System Architecture for a Dynamic-Spectrum Radio

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Abstract:

The increasing demand for wireless services necessitates a reassessment of how radio spectrum is allocated. This paper will propose the system architecture of a dynamic-spectrum radio. Such a radio system will seek out underutilized spectrum, and for a short period of time operate on these frequencies. With adequate available temporary spectrum, a realizable, moderate-cost, high-data rate radio network can be operated over paths in the 10 km range.

Finding spectrum that is not being used either passively or actively in a propagation environment that is non-homogenous and time varying with a high degree of certainty is the leading requirement for the system's design. An error in this process could cause the dynamic-spectrum radio system to generate disruptive interference to other spectrum users. The preliminary results of a 500 MHz to 6 GHz spectrum search in urban Atlanta, Georgia demonstrates the existence of usable temporary spectrum. This search examines radio spectrum in time, frequency, polarization, and azimuthal direction.

The operation of a wideband (one or more octave) dynamic-spectrum radio is limited by its low-noise amplifier (LNA) and power amplifier (PA). Intermodulation from the LNA reduces the sensitivity of the receiver; concealing the presence of other spectral users and requiring more transmit power to achieve the required carrier-to-noise ratio. Non-linearity from the transmit PA generates intermodulation that pollutes the spectral environment. Radio frequency (RF) filtering, amplifier predistortion, and intelligent control software can mitigate the impact of intermodulation. The resulting architecture will consider these effects, in addition to results from the spectrum studies.

Introduction:

The unrelenting demand for new allocations of radio spectrum for communications services necessitates a more efficient method of spectrum sharing.

In the United States, the Federal Communications Commission (FCC) is responsible for controlling commercial use of spectrum and the National Telecommunications and Information Administration (NTIA) has this responsibility for the government's use of spectrum. Currently the FCC assigns blocks of frequencies for a specific type of use in bands and then licenses a part of these bands to users as channels. By being licensed, one is guaranteed the exclusive right to a channel in a geographic region. The owner also has obligations placed on them by the FCC, both technical and policy-based.

The banding of frequencies for licensed and unlicensed channels allows for standardized media and telecommunications uses. This allows for TV, radio, terrestrial microwave, terrestrial cellular, satellite communications, radio navigation, and wireless networks to have fixed frequency ranges, regardless of locality. The main benefit of this is lower cost equipment and interoperability [1].

Radio spectrum can be shared in time, frequency, polarization, and space. Present allocation methods only consider frequency and geographic area. In free space propagation, electromagnetic waves can be polarized linearly (horizontal and vertical) or circularly (right hand and left hand) [2]. For environments where waves are reflected and scattered there are six possible states of polarization and angle separation that can be reused without interference [3]. Point-to-point microwave links and satellite communications reuse linear or circular polarization to double system capacity. The space variable is broader than just geographic area; it includes both location and the direction of the radiation for both the emitters and receiver.

Studies by the NTIA, FCC and preliminary results of research conducted at the Georgia Institute of Technology show that radio spectrum is not optimally utilized [4, 5]. Several spectrum surveys by the NTIA in different locations around the U.S. have shown that significant unused radio spectrum exists even in major metropolitan areas. The FCC has recently published limited data on the temporal use of spectrum, and this data does demonstrate the time dynamic nature of spectrum usage with significant periods of inactivity. Research being conducted by the authors examines radio spectrum usage in time, polarization, and azimuthal direction for the 500 MHz to 6 GHz frequency range. This study is also designed to find usage differences in urban, suburban and rural areas by an independent survey of each region.

System Architecture:

The paramount goal of a frequency agile smart radio system is to utilize dormant radio spectrum without interfering with incumbent spectral users in any harmful way. This can be accomplished with control algorithms and knowledge of the susceptibilities of protected users. Protected users encompass all spectral users either passive or active that have rights to allocated spectrum. Figure 1 shows a smart radio system deployed in an environment populated with other spectral users. For this example system, three users surround a single base station. Figure 2 shows a high-level block diagram for the transceiver present in each element of the example system.

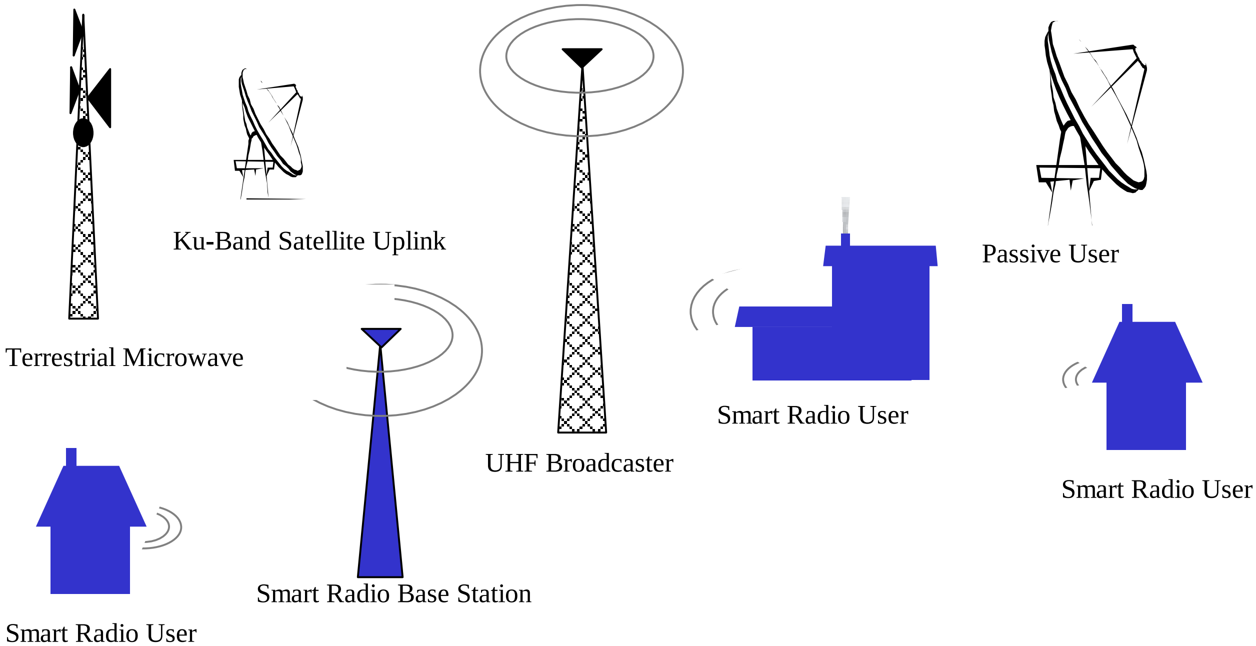

Figure 1 Spectrum Operation Environment

This transceiver includes a global positioning system (GPS) receiver, system controller, and RF subsystem. The antennas attached to the transceiver can be omnidirectional, directive, or a steerable array, depending the desired system cost, flexibility, and spectral efficiency.

The GPS receives provides location information and precise time. The location information is used for the propagation protection model and removes the possibility of device operation in a radio quite zone or near sensitive passive users. The time information is used to synchronize the system and could be used for some transmission methods. Indoor use of this system is not precluded by the use of GPS, given that the demand for E911 capabilities for cell phones has lead to the development of low cost and low power GPS receivers that are capable of operation in an attenuated indoor environment [6].

The system controller in the base station and the user terminals use their collective spectral environment information to supply information to the base station's propagation protection model. The base station is responsible for all dynamic assignment of spectrum by the smart radio system. For a larger implementation requiring several base stations, a higher-level controller would execute the propagation protection model, and subsequently assign dynamic spectrum.

When the user terminal is first activated, it would sweep the range of potential operating frequencies, measuring the power flux density (PFD). The data from this spectrum survey is used to determine frequencies that are unused. Subsequently the user terminal will look for the control channel from a base station.

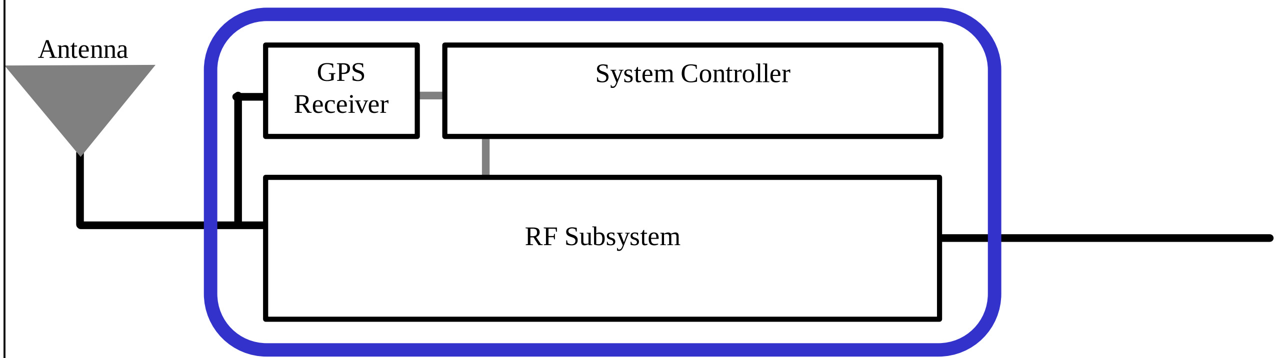

Figure 2 Transceiver Block Diagram

When this channel is found, the user terminal will combine the results of its spectrum search with a list of available channels broadcast by the base station to find a channel that both it and the base station have approved for use. With a communication channel now selected, the user terminal will send its location and spectrum survey data to the base station. The base station then composes its propagation protection model with the data from this user terminal and the other user terminals operating in the area along with the spectrum surveys it has performed, knowledge of the limitations of the detecting equipment, a digital elevation model (DEM) of the area, past spectral knowledge of that area, known protected users in that area, and an up-to-date knowledge of transmitting restrictions so as to assign the user terminal frequencies and transmitting method.

It would be naive to assume that protected users have adequate front-end filtering for dense spectral reuse. Thus even though a channel in a band is unused this does not necessary relate to *usable* spectrum for a smart radio system. Additionally unused spectrum adjacent to band is not always *usable* spectrum. To determine when unused spectrum is available for sharing requires knowledge of attributes of the protected user's receiver. Such information can be used in propagation protection model.

Since spectral occupancy varies with time due to usage patterns and propagation variability, the smart radio system will check several times per second in a "receive-only" mode, to see if the environment has changed, necessitating it to cease using that frequency to avoid creating interference. This would be done immediately to prevent disrupting the protected user.

Figure 3 shows the results of the propagation protection model for one of the user terminals in the system. This terminal is precluded from operating in areas of spectrum that it perceives as unused because of the information gathered by the rest of the system.

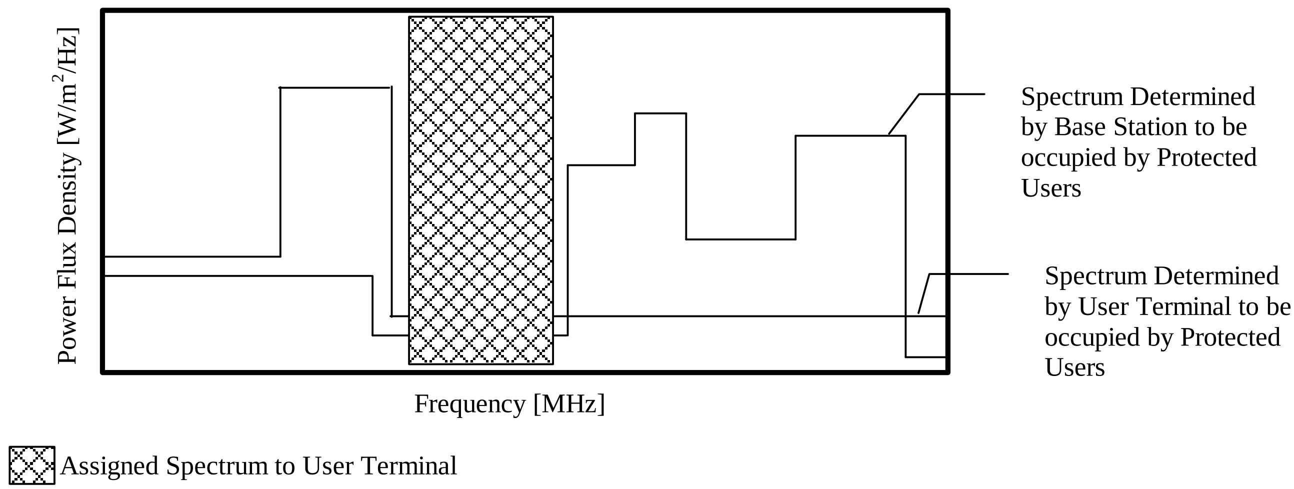

Figure 3 Spectrum Assignment Map for User Terminal, with Usage Profiles

Another advantage of this system architecture is the ability to conduct data mining of spectrum usage patterns; this reduces the probability of interfering with protected users and improves the smart radio's ability to manage its communication links.

RF Subsystem:

The RF subsystem comprises the most costly part of the transceiver, and places the greatest constraints on system performance.

Figure 4 shows the configuration of the RF subsystem. The low-noise amplifier (LNA) in this example is multi-octave to cover an extended bandwidth; such LNA's are commercially available [7]. If there is no filtering before the LNA, intermodulation (IM) from the polluted spectral environment will likely create IM products. IM products occur at frequencies $mf_1 \pm nf_2$ (where m,n = 0, 1, 2, …), with m+n being the order of the IM [8, 9]. In the Atlanta, GA area it was found that a 500 MHz to 8 GHz LNA with a high third order intercept point (IP3) of 27 dBm suffered an increased noise floor from additive IM, in areas of the spectrum adjacent to high usage. This increase in noise floor was measured to be about 10 dB. This rise in noise floor was in addition to discrete IM products. These discrete IM products falsely represent user signals, which reduce the perceived amount of spectrum available for reuse. Hence filtering before the LNA is essential for a smart radio's effective performance. Several switched microelectromechanical systems (MEMS) filter banks and tunable filters have been developed which could provide the necessary front-end filtering requirement [10-14].

The power amplifier (PA) can also generate undesired signals. Unlike the LNA these signals are emitted into the spectral environment. Several techniques for PA linearization have been demonstrated to reduce the filtering requirement needed to suppress these emissions [15-17].

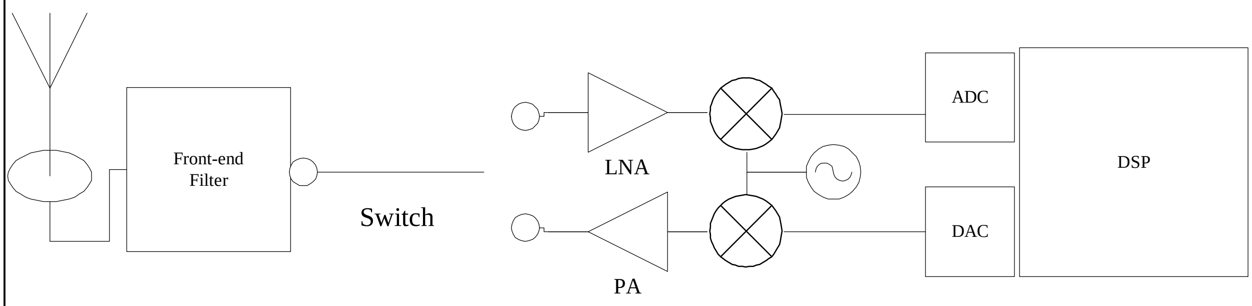

Figure 4 Smart Radio RF Subsystem

Time division duplexing (TDD) has been chosen for the nominal design since it allows reuse of a single front-end filtering system, and allows for insertion of a "dummy" time interval for all the network components to listen for protected user activity.

Conclusion:

This paper has proposed the architecture for a frequency-agile smart radio that honors the spectrum rights of present spectral users. The RF subsystem proposed incorporates several developing technologies to improve system performance.

Frequency-agile smart radios by their nature can adapt to the spectral environment surrounding them. This ability can allow for the establishment of smart radio networks without exhaustive spectrum availability studies and subsequent static reallocation. This could reduce barriers to entry in the wireless marketplace.

The authors are performing a radio spectrum usage study in the 500 MHz to 6 GHz frequency range. This study improves on ones previously conducted by measuring spectrum in time, polarization, and azimuthal direction. Furthermore all the data collected will be retained for post processing to find usage patterns. Information from this data mining could result in improvements to the smart radio system's architecture.

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