized in order to avoid the collision. With the proposed method, it is expected that WRAN cells can perform the channel switching effectively and the limited number of channels can be utilized effectively. We evaluate the performance of the proposed method by simulation, and we investigate the effectiveness of the proposed method.

The rest of the paper is organized as follows. Section 2 shows the system overview of IEEE 802.22 WRAN and some related works, and Section 3 explains our proposed dynamic channel switching based on rank accounting. Numerical examples are shown in Section 4 and finally, conclusions are presented in Section 5.

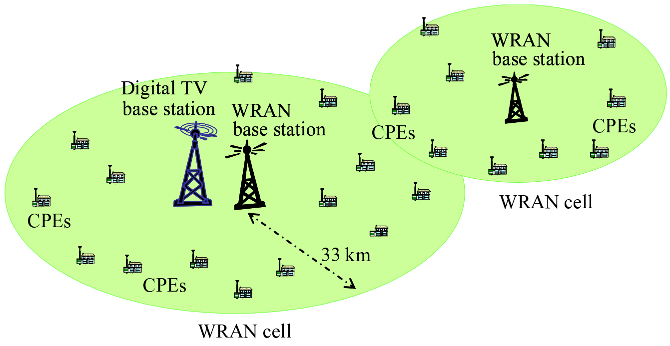


Figure 1: IEEE 802.22 WRAN system.

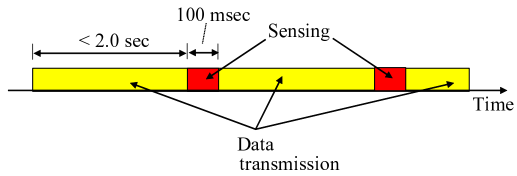


Figure 2: Data transmission and channel sensing on a channel.

2 IEEE 802.22 WRAN

2.1 System Overview

Recently, wireless regional area networks (WRAN) have been standardized in IEEE 802.22 as wireless broadband networks. In IEEE 802.22 WRAN, the channel allocated to TV broadcast services (from 41 MHz to 910 MHz) can be used by using cognitive radio technology [6, 7].

Figure 1 shows an example of IEEE 802.22 WRAN system. This WRAN system provides a fixed point-to-multipoint wireless network, and the current specified coverage area, which is called WRAN cell, has a 33 Km radius. This coverage area of WRAN system is much larger than those of other wireless network systems due to its higher power and the favorable propagation characteristics of TV frequency bands [7].

A WRAN cell consists of a base station and some consumer premise equipments (CPEs) as shown in Fig. 1. Each base station controls the medium access in its cell and transmits in the downstream direction to the various CPEs. On the other hand, each CPE transmits in the upstream direction. The minimum peak throughput at a cell edge is 1.5 Mbps for the downstream direction, and 384 kbps for the upstream one.

In WRAN system, it is indispensable to prevent the used channel from interfering with the incumbent services such as TV broadcast. For this end, WRAN system utilizes a distributed sensing technology. If a base station senses that the used channel has interfered with the incumbent services, it stops utilizing the channel and tries to use other channels. If a CPE senses the interference, the CPE sends the interference information to the base station and the base station tries to use other channels.

2.2 Dynamic Frequency Hopping

Each WRAN cell has to stop transmitting data and sense the used channel at least every two seconds to avoid the interference with digital TV service (see Fig. 2). A sensing period is required from tens of milliseconds up to more than 100 milliseconds. Because data can not be transmitted on the used channel during the sensing period as shown in Fig. 2, the sensing process decreases data throughput.

In order to increase data throughput by using channels effectively, dynamic frequency hopping (DFH) has been proposed [8]. In DFH, each WRAN cell uses an in-band channel for data transmission and performs spectrum sensing on out-of-band channels simultaneously, which is called simultaneous sensing and data transmission (SSDT) [9]. After a WRAN cell uses its own in-band channel for at most two seconds, the WRAN cell selects a channel among out-of-band channels which has not been used by incumbent services. Then, the WRAN cell uses the selected channel to transmit data and performs spectrum sensing on out-of-band channels again. The WRAN cell repeats this procedure every two seconds.

Figure 3 shows how a WRAN cell performs DFH on four channels. In the first period, the WRAN cell uses CH2 for data transmission and performs spectrum sensing on

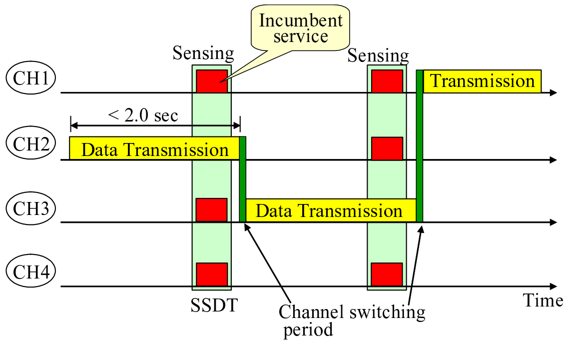


Figure 3: Dynamic frequency hopping with simultaneous sensing and data transmission.

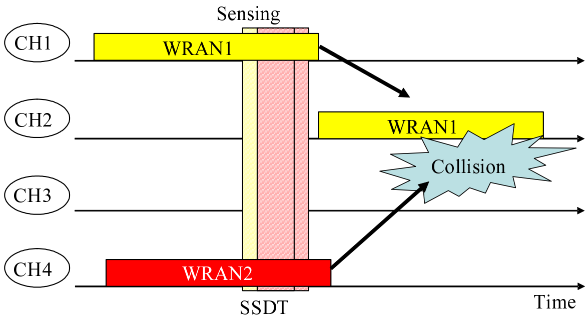


Figure 4: Collision for channel switching.

CH1, CH3, and CH4. Because CH1 has been used by an incumbent service during spectrum sensing, the WRAN cell selects CH3 as the next channel among CH3 and CH4. After the channel switching period finishes, the WRAN cell uses CH3 for data transmission and performs spectrum sensing on other channels.

2.3 Phase-Shifting DFH

When a WRAN cell uses channels according to DFH, the WRAN cell requires at least two channels in order to perform data transmission and reliable sensing in parallel. Figure 4 shows how a collision occurs when two WRAN cells perform DFH respectively. This fact implies that the number of channels has to be twice as much as the number of WRAN cells to avoid collisions. If the number of WRAN cells is two, four channels are required as shown in Fig. 5. Therefore, DFH still requires a large number of channels.

In order to resolve this issue, a phase-shifting DFH has been proposed [9]. Figure 6 shows how three WRAN cells utilize four channels by using the phase-shifting DFH. As shown in this figure, each WRAN cell shifts its own DFH operation phase by one quiet time against the operation phase of the previous WRAN cell. During a quiet time, only one WRAN cell performs spectrum sensing. Hence,

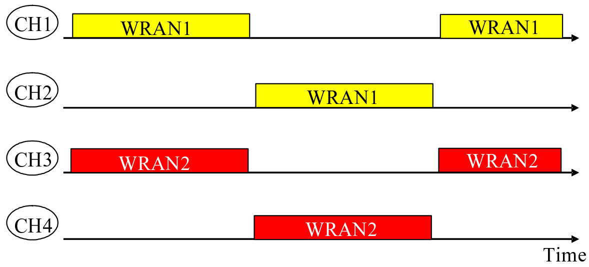


Figure 5: Channel utilization for collision avoidance in case of two cells.

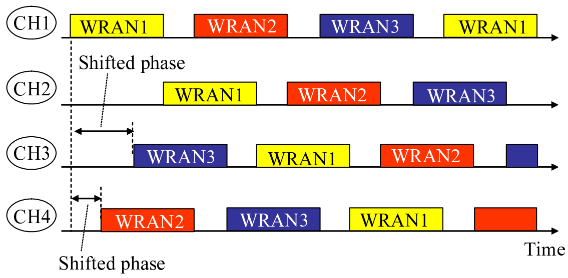


Figure 6: DFHC operation.

each WRAN cell can always use an idle channel without collisions. When the number of WRAN cells is N, $N+1$ channels are used, decreasing the number of the used channels.

On the other hand, in the phase-shifting DFH, strict coordination has to be performed among all WRAN cells. This strict coordination can be achieved by using DFH community (DFHC) [9]. Nevertheless, the utilization of phase-shifting DFH is still difficult due to strict coordination.

3 Dynamic Channel Switching Based on Rank Accounting

In this paper, we propose a dynamic channel switching method with ranking database. This method never requires strict coordination for all WRAN cells, and each WRAN cell operates independently. Hence, the operation of this method is simple.

3.1 Channel Switching Procedure

In the proposed method, a base station in each WRAN cell has a ranking database which includes rank information for each channel. Channels with higher (lower) ranks are (are not) likely to be frequently used for data transmission by WRAN cells.

Now, we consider the channel switching for a WRAN cell when the number of channels is M. Let $r_i(n)$ $(0 \leq$

ISBN: 978-988-98671-0-2

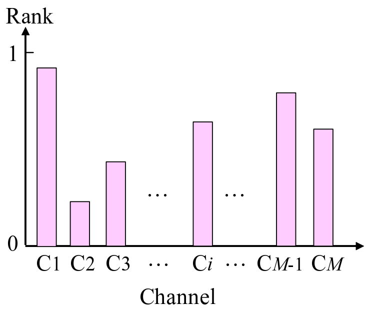


Figure 7: Rank information for each channel.

$r_i(n) \leq 1$) denote the rank of channel c_i $(i = 1, \cdots, M)$ after the nth channel switching (see Fig. 7). Moreover, let $F(n)$ denote the number of failures of the channel switching among the n channel switchings, where $F(0)$ is equal to zero. The base station in the WRAN cell performs the $n+1$th channel switching by using the proposed method as follows.

1. The base station performs spectrum sensing, and it checks which channels have been utilized by other WRAN cells.

2. The base station updates its own ranking database so that rank $r_i(n)$ of the used (unused) channel i increases (decreases). The details are explained in the next subsection 3.2.

3. The base station selects an unused channel whose rank is the $\{F(n)+1\}$th largest among all the unused channels.

4. If the $n+1$th channel switching succeeds at step 3, $F(n+1) = F(n)$. Otherwise, $F(n+1) = F(n) + 1$. Then, return to step 1.

3.2 Rank Accounting

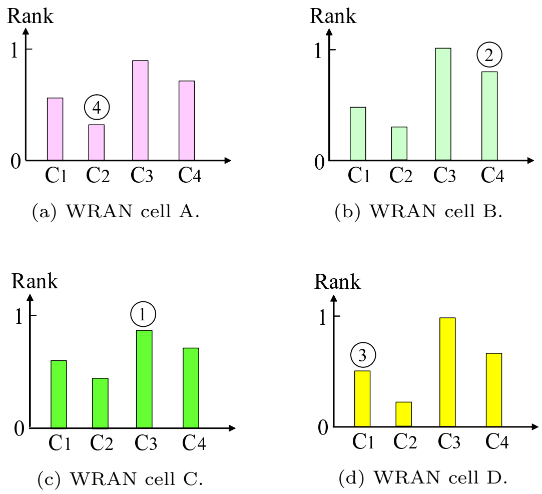
At step 2 of the proposed method, the base station updates its own ranking database based on the channel usage information which is obtained by spectrum sensing. In our proposed method, exponential moving average is used due to its simple implementation.

For channel x which has been used by another WRAN cell, rank $r_x(n)$ is updated as follows.

$$r_x(n+1) = (1-\alpha)r_x(n) + \alpha, \qquad (1)$$

where α is a parameter in the interval [0,1]. For channel y which has not been used, rank $r_y(n)$ is updated as follows.

$$r_y(n+1) = (1-\alpha)r_y(n). \qquad (2)$$



(a) WRAN cell A. (b) WRAN cell B. (c) WRAN cell C. (d) WRAN cell D.

Figure 8: Ranking database of each cell.

For in-use channel z, rank $r_z(n)$ is updated as follows.

$$r_z(n+1) = (1-\alpha)r_z(n) + \alpha. \qquad (3)$$

In order to use the limited number of channels effectively, each WRAN cell should use channels which are not currently used but are likely to be used. From (1) and (2), ranks of channels which are likely to be used are high and ranks of channels which are not likely to be used are low. Therefore, at step 3 in our proposed method, each WRAN cell selects an idle channel whose rank is large.

3.3 Collision Avoidance

In WRAN system, the channel switching is performed quickly after the spectrum sensing. Therefore, each WRAN cell does not finish spectrum sensing while a WRAN cell is changing the in-use channel. This ensures that the ranking order of channels are the same for all WRAN cells. Figure 8 shows ranking databases of four WRAN cells, and $r_2(n) < r_1(n) < r_4(n) < r_3(n)$ is satisfied for all cells.

When multiple WRAN cells perform the channel switching nearly simultaneously, WRAN cells may select the same channel. In this case, a collision occurs and results in the failure of channel switching. In order to avoid this collision, all WRAN cells have to select different channels. Fortunately, the ranking orders in all ranking databases are the same. Therefore, the proposed method utilizes the number of failures of the channel switching $F(n)$. By using $F(n)$, all WRAN cells can use different channels without collision. For example, in Fig. 8, $F(n)$ of cells A, B, C, and D is four, two, one, and three, respectively. Therefore, each WRAN cell can select different channels without collision.

ISBN: 978-988-98671-0-2

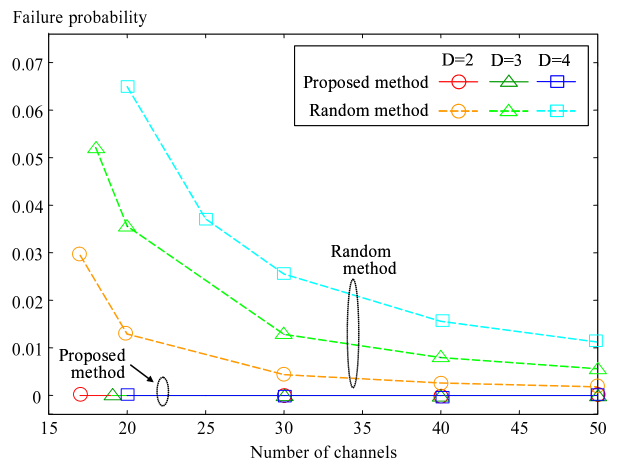


Figure 9: Failure probability of channel switching vs. number of channels.

4 Numerical Examples

In this section, we evaluate the performance of the proposed method by monte-carlo simulation. In the following, the number of WRAN cells is 15 and the number of available channels is M. We assume that each base station performs the channel switching every two seconds and that the sensing period is 10 ms. In addition, the channel switching period is set to 100 μs.

Each WRAN cell starts the operation from a start time which is uniformly distributed on [0, 2]. As shown in the previous subsection 3.3, we assume that each WRAN cell does not finish spectrum sensing while a WRAN cell is changing the in-use channel. In the situation, each WRAN cell performs channel switching by using the proposed method. In the following, α is set to 0.2 in (1), (2), and (3).

For the performance comparison, we also evaluate the performance of a simple channel switching method, which is called random method. In this method, each base station selects a channel among idle channels at random.

4.1 Impact on Failure Probability of Channel Switching

First, we investigate how the failure probability of channel switching changes by using the proposed method. Figure 9 shows the failure probabilities for the proposed method and the random method against the number of channels M. In this figure, D denotes the number of WRAN cells which perform the channel switching at the same time. Therefore, a collision occurs when some cells among D WRAN cells select the same channel. If the collision can not be avoided, the channel switching of some WRAN cells fails.

From this figure, we find that the failure probability of the random method becomes large as D increases. This is because collisions occur frequently when D is large. In addition, we find that the failure probability of the random method decreases as the number of channels increases. This is because the number of idle channels is large and D WRAN cells can select different channels with higher probability. Nevertheless, the failure probability never becomes zero because each base station selects a channel for data transmission at random.

On the other hand, by using the proposed method, the failure probability is almost zero regardless of D. This is because the proposed method can avoid collisions by using $F(n)$ as explained in the subsection 3.3. From the above, the proposed method is much effective for dynamic channel switching in IEEE 802.22 WRAN system.

4.2 Impact on Number of Used Channels

Next, we investigate the impact of the proposed method on the number of channels which have been used at least once. Figure 10 shows the number of the used channels for the proposed method and the random method against the number of channels. Moreover, the number of the used channels for phase-shifting DFH, which is equal to 16, is shown in this figure.

From Fig. 10, we find that the number of the used channels for the random method increases as the number of channels increases. From the comparison with the phase-shifting DFH, the random method requires a large number of channels. We also find the the number of the used channels is the same as the number of channels M. This denotes that all channels are used by using the random method. On the other hand, by using the proposed method, the number of the used channel is about $(15+D)$. This is because D WRAN cells have to different channels. Therefore, when D is small, the number of the used channels for the proposed method is close to that for the phase-shifted DFH.

4.3 Impact on Channel Utilization Factor

Finally, we investigate the impact of the proposed method on the utilization factor of each channel. Figure 11 shows the channel utilization factor for the proposed method and the random method against the number of channels. The channel utilization factor for phase-shifting DFH is also shown in this figure.

From Fig. 11, we find that the channel utilization factor for the random method becomes small significantly as the number of channels increases. This is because the random method utilizes all channels.

On the other hand, by using the proposed method, each channel is utilized frequently. When D is equal to two, the channel utilization factor of the proposed method is

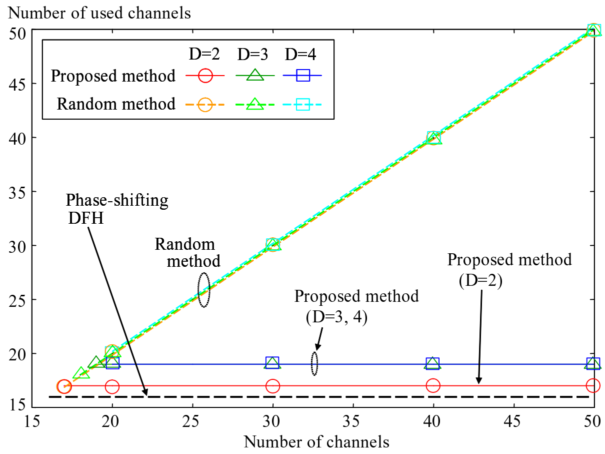


Figure 10: Number of used channels vs. number of channels.

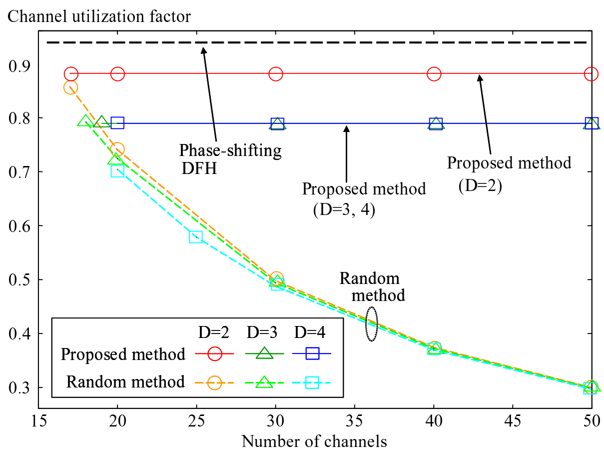


Figure 11: Channel utilization factor vs. number of channels.

close to that of phase-shifting DFH. Therefore, the proposed method can use the limited number of channel resources effectively without strict coordination.

5 Conclusions

In this paper, we proposed dynamic channel switching based on rank accounting in order to utilize finite channel resources effectively. In the proposed method, each WRAN base station has ranking database and selects a unused channel with high rank for data transmission. From numerical examples, we found that the failure probability of channel switching becomes almost zero by using the proposed method. In addition, the proposed method can restrict the number of used channels, and only limited channels are used frequently. Because the proposed method never requires strict coordination for WRAN cells, the proposed method is much effective for dynamic channel switching.

References

[1] Hanaoka, S., Yano, M., Hirata, T., "Testbed System of Inter-Radio System Switching for Cognitive Radio," *IEICE Trans. Commun.*, VE91-B, N1, pp. 14-21, 1/08.

[2] Mitola, J., "Cognitive Radio: Making Software Radios More Personal," *IEEE Personal Communications*, V6, N4, pp. 13-18, 8/99.

[3] Haykin, S., "Cognitive Radio: Brain-Empowered Wireless Communications," *IEEE Journal on Selected Areas in Communications*, V23, N2, pp. 201-220, 2/05.

[4] Mitola, J., "The Software Radio Architecture," *IEEE Commun. Mag.*, V33, N5, pp. 26-38, 5/95.

[5] Srikanteswara, S., Palat, R., Reed, J., Athanas, P., "An Overview of Configurable Computing Machines for Software Radio Handsets," *IEEE Commun. Mag.*, V41, N7, pp. 134-141, 7/02.

[6] IEEE 802.22 Working Group on Wireless Regional Area Networks, http://www.ieee802.org/22/.

[7] Cordeiro, C., Challapali, K., Birru, D., Shankar, S., "IEEE 802.22: The First Worldwide Wireless Standard based on Cognitive Radios," *IEEE DySPAN 2005*, 11/05.

[8] IEEE 802.22 Wireless Gropu on Wireless Regional Area Networks, "Draft Std for Wireless Regional Area Networks Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands," *IEEE 802.22/D0.1*, 5/06.

[9] Hu, W., Willkomm, D., Vlantis, G., Gerla, M., Wolisz, A., "Dynamic Frequency Hopping Communities for Efficient IEEE 802.22 Operation," *IEEE Commun. Mag.*, V45, N5, pp. 80-87, 5/07.