Cognitive Radio Over Fibre: Potential advantages for spectrum management

(Invited)

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The paper explores some of the advantages that radio over fibre technologies can bring to wireless networks when combined with cognitive radio techniques.

1. Introduction

Radio over fibre (RoF) techniques [1] have been researched from many years and although there are numerous deployments world-wide, the technology is still to have a major impact on mainstream wireless and cellular networks [2]. To date the offerings of the major vendors such as Andrew, ADC and Zinwave, have focused on what are essentially distributed antenna systems. However, as this paper will explore, once the radio processing for a large number of cells is centralised there is the possibility to take advantage of advanced network and spectrum management functions that would not be available in a network of distributed equipment. In particular this paper looks at how radio-over-fibre technologies might support cognitive radio techniques to provide flexible and dynamic spectrum management.

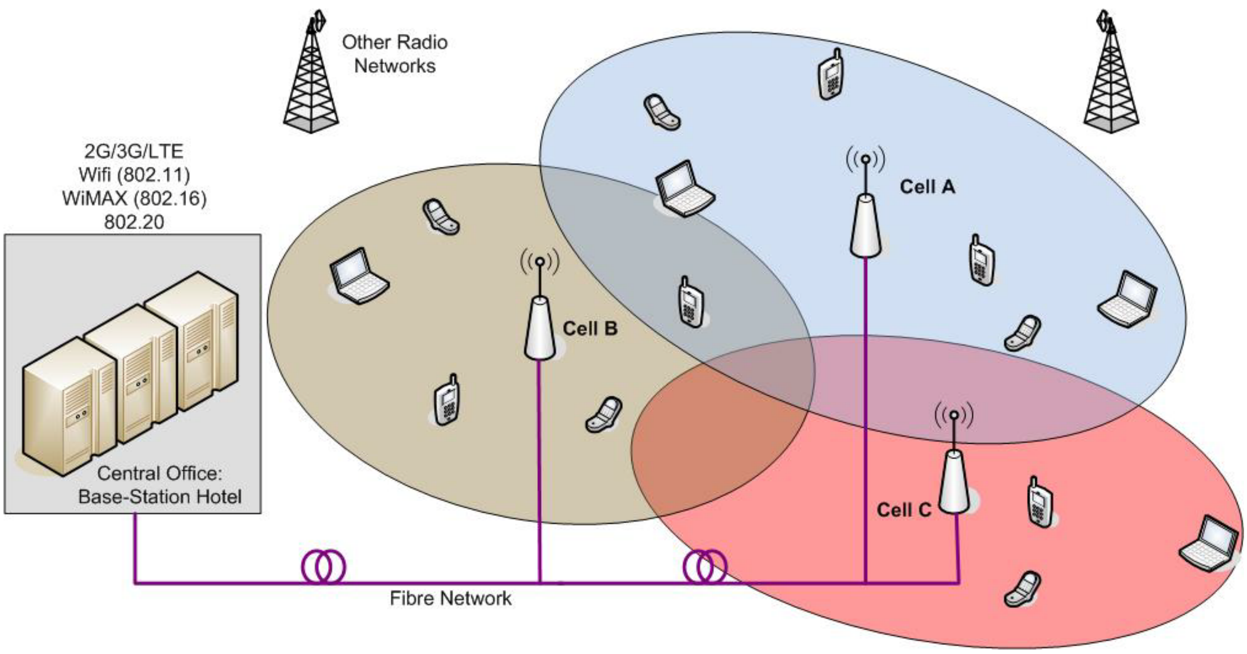

Figure 1: A radio over fibre network

The basic construction of a radio over fibre network is shown in fig. 1. Rather than feed digital signals to base-stations and locate all the digital processing at that site, an RoF network co-locates all the processing at a single site and uses the optical network to transport signals to and from the base-station site (now termed a Remote Access Unit or RAU) in a format so that they require very little processing. Ideally, the RAU will consist of just the optical to electrical (O/E) and electrical to optical (E/O) converters (photo-receivers and lasers for example), amplification and antennas.

2. Cognitive Radio

In the defining article on the subject [3], cognitive radio is described as a radio that understands the context in which it finds itself and as a result can tailor the communication process in line with that understanding. Although there are many aspects of its behaviour that could be 'tailored', one of the most exciting current areas of research involves opportunistic use of unused radio spectrum. For example the IEEE 802.22 working group is developing an air interface for opportunistic secondary access to the white space within the TV spectrum to offer data services over large distances.

To be able to exploit transmission opportunities using available spectrum a decision-making cycle must be implement to avoid these secondary users from interfering with the primary users of the spectrum. This process is called an observe, decide, act cycle. In this work our main consideration will be spectrum sensing which falls within the observe part of the cycle. This process can either be non-cooperative, where each individual node sense the spectrum and act locally and autonomously, or cooperative, where information is shared between a group of radios before decisions are made. Cooperative sensing has benefits, including increased sensitivity and reduced probability of false alarms [4], but can also increase complexity and signalling overhead.

There are still many challenges in spectrum sensing and cooperative sensing [5], many of which are related to the issues of collaborative sensing and decision making and the accurate determination of the presence and location of primary users.

3. Advantages of RoF

As discuss above, one of the most active areas of research in cognitive radio is that of spectrum sensing. The ability of the network to adapt and avoid interference is directly proportional to the accuracy and timeliness of the information it can ascertain of the current usage of the network. The introduction of Radio over Fibre brings two distinct advantages to the problem. Firstly, as each antenna at the RAU will collect the whole of a particular band, with each RAU potentially enabled to collect multiple radio bands, information is available to the network about the totality of each band. Although this is possible with the traditional base-station structure, more importantly in RoF all this information can be processed and interpreted centrally to instruct the formation of the networks at the point where fully dynamic allocation of spectrum is possible [6].

Consider the network as described in fig 1. Information about a number of radio channels can be collected but the RAU at the centre of each cell, so that rather than just serving its own primary users it may also coordinate secondary use of the spectrum in its locality.

At the central station functionality must be put in place to enable what is usually termed the ‘observe’ function of the cognitive system. There are a number of methods available to determine spectrum usage over a given band. They range from energy detection, which can only estimate the presence of a signal without determining the type, feature detection which seeks to identify the type of signal by analyzing features of the signal such as its cyclostationarity, or matched filter detection which can provide highly accurate information about primary user signals of a known type [5].

Figure 2 shows an example of how a radio over fibre network might be formed. The optical layer may be a PON (GPON, NG-PON or WDM-PON) or a bespoke optical access layer. To get maximum flexibility some form of wavelength selectability is required [6]. The RAUs at the centre of the cells would collect and backhaul entire bands for subsequent processing. At the Central office primary radio channels served by this particular network would be routed to dedicated transceivers. In addition the bands of interest would be routed to a spectrum sensing function based on one or more of the techniques discussed above.

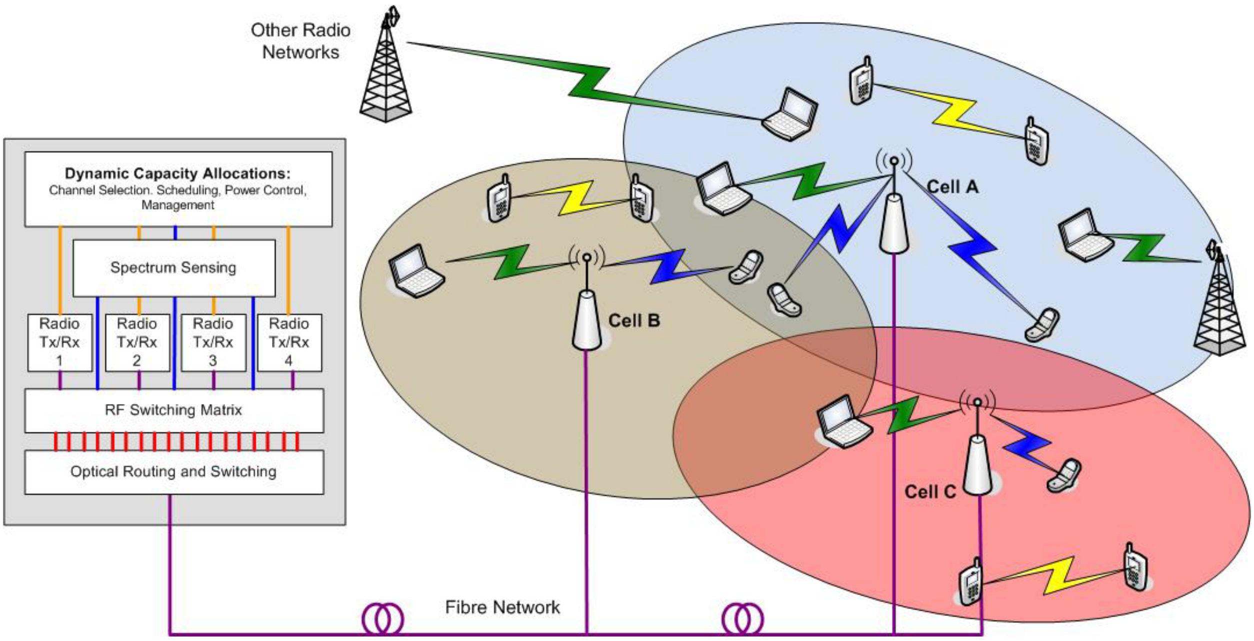

Figure 2: Integration of Cognitive Radio in a Radio over Fibre Network

Taking information from both the spectrum sensing function as well as from the radio channels served by this network, a Dynamic Capacity Allocation (DCA) function would control the resource allocation to enable opportunistic operations within the network. This could be centrally managed by the base-stations or broadcast on open (ISM band) channels to allow users within the coverage area to select channels.

4. Challenges

Although this cognitive structure offers many potential benefits it also significantly increases the complexity of the management of the network. We have for some time advocated a vertically integrated approach to the design of radio over fibre networks [6]. The important of such an approach is paramount in networks where the performance benefits are derived from the interaction of radio resources being dynamically allocated to optical wavelengths which are then assigned to optical fibres to address remote nodes. In this situation the interaction of multiple media access control mechanism can, in itself, create significant design issues.

The main challenge of this vertical integration is due to the interdependencies created between the optical and radio layers. The optical layer must inherently enable the functionalities being introduced at the radio layer without interfering with their ability to sense the RF channel. For example MIMO processing and adaptive beamforming require accurate sensing of the radio channel which must not be distorted (both in terms of signal corruption and time delay) by the optical process in the network. From the radio layer, control functionalities must be included to enable the reconfiguration required to dynamically allocate and re-allocate spectrum and capacity on the appropriate time scales without affecting the user experience.

5. Conclusion

The introduction of radio fibre techniques into wireless networks offers significant opportunities to increase flexibility and spectrum efficiency. However, before these benefits can be enjoyed a number of research challenges exist that require cross-layer design and a vertical integration of the optical and radio layers.

Acknowledgements

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