Avoiding Spectral Congestion: An Enhanced Cognitive Radio Approach

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Abstract: Currently, cognitive radio solves the problem of spectral congestion by load sharing wireless traffic across different licensed spectrum bands. However, it is thought that a more powerful approach would be to load share the traffic across both fixed and wireless access networks. It is thought that such an approach will be able to prevent spectral congestion for the foreseeable future for a significant number of users without having to resort to the relatively complex approach currently used by cognitive radio. However, this new approach is still the subject of ongoing research, so the main aim of this paper is to provide a conceptual understanding of how load sharing traffic across both fixed and wireless access could potentially enhance / simplify the spectral sharing approach currently used by cognitive radio.

1 Introduction

During the past decade [1] there has been growing interest in cognitive radio networking concepts and this has now become an internationally hot research topic. The main drivers currently underpinning this cognitive radio research drive is, in essence, captured by the following four quotes [2-3]:

> '… rapid proliferation of wireless technologies is expected to increase the demand for radio spectrum by orders of magnitude over the next decade …'
>
> '… there is a significant increase in the demand for wireless broadband data, rendering the radio spectrum more and more valuable …'
>
> '… It has been thought to be a scarce resource, but lately, it is being claimed that a considerable proportion of the radio spectrum is underutilized …'
>
> '… motivation for cognitive radio stems from various measurements of spectrum utilization, which generally show that spectrum is under-utilized. This means that there are many "holes" in the radio spectrum that could be exploited by the secondary users…'

Broadly speaking, the first two quotes position the perceived problem: which is that it is anticipated that due to a significant increase in the number of primary users and / or their average data-rate, congestion will eventually occur in certain licensed spectral bands for significant periods of time [4]. The final two quotes suggest that one approach for addressing this problem is to enable some of the primary users in congested licensed bands to become secondary users in any underutilised licensed bands. At first sight, an obvious question to ask is why use cognitive radio to share spectrum when the congestion problem could be solved simply by deploying more base stations using the same spectrum? The author suspects the answer is one of cost because it is anticipated that deploying more base stations will eventually become more expensive than using a Cognitive Radio (CR) spectrum selection solution. Assuming this to be the case, and knowing that CR spectrum selection effectively load balances traffic across a number of different licensed spectral bands, raises the question as to whether or not simpler technical solutions would be possible if the traffic were to be load balanced across both fixed and wireless access networks.

The reasoning behind this question is that when spectral congestions occurs it is very likely that a significant number of the users will be at locations where they could just as easily have used fixed (direct or over a wireless hop up to several metres long) rather than wireless connectivity (a wireless hop in excess of several tens of meters long). In fact, wireless traffic surveys / forecasts state that approximately 75% of wireless traffic originates indoors [5]. Therefore, it should be possible to avoid spectrum congestion for a significant number of users by off-loading them onto a fixed network rather than load balancing them across a number of underutilised licensed spectrum bands. This could potentially remove the need for conventional CR spectral solutions at such locations.

It is thought that load balancing across both fixed and wireless networks, which from here on will be referred to generally as Open Access (OA), has the potential to reduce spectral congestion at least as effectively as CR spectrum selection solutions and possibly in ways that may be technically / operationally simpler, more cost effective and commercially more acceptable. Using OA as a means for enhancing CR spectral selection will now be considered in more detail, beginning with an overview of CR spectrum selection.

2. High-Level Architecture for Current CR Spectrum Selection

Figure 1 shows a high-level a functional architecture for CR spectral usage measurement and selection. The spectrum usage database stores the spectral usage information periodically gathered by the spectrum usage measurement protocol. This stored information is monitored by the spectral access control and if it detects usage in excess of some predefined maximum usage threshold it carries out the following two actions: it identifies which wireless nodes are operating in the affected location and also identifies the spectral bands available for secondary users which are currently operating below a particular pre-defined lower usage threshold. Then the spectrum access control selects which of the available spectral bands to use and instructs the frequency allocation protocol[1] to change the operating frequency of the devices belonging to the users who are to become secondary users.

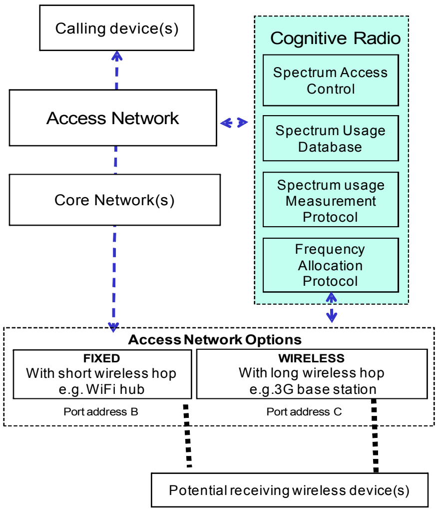

Figure 1. Cognitive radio and an example of CR spectral selection flow

A key issue with CR spectral selection is that the approach currently used for gathering spectral usage information has limitations that may be difficult to overcome within the timescale that it is envisaged that spectral congestion will become a significant problem. Another issue is that CR can only prevent spectral congestion in regions where a number of different, co-located and co-operating wireless networks exist, so if fixed network connectivity also exists at these locations why not include it as one of the co-operating networks. This broader approach of avoiding spectral congestion by enabling co-operation between co-located wireless and fixed networks, which will be called Open Access enhanced CR spectral selection from here on, is discussed in more detail in the next section.

3. High-Level Architecture for Open Access enhanced CR spectral selection

A high-level functional architecture of OA enhanced CR spectral selection is shown in Figure 2. This is simply Figure 1 with the addition of the OA network selection functionality, which in its simplest form associates a user with a single fixed and a single wireless network address and then uses this information to decide which one to use during call set up. This is achieved as follows. The fixed and wireless access nodes both use the connectivity discovery protocol to send their node ID, type of connectivity and network address to the connectivity database for storage. They also run the location protocol which detects users entering and leaving the fixed / wireless coverage areas. When a user comes within range[2] of a network node, the location protocol obtains the user's unique ID from his device and sends this along with the node ID to the connectivity database for storage. The database then uses the node IDs gathered by both protocols to

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[1] For the purposes of this paper it is assumed that frequency allocation protocol messages are carried over the network on which the user is a primary user.

[2] Because this paper is reporting early stages of ongoing research, it has been assumed that protocols exist for enabling user devices to exchanging control messages with any network within range.

associate the user's ID with the fixed and wireless addresses that should be used to contact him at his current location. When a user leaves a node's coverage area, the location protocol removes the appropriate user information from the connectivity database including any of its associations. When call set up is invoked, connectivity selection decides whether to use fixed or wireless access. The following gives a very simple example of how this is achieved for a called user who is essentially stationary:

1. The calling user sends a connection set up message to his access node.
2. The access node then extracts the called user's ID from this message and uses the connectivity selection protocol to send this ID to the OA connectivity selection process.
3. The selection process then searches the connectivity database for the called user's ID to identify which fixed / wireless network addresses can be used to contact him. It then invokes the following actions:
    a. If a fixed network address is available the connectivity selection protocol delivers it to the call set up process.
    b. If a fixed network address is unavailable it delivers the wireless address to the call set up process.
    c. If neither type of network address is available it sends a 'called user unavailable' message to the call set up process, which then terminates.

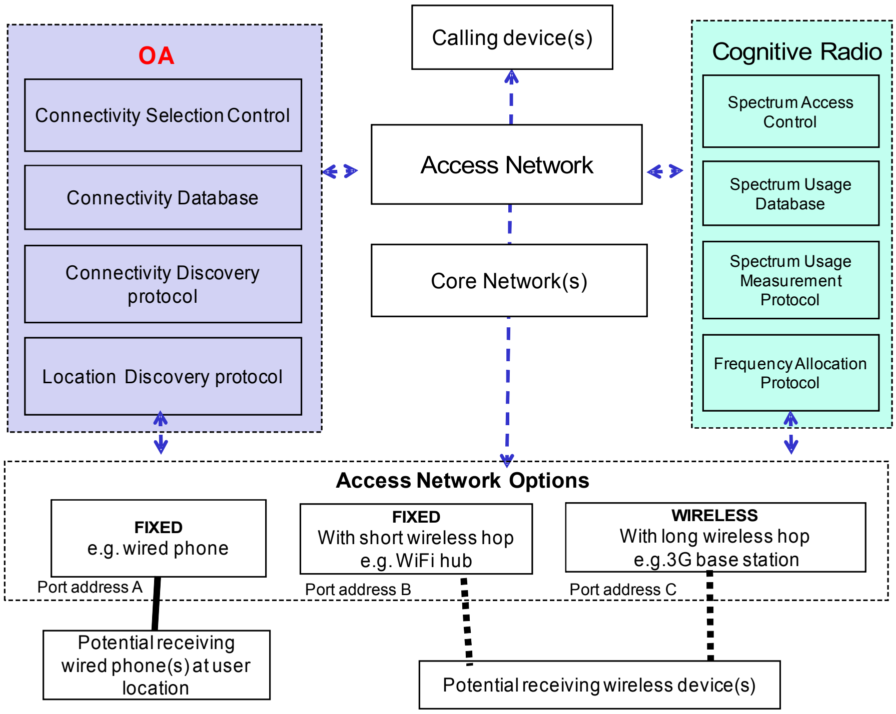

Figure 2. OA enhanced CR architecture

Overall, OA enhanced CR spectrum selection will only need to resort to conventional CR spectral selection when traffic levels are such that congestion cannot be avoided simply by load balancing across a fixed network. Therefore, it is very likely that CR spectral selection will only be invoked for users who are at outdoor locations and / or require that certain specific mobility requirements are satisfied, which according to recent traffic forecasts would only account for 25% of the total wireless traffic generated [5].

Although OA network selection promises to be a beneficial enhancement of CR spectral selection, the likely complexity of the mechanisms needed for enabling user devices to exchange control messages with all networks within their range will eventually need to be compared and contrasted with the complexities of CR spectrum usage measurement, but at the moment this is the subject of ongoing research.

4 Discussion

To some extent, it is now obvious that the way in which the OA connectivity selection and CR spectral selection solutions are both able to prevent spectral congestion simply highlights that the perceived emergent congestion problem is essentially a direct result of the rigid vertical stove-piped connectivity infrastructure models that have been evolved over the years to support specific business models. This has resulted in the various different access networks being tied to particular types-of-service, whereas, ideally, all 'end-user-services' would be completely decoupled from the underlying physical access network; a situation which is loosely referred to as either copper or wireless unbundling depending upon the type of network. This is potentially what more powerful versions of OA, which will be denoted OA+ from here on, could achieve. By enabling services and connectivity to become completely independent of each other, OA+ would enable a connectivity provider to have free choice of which types of connectivity to use for service delivery (cable, any licensed and/or license-exempt spectrum). In other words, service retailers are provided with commodity connectivity. However, this will be commodity connectivity within the constraint of the connectivity provider having to meet the particular service requirements specified by the various service retailers when agreeing their contracts with the connectivity provider. With commodity connectivity no distinction is made between fixed and wireless and both are potentially managed by a single authority who is concerned only about meeting the capacity requirements of the various retail service providers, irrespective of the particular services they provide to the general public, but with the advantage of a broader and more flexible network management capability. When services and connectivity are completely decoupled in this way, the functional representation of the communications environment would probably have a structure similar to that shown in Figure 3.

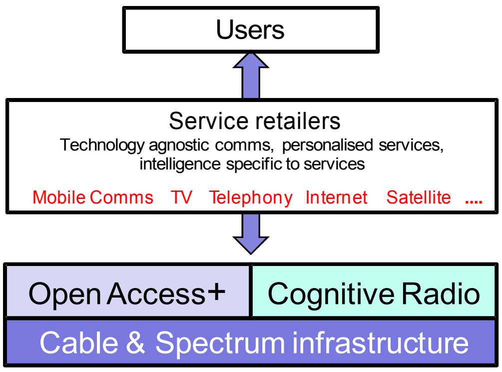

Figure 3. OA+ enhanced CR architecture (where wired or wireless infrastructure is effectively treated as potentially having a wireless access hop at each end)

5. Conclusion.

This paper has proposed an approach called OA enhanced CR spectrum selection to enhance cognitive radio spectrum congestion avoidance by enabling load balancing across both fixed and wireless networks. It has presented an argument for why this approach may be a beneficial enhancement for CR spectral selection; especially as is has been reported that 75% of wireless traffic originates from indoor locations. However, at this stage the potential benefits of the OA concept and potential future variants cannot be fully quantified because they are still the subject of on going research, which has an overall aim of providing new insights into and providing specifications for the new control protocols that will be needed to enable commodity connectivity to become a reality for future forms of CR.

References

[1] J. Mitola III, "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio," PhD Dissertation Royal Institute of Technology, Stockholm, Sweden, May 2000

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[5] Brydon, A. and Heath, M., *Wireless network traffic 2008–2015: forecasts and analysis*, Analysys Mason (Cambridge,2008).