IEEE P802.22
Wireless RANs

Directional Antennas; Full Duplex Communication

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Abstract

This contribution is, essentially, a meta-contribution covering both directional antennas and full-duplex communication. At the start of the coverage of each of these topics is a quick introduction comprising ideas that are more related to 802.22 (Revision), and will need to be considered in 802.22 Revision work at a later stage. Next, for each of the topics, follows a dedicated text that is 802.22.3-relevant; those texts are the reason for bringing this contribution to the 802.22.3 sessions, as participation is not possible in the 802.22 sessions for this meeting.

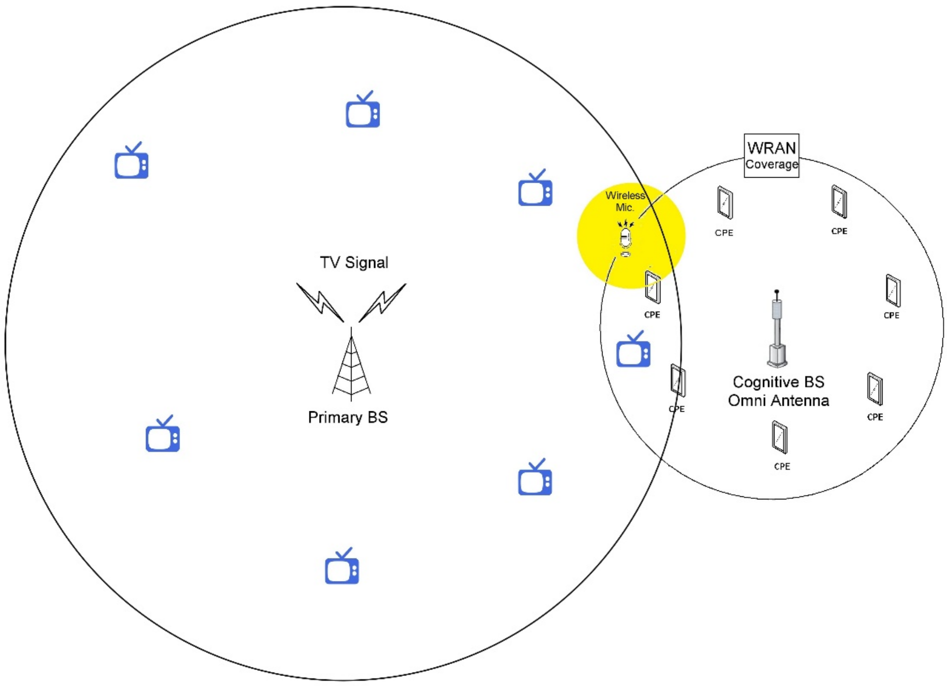
Use of Directional Antennas (Topic 1)

Better Use of Sensing Information based on Sector Antennas (Mostly Relevant to 802.22)

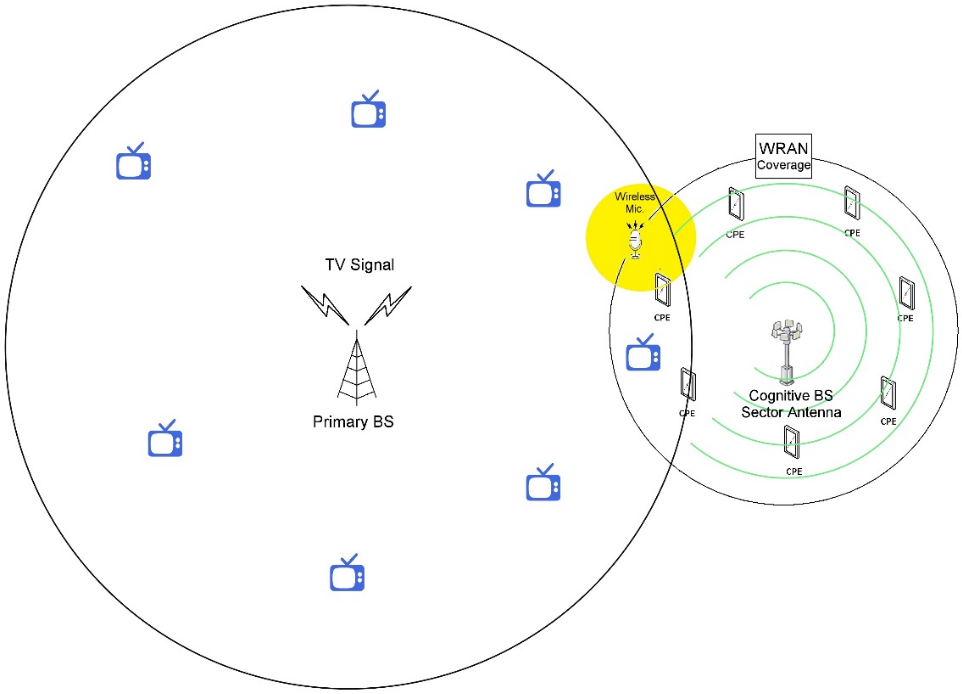
Background information/suggestions; will require more consideration in a later (likely 802.22 Revision?) meeting

Detection of active incumbent users in IEEE 802.22 standard is performed by all secondary network CPEs and Secondary BSs in a cooperative manner. The BS fuses the results of all CPEs' signal detection and makes the final decision about the channel occupancy. In case the BS decides that the channel is not available, it will not let any of the CPEs to communicate over the channel in question, and will switch to other channels.

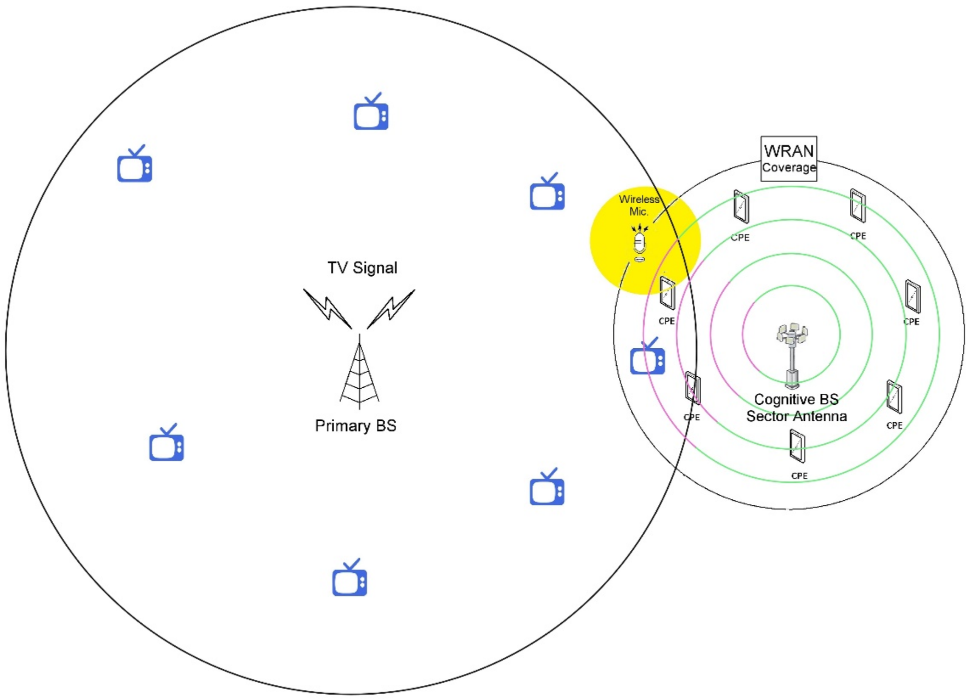
It may happen that some CPEs are in the coverage area of an incumbent user but other CPEs are far from it. In such case, some CPEs will detect an incumbent signal or beacon (in case of wireless microphones) and will inform the BS that the channel is not available. This situation is depicted in the following figure.



But if we equip the BS with directional sector antenna (such as those of WiMAX or mobile networks), the BS can differentiate between the CPEs experiencing interference, and those not in interference. Then it may limit its communication over this channel only with those CPEs which have not detected the incumbent signal, and are far from the coverage area of incumbent signal. Hence, the channel may be used for some CPEs and good throughput harvested without any interference. This scheme would be specially feasible when wireless microphones (with a small coverage area) are present. This scheme is depicted in the following figure.



In this scenario, Cognitive BS may use another available channel for communication with those CPE's experiencing an incumbent signal, as is shown in the following figure.



<u>Generalization for Directional Antennas with Relevance to 802.22.3</u>

Further work and consideration is needed w.r.t. the abovementioned 802.22 suggestions/observations. However, Various implications for 802.22.3 of such sectorised/directional antennas, in the scope of sensing, can be derived—hence bringing to this meeting.

First, 802.22.3 should support the ability to define directional (in azimuthal plane) sensing and antennas thereof. Suggest that there should be two modes of support specified:

- Fixed directional antenna sensing
- Configurable/flexible directional antenna sensing

Our reading of the current first pass submissions (DCN 22-16-0021-01) is that directional antennas are not currently supported (or at least not indicated as such), however, it would be good to add this capability. There are many potential uses. E.g., regulatory “drive-analysis” (not sure of the correct technical term for this) of interference/interferers, with directional antennas mounted on the vehicles that have GPS and angle/orientation capability already incorporated within (operating within certain error bounds), taking measurements in realtime and feeding to the analysis/storage/archive in the SCOS. We think the scope of 802.22.3 should not be contrained to rule out such things.

This requires the definition of new antenna types. Using Antenna type (DCN 22-16-0021-01, Clause 7.2), two new enumerators are required (suggestion):

3. Fixed directional
4. Configurable directional

Suggest perhaps also a flag indicating whether “multi-antenna” (or composite antenna?) or not. Note that, if the “multi-antenna” flag is TRUE, the additional information types we add below are as lists of parameters representing antenna elements. If the “multi-antenna” flag is FALSE, then these items are instead single values of parameters.

Additional information types required are:

- List of angles (inclination, degrees?) from True North of each of the beams of the directional antennas, in order of clockwise rotation in azimuth of their azimuth directions starting at True North.

The Antenna orientation parameter (DCN 22-16-0021-01, Clause 7.2) seems to be related to the omni case only. However, can be expanded to the case of (directional) antenna elements, and expressed as list instead representing the inclination (as opposed to azimuth) for each of the elements. In the case that multi-antenna is “TRUE”, then this parameter becomes as list representing the antenna elements instead of a single value.

- List of angles (in azimuth, degrees?) from True North of each of the beams of the directional antenna, in order of clockwise rotation in azimuth starting at True North.

Also need to handle azimuth in case of directional antennas. Therefore, suggest new Antenna orientation directional parameter (DCN 22-16-0021-01, Clause 7.2). Applies only if Antenna type is 3. or 4. Note, is not a list if multi-antenna is FALSE. Add to DCN 22-16-0021-01, Clause 7.1:

Antenna orientation azimuth (S): If multi antenna==TRUE, a list of orientations of the antenna elements in azimuth defined as the azimuthal angles (degrees?) from True North of the highest-gain points of their beams, in order of increasing azimuth starting at True North. If multi antenna==FALSE, then this is a single value instead of a list.

Also the error in azimuth antenna orientation, and confidence level associated with that error, are both necessary.

- List of errors (associated with confidence limits, in list below) associated with each of the antenna directions in the same order as the Antenna orientation directions specified in Antenna orientation directional. Applies only if Antenna type is 3. or 4. Add to DCN 22-16-0021-01, Clause 7.1:

Antenna orientation error azimuth (S): If multi antenna==TRUE, a list of maximum errors (divergences) in azimuth angles (degrees?) of the antenna elements' azimuth orientations, associated with confidence limits specified in **Antenna orientation error confidence azimuth (S)**. If multi antenna==FALSE, then this is a single value instead of a list.

- And confidence. Also Add to DCN 22-16-0021-01, Clause 7.1:

Antenna orientation error confidence azimuth (S): If multi antenna==TRUE, a list of confidences in the **Antenna orientation azimuth (S)** values, specificed as %. If multi antenna==FALSE, then this is a single value instead of a list.

- Antenna gains are necessary. List of gains of each of the beams. Note, this may be different from the antennas gain that is already present in DCN 22-16-0021-01, as that antenna gain is for omni antennas, i.e., the antenna gain is due to variation at different inclinations (thetas) (? – I believe). Is not a list if multi-antenna is FALSE. Add to DCN 22-16-0021-01, Clause 7.1

Antenna gain azimuth (S): If multi antenna==TRUE, a list of gains of the antenna elements (calaculated in azimuth plane only? -TBD; consider interaction with inclination (theta)) gain associated with directional sensing antennas. If multi antenna==FALSE, then this is a single value instead of a list.

- List of beam widths (in angle azimuth, degrees?, 3 dB down?) of each of the beams is also necessary. Is not a list if multi-antenna is FALSE.

Antenna beam width azimuth (S): If multi antenna==TRUE, a list of beam widths of the antenna elements associated with directional sensing antennas. If multi antenna==FALSE, then this is a single value instead of a list.

Perhaps also other items could be useful to add? Antenna (/element?) front-to back ratio? Antenna peak-to-trough (not sure or can't recall correct terminology for this)? Representation of the angles and values of the side-lobes' gains and side-nulls negative gains or dBs down from the side-lobes (again, forget the terminology, if there is one), again as paired lists?

The above also need to be added/changed in the table in 7.2:

- Changes to antenna type enumerator
- Antenna orientation needs to be changed
- Multi-antenna, flag (if this correct for bool?), bool
- Antenna orientation azimuth, numerical list (not list if multi-antenna==FALSE), double (1dp) (why are they all as double as opposed to float?)
- Antenna orientation error azimuth, numerical list (not list if multi-antenna==FALSE), double (1dp) (why are they all as double as opposed to float?)
- Antenna orientation error confidence azimuth, numerical list (not list if multi-antenna==FALSE), double (1dp) (why are they all as double as opposed to float?)
- Antenna gain azimuth, numerical list (not list if multi-antenna==FALSE), double (1dp) (why are they all as double as opposed to float?)
- Antenna beam width azimuth, numerical list (not list if multi-antenna==FALSE), double (1dp) (why are they all as double as opposed to float?)
- Other changes related to additional representations of the antenna characteristics that we might choose to add

Also likely needs to be updated (keep an eye on these as they are developing, again based on DCN 22-16-0021-01):

- 6.1.7 Platform Control Messages
- 5.1 and 5.2, Reference architecture and management reference architecture, e.g., signalling exchanges, and information therein (as defined in Section 7?)—e.g., metadata in 5.1.1

"Areas of 802.22" analysis in DCN 22-16-0021-01 also relevant here:

- 9.12 Antenna (e.g., 9.12.1.2 clearly specifying only omni antenna)—could be changed
- 10.7.6 Antenna primitives ?
- 14.2.1.6 Antenna primitives

Full Duplex Communication (Topic 2)

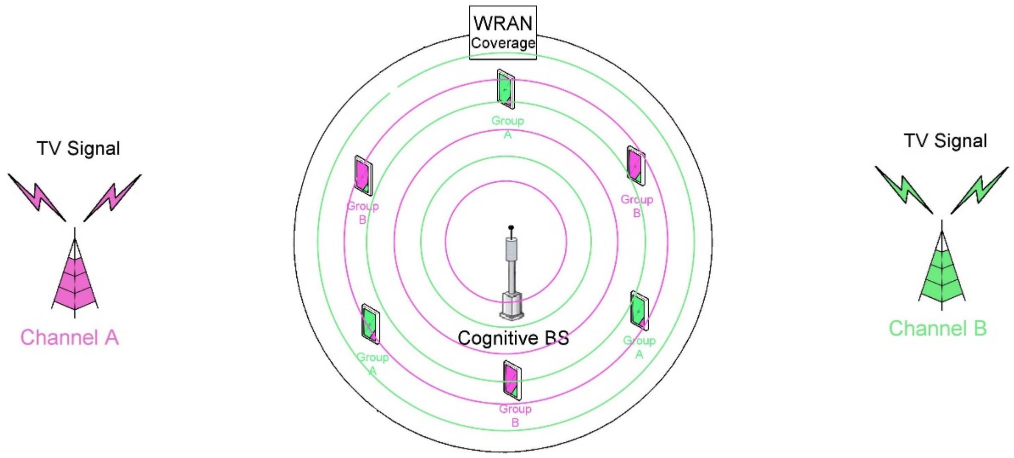
<u>Use of Full Duplex in General (Mostly Relevant to 802.22)</u>

Background information/suggestions; will require more consideration in a later (likely 802.22 Revision?) meeting

Thanks to the recent advances in self-interference cancellation techniques, the Cognitive Radio network can operate in a Full Duplex bidirectional or non-bidirectional manner over the available TV channels. In non-bidirectional schemes, a secondary user (BS or CPE) will transmit over the detected free channel, and at the same time senses the same channel for re-appearance of any incumbent signal. Such schemes are called trans-sensing. Such methods will not increase the cognitive network throughput significantly, and mainly improve the protection of primary network against collision with secondary signals.

In a bidirectional Full Duplex communication, the BS and CPEs transmit and receive data concurrently over a single channel. This will increase the throughput significantly (nearly double), but the main issue with such methods would be the sensing of the channel for re-appearance of a primary signal. Methods such as Listen Before Talk (LBT) may be applied, and a new method proposed in [1] based on collision event is an alternative (with better performance compared to LBT method). However, in a secondary network equipped with multiple mod/demod units at BS, we can exploit the following protocol which is simpler and more efficient.

The BS will communicate bidirectionally with some CPEs (Group A) in one of the available channels (Channel A), and with the remaining CPEs (Group B) in another free channel (Channel B). As the CPEs in IEEE 802.22 have two separate antennas (one for sensing and one for communication), the CPEs can perform the sensing and communication concurrently. The CPEs in group A communicate in a bidirectional full duplex manner with the BS over channel A, and at the same time sense the presence of the primary signal in channel B. The CPEs in group B do the similar task (communicating over channel B, and sensing channel A).



Whenever CPEs in a group detect the re-appearance of a Primary signal (TV signal), BS will turn off communication over that channel and will switch to another available channel. The detection and false alarm probability in this protocol depends on the number of active CPEs.

This Scenario may be extended to more than two Channels.

Generalization for Full Duplex with Relevance to 802.22.3

Further work and consideration is needed w.r.t. the abovementioned 802.22 suggestions/observations. However, Various implications for 802.22.3 of such full duplex, in the scope of sensing, can be derived—hence bringing to this meeting.

Of particular interest here is the case where a device (incorporating a sensor, compliant with 802.22.3) is transmitting and sensing at the same time using full duplex capability (known as "trans-sensing"). While acknowledging that this is extremely challenging (e.g., massive dBs isolation necessary between the transmitter and sensor in many conventional sensing scenarios), there are many extremely interesting and useful purposes for this.

For instance, will be possible to characterise the environment in the vicinity of the trans-sensor, even with poor isolation (e.g., a few 10's of m??) which will be very useful in deriving information about the context of the sensor placement, the shadowing environment, derived from reflections, etc.).

There are also increases in the spectral efficiency and performance of systems that are using such a capability, if the transmitter/sensor isolation is sufficient. Many other benefits of being able support this (even with relatively "poor" quality full-duplex technology). E.g., can be used to characterise self-reflection through trans-sensing and use that to negate from a received transmitted signal and make full-duplex (more?) easy to implement.

Has many implications, e.g., in terms of the information types that 802.22.3 needs to consider. E.g., would be useful to represent the power (and other charateristics?) of the transmission of the trans-sensor, the isolation (dBs) between the transmitter and sensor (both of the former useful such that the contribution to background power/noise of self-interference can be understood better by the SCOS analysis using the trans-sensor), others?

Changes/additions in 802.22.3 related to this will be linked to the sensing information and sensor characteristics information; may also be relevant to sensor configuration information (e.g., configuring whether you want the sensor to be allowed to operate in trans-sensing mode, or it should operate in sensing-only mode in order to effectively increase its sensitivity).

References:

[1] V. Towhidlou & M.S. Bahaei, "Asynchronous Full Duplex Cognitive Radio", in the Proceedings of VTC-Fall 2016 Conference.