A Cognitive Radio TV Prototype for Effective TV Spectrum Sharing

Davis Rempe, Mitchell Snyder, Andrew Pracht, Andrew Schwarz, Tri Nguyen, Mitchel Vostrez,*
Zhongyuan Zhao, and Mehmet C. Vuran†
Department of Computer Science and Engineering, University of Nebraska-Lincoln, Lincoln, Nebraska 68588
*Email: {davrempe, mitchell.snyder16, prachtaine33, schwarzyz, ligintel, mitchelvostrez}@gmail.com
†Email: {zhzhao, mcvuran}@cse.unl.edu

***Abstract*—With the next-generation over-the-air (OTA) TV standard, Advanced Television Systems Committee (ATSC) 3.0, TV receiver feedback via broadband or dedicated radio channel will become a standard feature. Real-time TV receiver feedback potentially allows secondary users to access active TV channels without interfering with TV users, which would bring 6-10-fold data rate increase on top of the current TV white-space (TVWS) policy in many metropolitan areas, where a few TVWS channels are available. This demonstration is a proof of concept prototype implementation of a cognitive radio TV (CR-TV) set that allows for dynamic usage of underutilized TV spectrum bands. The demonstration will show the main system capabilities of watching broadcast television, determining unused TV bands in a neighborhood through a spectrum database, and transmitting a custom ATSC signal on the optimal unused channel. Additionally, the system ensures the precedence of licensed users by quickly evacuating channels that are taken by a primary user and finding the next most optimal channel, causing minimal interference. The primary user assisted secondary spectrum access could substantially alleviate the spectrum shortage in areas with the highest wireless traffic volume. In addition, to the best of our knowledge, the demonstration provides the first USRP implementation of an ATSC transmitter, which can benefit the community.**

Keywords*—*Dynamic Spectrum Access, broadcast, TV, ATSC, ATSC 3.0, Cognitive Radio Network

I. Introduction

To facilitate the economic growth driven by new technologies such as the booming personal smart devices, Internet of Things, and emerging connected vehicles, regulators began to adopt a new dynamic spectrum access (DSA)-based spectrum regulatory model, aiming to enable more spectrum for the skyrocketing wireless data traffic. As the first initiative, TV white-space (TVWS)–a spectral and geographical area where over-the-air (OTA) TV services are unavailable–is allowed for unlicensed access in countries like the United States [1] and United Kingdom. However, the most important TV and broadband markets, i.e., metropolitan areas, were left with very few TVWS, e.g., 4 out of 5 top cities in the US by population (New York, Los Angeles, Chicago, Philadelphia), have less than 4 TVWS channels for portable devices [2]. As a result, areas with the highest population and most dynamic economy, as well as the highest wireless traffic volume, cannot benefit from the TVWS technology.

A more flexible dynamic TV spectrum access based on TV receiver feedback has been envisioned to address the spectrum crisis in metropolitan areas [3], [4]. With real-time channel occupation information of TV users, secondary users (SUs) can access active TV channels without interfering with nearby TV viewers. Accordingly, 6-10-fold data rate increase can be achieved in big cities, such as New York [3], and Houston [4].

Despite the potential of primary user (PU)-SU cooperation, there are concerns over the feasibility of large-scale TV receiver feedback and the potential degradation of TV viewer experience. To this end, TV receiver feedback via broadband or dedicated return channel will become a standard feature in the next generation broadcast TV standard, ATSC 3.0 [5], which is slated to be finalized in 2017. This new standard emphasizes interactivity and personalization in the future TV services, where TV set feedback will be essential. Therefore, obtaining real-time channel occupation information of TV receivers in large scale may no longer be difficult.

TV receiver feedback-assisted TV spectrum access can be of significant importance for the residential and business environments, which are being filled with more and more devices producing wireless traffic and relying on wireless interface. For large cities with high population density and limited TVWS, the promised quality of many services, include ATSC 3.0 itself (with many features relying on wireless broadband), could face challenges in an over-crowded radio environment. A spectrum management system based on TV set feedback could improve the situation by enabling additional spectrum.

The proposed demonstration, named as cognitive radio TV set (CR-TV), will show the benefit and impact of TV receiver feedback-assisted DSA on both PUs (TV viewers) and SUs. The CR-TV functions as a regular TV set meanwhile streaming data over unwatched active TV channels as SU. Two screens are used for display: one for live TV program from TV stations, and another for customized video streamed over the secondary link. Spectrum handover of the secondary link will be triggered by channel switching of TV viewers, and the impacts of SU evacuating channels on both TV viewer and SU will be displayed on these two screens. The demonstration utilizes an offline video that is streamed on a secondary link by an USRP using the ATSC 1.0 standard [6]. To the best of our knowledge, this is the first demonstration of a cognitive radio equipped TV system, and also the first USRP-based ATSC transmitter, which could benefit the community.

II. Cognitive Radio TV Demo Platform

The CR-TV demo platform contains four parts as shown in Fig. 1: CR-TV, secondary receiver (SR), spectrum database, and neighboring CR-TV users. CR-TV acts as both a PU and a secondary transmitter (ST). The CR-TV receives OTA TV

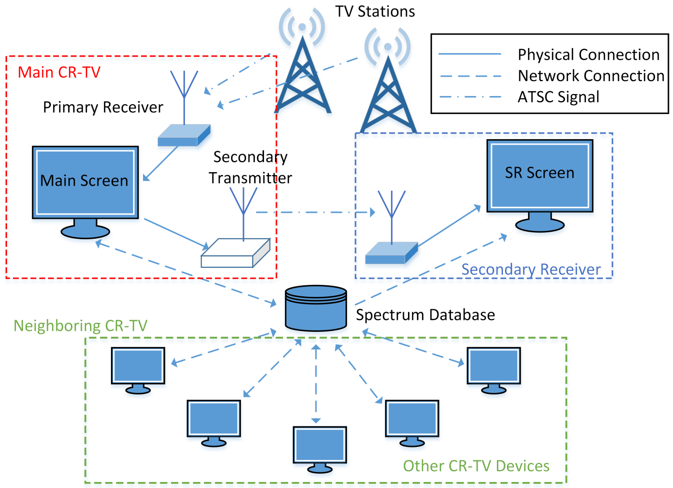

Fig. 1. Cognitive Radio TV Demo System Prototype

programs from TV stations with a TV tuner and displays the TV content on the main screen. Meanwhile it also streams a customized video to the SR through a ST. The ST is an USRP-based ATSC transmitter, and SR receives the customized video with another TV tuner. A circular buffer is implemented to ensure the streamed video looks seamless as long as the secondary link is active. Neighboring CR-TVs, simulated by program, also utilize the TV channel, and are used to emulate nearby TV user traffic. Spectrum sensing is performed by CR-TVs and the spectrum database is updated with the TV channels used for primary and secondary usage, as well as the TV signal strength of active TV channels measured by primary receivers. Moreover, local TVWS channels are updated in to the spectrum database according to the geolocation of the demo platform. The spectrum management is performed by the database according to the feedback of TV receivers, and TV channels being watched by main user and other neighboring TV users will be labeled as unavailable. The ST and SR periodically query the database for available TV channels, and switch to other unwatched channels once current channel becomes unavailable due to usage by either the main CR-TV or the neighboring CR-TVs.

The main CR-TV, SR, and spectrum database are all implemented on PCs with Ubuntu Linux operating system. Two HDHomeRun (HDHR) [7] dual ATSC tuners are used as ATSC receivers and spectrum sensors in the CR-TV and SR. A GNURadio-based open source ATSC transmitter [6] is customized to work on software defined radio platform USRP B200 [8]. MythTV [9], an open source Digital Video Record (DVR) platform, is used for viewing live TV programs and the streamed video. Our stress tests with 99 to 999 simulated neighboring CR-TVs show that it takes less than 0.25 s on average for the SUs to evacuate the primary channel when a PU arrives, and the period of interruption on the secondary link lasts on average 0.058 s with minor visual artifacts.

III. Demonstration Setup and Flow

The flow of cognitive radio process is illustrated in Fig. 2: (1) A neighboring CR-TV user switches to a channel, e.g. Ch. 48, and (2) updates the spectrum database. (3) After a short period, the main CR-TV sees that Ch. 48 is no longer available via periodical database query, so (4) it initiates a

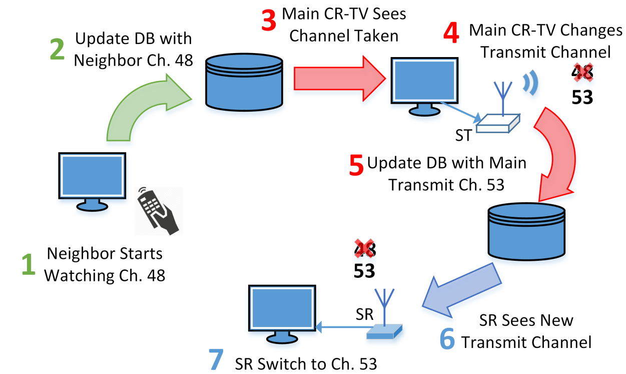

Fig. 2. An exemplary spectrum handover process triggered by CR-TV user switching channels. Green arrow for CR-TV user operations, red and blue ones for secondary transmitter and receiver, respectively.

spectrum handover, and switches ST to an available channel, e.g. Ch. 53, and (5) informs the database accordingly. (6) SR sees ST has switched to Ch. 53, and (7) it switches to Ch. 53 to continue receiving the customized video. Since unlicensed transmission on active TV channels is currently not allowed, the demonstration will emulate this functionality by mirroring active TV channels to TVWS channels (21-26, 31, 44, 49, 51 for Baltimore, MD). Accordingly, while the CR-TV is showing a feed from an active TV channel in Baltimore, MD, the spectrum database will indicate this channel as one of the TVWS channels in this area and the secondary transmission will be conducted through this TVWS band. The secondary link will be established at the end of initialization, with transmit power lower than the allowed 40mW limit [2].

During the demonstration, attendees will be able to change the TV channels of the CR-TV at will, and watch according TV program on the main screen. In the meantime, an offline video file will be streamed via a secondary link, which will be displayed on the SR screen. As the attendees change channels, a seamless spectrum handover can be observed on the quality of secondary link video. The TV signal strength, occupation information, and video error rates will be displayed in a window on the main screen.

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