Spectrum Usage Estimation and Channel Allocation in IEEE 802.22 Networks[*]

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ABSTRACT

In this paper, we propose and evaluate a novel spectrum usage estimation methodology for IEEE 802.22 networks and use that to efficiently allocate data channels to consumer premise equipments (CPEs). We specifically analyze the problem of estimating the spectrum usage report at any arbitrary CPE location. A base station (BS) achieves this by opportunistically sharing and fusing the raw spectrum usage reports from different BSs using the well known Shepard's interpolation technique for irregular data sets in a multi dimensional space [2]. Once the spectrum usage is estimated, the BS performs uplink and downlink channel allocation to the CPE. We evaluate our estimation and allocation framework by analyzing the number of allocated CPEs, the number of BSs required for efficient estimation, and by verifying the nature of spectrum estimation with trace results.

1. SPECTRUM USAGE SHARING IN IEEE 802.22 NETWORKS

IEEE 802.22 based wireless regional area networks (WRAN) [1] is a cognitive radio technology that operates on the underutilized and unused sub-900 MHz bands used primarily for TV services. The core components of an IEEE 802.22 network are the base stations (BS) and the consumer premise equipments (CPE). These secondary nodes opportunistically access unused or underutilized license bands of primary users. Secondary nodes monitor the activity of primary users on a constant basis using spectrum sensing mechanisms, thereby building a knowledge of spectrum usage called the *spectrum or channel usage* report. This report empowers the secondary users to better adapt their transmission parameters to the current conditions. Channel allocation to CPEs is performed by the BS, which is assumed to have an accurate estimation of spectrum usage report of all CPEs in range. Hence, efficient channel allocation and sustenance of high data rates with low interference in WRAN largely rests upon the BS's ability to accurately estimate spectrum usage and allocate unused bandwidth to the CPEs.

A base station initiates communication with a potentially allocable CPE through beacon broadcast. The base station periodically tunes itself to a particular channel, listens for any primary signal, and if none found then sends a connection establishment beacon to channel. Only a CPE tuned to that channel at that particular time can listen to that beacon and send a channel allocation request back to the base station through the same channel.

Once a base station receives a channel allocation request from a CPE, it finds the nearest (from the CPE) spectrum sensing capable nodes (i.e., other base stations) who share their spectrum usage reports through the common control channel. Selection of these base stations depends on the search radius being considered.

2. SPECTRUM USAGE ESTIMATION

To estimate the spectrum usage at any arbitrary CPE location, we seek to define a continuous two-dimensional interpolation function which passes through all the given irregularly-spaced data points i.e., the base stations that share their spectrum usage.

Let e_i be the value of the detected energy from the spectrum usage report of base station BS_i. Let d_i be the Euclidean distance between BS_i and a CPE c and N be the total number of channels in the spectrum. We adopt an approach to interpolate values using weighted averages. Although the basic weighted average technique of finding expected value at an arbitrary point is easy to compute, it overlooks some key aspects: those being the number, locations, and the relative positions

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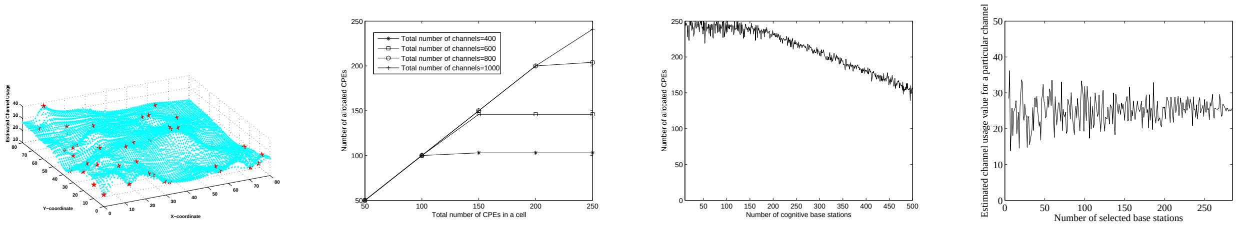

(a) (b) (c) (d)

Figure 1: Performance of the proposed estimation and channel allocation technique

of the known data points with respect to point where the value is to be determined. Considering all these effects on c, the interpolation function is defined as

$$F(c) = \begin{cases} \dfrac{\sum\limits_{BS_i \in R_c^n} w_i e_i}{\sum\limits_{BS_i \in R_c^n} w_i} & if\ d_i \neq 0\ for\ all\ BS_i \\ e_i & if\ d_i = 0\ for\ some\ BS_i \end{cases}$$

Here the weighing factor is defined as $w_i = (p_i)^2(1 + a_i)$ where a_i denotes the directional weighing factor and p_j denotes the distance weighing factor. With the usage for the entire spectrum estimated, the base station can predict the set of free channels at c.

3. CHANNEL ALLOCATION

Once the potentially available channels at c is determined, the BS initiates channel allocation process. Successful channel allocation to a CPE involves allocating a pair of channels, downlink and uplink. Only those channels can be allocated as downlinks and uplinks which are free both at the CPE and at BS, otherwise it will cause harmful interference with primary transmission. Whenever two channels are allocated to a CPE, they are added to the sets of allocated downlink and uplink channels. This helps the BS to ensure spatial reuse of the channels within its cell.

If CPE c wants to relinquish its channels, they are removed from their respective sets. There may be several reasons for channel relinquishment. Session termination by the CPE c or change in spectrum usage scenario in either BS or CPE side because of arrival of primary incumbent. In that case these channels cannot be used any longer until they are freed by primary incumbent, and thus the CPE in question has to be reallocated within the channel move time or kept starving.

4. SIMULATION RESULTS

We conduct extensive simulations to validate the performance of the proposed channel allocation techniques in C and MATLAB.

In Fig. 1(a) we show the spectrum map for the entire region, i.e., the estimated channel usage of a particular channel at every point in the region with 40 participating base stations. The base stations, shown by stars, are the actual data points which are used for interpolation. Fig. 1(b) shows the number of allocated CPEs under a particular base station with varying number of CPEs in that cell. This channel allocation performance is shown for a particular base station with coverage radius of 10 units and search radius of 30 units. A 45 ° slope is ideal implying complete allocation where all CPEs are assigned channels. Our success rate (0.96) is very close to ideal. In Fig. 1(c), we show the number of CPEs *in a particular cell* that were allocated channels successfully with varying number of base stations. We see that the number of allocated CPEs starts to decrease as number of cognitive base stations goes beyond a certain number. This observation is in accordance with Shepard's method [2] which says that increase in the number of selected data-points beyond a certain point will introduce errors in the estimation process thereby affecting allocation. Fig. 1(d) shows the estimated channel usage for a particular channel with varying number of selected base stations. The result that the estimated value reaches a steady state as number of base stations gradually increases is intuitive.

5. CONCLUSIONS

In this paper, we use a modified version of Shepard's interpolation function to estimate the channel usage at any arbitrary CPE location in an IEEE 802.22 network. We also described how such estimations help the base station to efficiently allocate uplink and downlink channels to the CPEs. Through simulation experiments, we showed the efficiency of the allocation technique, effect of total number of base stations and number of selected cognitive nodes on the accuracy of estimation.

6. REFERENCES

[1] IEEE 802.22, Working Group on Wireless Regional Area Networks (WRAN), http://grouper.ieee.org/ groups /802/22.

[2] D. Shepard, "A Two-Dimensional Interpolation Function for Irregularly-Spaced Data," *ACM National Conference*, 1968.