Study and Analysis of Cognitive Radio Channel Scanning Technology for Wi-Fi Networks

Reshma Syeda*
Faculty: Vinod Namboodiri
Department of Electrical Engineering and Computer Sciences

Abstract. Wi-Fi has become a ubiquitous wireless technology in a short period of time. Each one of us has wireless gadgets competing for the Wi-Fi bandwidth. In contrast to this, studies show that the legacy technologies' spectrum like the TV spectrum was found to be unoccupied 90% of the time. Cognitive Radio (CR) Technology is the riposte to this paradoxical situation. A CR is an intelligent radio which scans the radio spectrum for free channels and uses them to its own advantage. CRs coordinate among themselves using cooperative spectrum sensing schemes to sense the spectrum efficiently. Not much is known about their energy efficiency. To study this, we develop an energy model and perform an energy efficiency analysis of two basic/generic cooperative sensing schemes – distributed and centralized, for the ad hoc WLAN scenario. We further propose corresponding modified versions for these two schemes where only a fraction of secondary nodes scan in each sensing cycle as opposed to all the nodes and show the amount of energy savings over their generic counterparts.

1. Introduction

Cognitive Radios (CRs) opportunistically use the vacant spectrum that is not being used by the rightful owners in time, frequency, space and code dimensions of a signal to make their communications efficient. In the field of CR technology, the rightful users of the licensed spectrum are termed the primary users (PUs) where as the other CR users trying to use this spectrum opportunistically are the secondary users (SUs). The SUs, before dynamically accessing this licensed spectrum should make sure that it is not occupied by a PU in their vicinity to avoid interference to the PUs. The key component to achieve this is the sensing of the spectrum with high reliability. As the transmitter based techniques like energy detection and matched filtering are local and rely solely on the PU signal detection; there is a high chance for the CR to be blinded/mislead due to fading, shadowing and interference phenomenon further causing degradation of the accuracy of these local sensing techniques. To overcome these blinding phenomena, cooperative sensing has been found to be far superior to this local sensing.

The goal of our work is to study the amount of energy consumed by the SUs to cooperatively sense the spectrum. This paper complements the work done in [1] where an energy efficiency analysis of CRs was done and a local sensing scheme 'optimal scanning' scheme was proposed in which each node in the network scans all the channels. A comparison against cooperative sensing schemes was not made in this work. Hence, we study two cooperative sensing schemes suitable for the wireless LAN (WLAN) ad hoc scenario-a no frills, generic distributed Scheme and a centralized cluster based scheme. In addition to showing the energy efficiency of these generic cooperative schemes over the local sensing schemes using our energy model, we further propose modified versions of these two generic schemes, namely the distributed- and cluster based centralized- schemes and show additional energy savings over the generic schemes. Most of the work done to date on CR cooperative sensing mainly focuses on increasing the spectrum sensing efficiency/accuracy of the schemes but relatively limited analysis has been done on their energy efficiency.

2. Problem Definition

Sensing Model:

We consider an ad hoc WLAN scenario where all the nodes are in the hearing range of each other. Since we consider that each node senses a different channel in a given sensing cycle (SC), it is very important that all the nodes share this information.

A SC consists of a scanning period (SP) and a reporting period (RP). The total number of channels to be scanned is decided prior to the start of the SC based on the node density. Once each node scans the channels assigned to it, they share this information with their neighbors during the RP through sensing reports (SRs) which is assumed a broadcast packet. The energy consumed by each node in one SC is given by the sum of energy to scan the channels, energy to switch between channels, energy to transmit the sensing report to the remaining nodes and energy to receive the reports [2]. The energy calculations done further in this work are specific to one SC.

Energy consumption analysis

A. Distributed Sensing Scheme

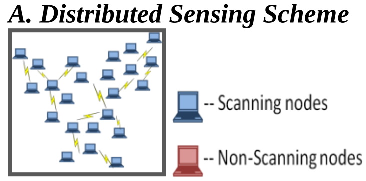

Fig.1. Distributed Scheme-Basic

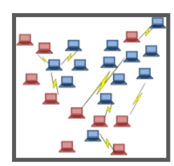

Fig.2. Distributed Scheme-α

Distributed Scheme–Basic: Let us consider an ad hoc WLAN of 'N' nodes with 'C' channels to be sensed. So the energy cost of each node $N(N < C)$ in this distributed scheme is given by,

$$E_{S-B} = \left(\frac{C}{N}\right) E_{Scan} + \left(\frac{C}{N} - 1\right) E_{Sw} + E_{Srt} + (N-1) E_{Srd}$$

E_{Scan}, E_{Sw} is the energy consumed to scan, switch channels and E_{Srt}, E_{Srd} is the energy to transmit and receive SRs. Total energy consumption of the whole scheme is,

$$E_{DS-B} = CE_{Scan} + (C-N)E_{Sw} + NE_{Srt} + N(N-1)E_{Srd}$$

<u>Distributed Scheme–α:</u> In this scheme, only a fraction $\alpha \; (0 < (\frac{1}{N}) \leq \alpha \leq 1)$ of the 'N' nodes scan in each SC i.e., αN nodes scan the channels and $(N - \alpha N)$ do not scan. Then the energy equation for each of the $\alpha N (N \leq C)$ nodes is as follows:

$$E_{S-\alpha} = \left(\frac{C}{\alpha N}\right) E_{Scan} + \left(\frac{C}{\alpha N} - 1\right) E_{Sw} + E_{Srt} + (\alpha N - 1)E_{Srd}$$

Total energy consumption of the whole scheme is,

$$E_{DS-\alpha} = CE_{Scan} + (C - \alpha N)E_{Sw} + \alpha N E_{Srt} + \alpha N(N - 1)E_{Srd}$$

B. Cluster based Centralized Sensing Scheme

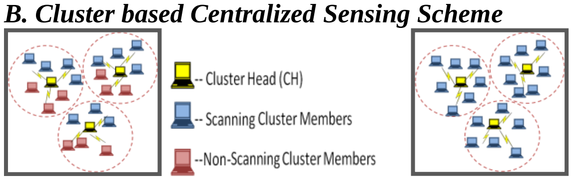

Fig.3. Centralized Scheme-Basic Fig.4. Centralized Scheme-α

<u>Centralized Scheme – Basic:</u> In this Scheme, the network of 'N' nodes can be divided into 'K' clusters based on some higher layer protocol with each cluster having 'M' cluster members (CMs) excluding the cluster head (CH) such that $N = K(M-1)$. Total energy consumption of the whole Scheme is,

$$E_{CS-B} = CE_{Scan} + (C - KM)E_{Sw} + K(M+2)E_{Srt} + K\big(2M + (K-1)\big)E_{Srd}$$

<u>Centralized Scheme – α:</u> In this α scheme, αM CMs sense the channels $(M - \alpha M)$ do not sense per SC. Total energy consumption of the whole Scheme is,

$$E_{CS-\alpha} = CE_{Scan} + (C - K\alpha M)E_{Sw} + K(\alpha M + 2)E_{Srt} + K\left((1+\alpha)M + (K-1)\right)E_{Srd}$$

<u>Evaluation</u>

The energy plot Fig.5 for varying node density'N' $(C = 20)$ clearly depicts that centralized scheme has lower energy costs compared to distributed and also that α schemes save more energy than their generic counterparts. This trend is more noticeable for higher values of 'N'.

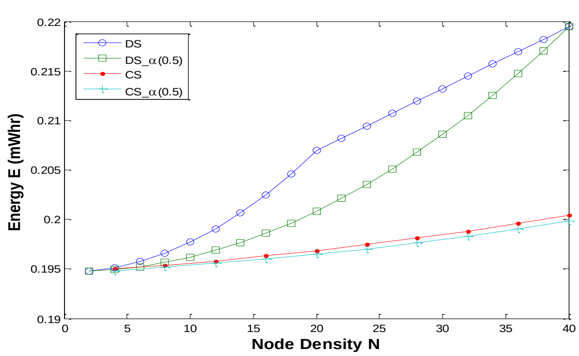

Fig.5. Energy plots of cooperative sensing schemes

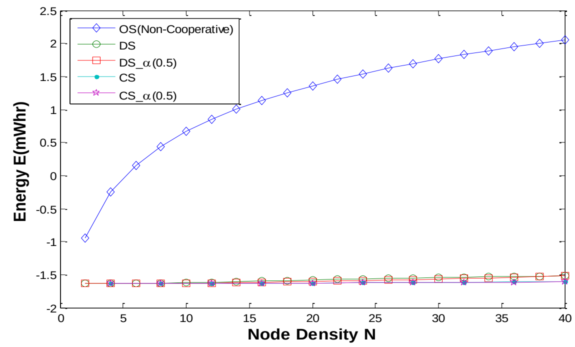

Fig.6. Comparison of cooperative and non-cooperative schemes

The above plot of Fig.6 gives a comparison of the optimal scan non-cooperative scheme and cooperative schemes for the log scale of energy. The optimal scheme energy increases exponentially with the increase of node density while the cooperative schemes remain almost flat.

3. Conclusions

The cluster based scheme saves up to 13% of energy over the distributed scheme for higher 'N'. The distributed-α (0.5) scheme is 3% energy efficient than the basic distributed scheme. The savings can as higher as 7% for lower value of α of 0.2. The energy savings are higher for lower values of α and this trend is more significant in the distributed scheme. However, as α increases the per node energy costs would also be higher than the per node energy costs of the basic schemes. Hence, in our future work we derive optimal values of α to maximize the savings. For a constant 'N', as the number of clusters 'K' increases the energy costs proportionately increase. So ideally having one cluster would be the most energy efficient case of clustered scheme. The cooperative sensing schemes analyzed in this paper save about 49%-96% energy over the optimal non-cooperative scheme in [1] for varying values of 'N'.

4. Acknowledgements

I would like to thank my thesis advisor Dr. Vinod Namboodiri for all his guidance throughout this work.

References

[1] Namboodiri V., "Are Cognitive Radios energy efficient? A study of the Wireless LAN scenario", 2009

[2] Wenfang Xia., "Cluster-Based Energy Efficient Cooperative Spectrum Sensing in Cognitive Radios", 2009