MAC Layer Spectrum Sensing

Analysis of a Logical Channel Cognitive MAC Scheme

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SUMMARY

Spectrum sensing is the first step in the realization of the cognitive radio communications. Therefore, lately it has attracted the interest of many researchers. The sensing problem mostly being considered as a physical layer issue, should also be designed from the perspective of the medium access control (MAC) layer. Briefly, the timing of spectrum sensing periods, the channels to sense and their order of sensing are major issues that should be also considered for an efficient sensing scheme. In this work, after an overview of the MAC layer sensing issues and current work on the subject, we analyze the performance of a MAC protocol which regulates access to the spectrum opportunities in a contention based manner. The spectrum opportunities are tied together to form a high capacity frequency band dubbed as logical channel. Additionally, we propose an enhancement for the analyzed MAC scheme, that forms clusters of sub-channels. Hence, this modification decreases the average medium access delay compared to the single logical channel scheme.

Motivation

• Spectrum is said to be a scarce resource, but some recent research studies show that spectrum usage is very low in some bands whereas very high in others, e.g. ISM bands.

• The problem is: Spectrum is not scarce but the static assignment policy results in the illusion that it is. As a solution, accessing the empty spectrum bands dynamically is proposed. In order to find temporarily/spatially unused bands, spectrum sensing is performed.

• In this work, we analyze MAC layer sensing mechanism based on a logical channel and we propose a clustered approach that decreases the delay in the logical scheme approach.

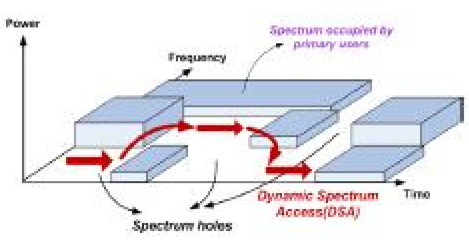
Dynamic Spectrum Access (DSA)

• Secondary users (SU) who do not have license for a specific band can also access the spectrum holes in case the band is not used by a Primary User (PU, also called licensed user).

• What is Spectrum hole?

the potential opportunities for non-interfering (safe) use of spectrum and can be considered as multidimensional regions within frequency, time, and space [1].

Secondary user using the spectrum holes for transmission



How to understand a PU appears in the band SU transmits?

Spectrum Sensing: PHY + MAC + Network

Secondary users perform spectrum sensing in order to determine spectrum holes and to detect the existence of a primary user.

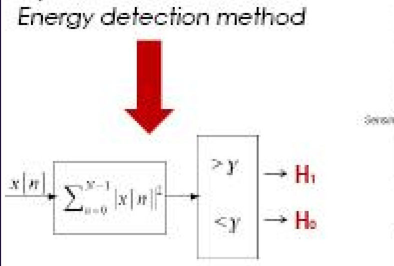
Primary user detection is modeled as binary hypothesis test.

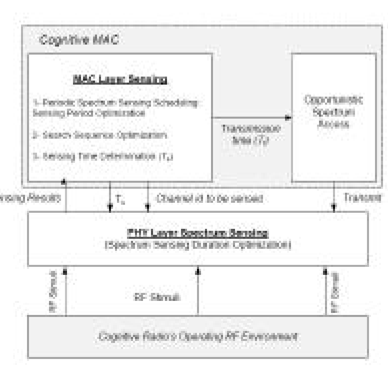
$$\mathcal{H}_0 : Y[n] = \alpha W[n] \quad n = 1, \ldots, N$$
$$\mathcal{H}_1 : Y[n] = \alpha W[n] + h_s X[n] \quad n = 1, \ldots, N \quad (1)$$

Y[n]: received signal at SU receiver
W[n]: Noise samples
X [n]: PU signal
N: # of samples

H_0 The band is empty, no PU
H_1 There is PU in that band

One of the well-known PHY layer detection method: Energy detection method





PHY Layer Sensing Accuracy

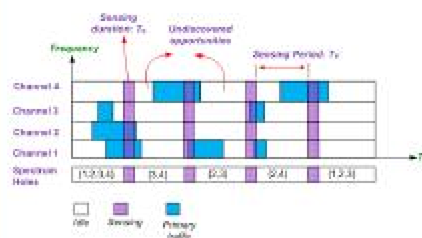
Highly depends on Sensing Duration, the Longer the sensing time the more reliable it is.

PHY sensing makes each SU to detect available spectrum opportunities locally. In case of channel impairments, e.g. noise and shadowing, joint decision of SUs gives more accurate results.

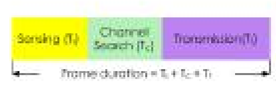
SU Cooperation → Sometimes called *Network Layer Sensing*

MAC Layer Sensing

PHY sensing is more about statistical signal analysis, whereas MAC sensing is about the management of time slots for *sensing, transmission and channel search.*



Quiet periods for sensing, otherwise challenging to distinguish PU signal from SU



Spectrum Efficiency

$$\eta = \frac{T_t}{T_s + T_c + T_t}$$

MAC Layer Sensing consists of three issues

1. Channel Sensing Period Decision
2. Channel Search Order Decision
3. Channel Sensing Time Decision (with PHY)

Optimization Problems

1. Minimize undiscovered opportunities
2. Maximize Spectrum Efficiency

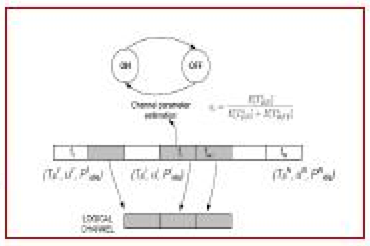
To achieve (1), apply Adaptive Sensing Period for each channel utilizing the channel statistics.

Kim and Shin [2] proposed an optimal sensing framework that uses a logical channel approach. The available frequency bands are joint together to form the logical band for SU access. Our work is based on analysis of [2] and we propose an enhancement for this optimal sensing framework.

Find Optimal Periods Vector [2]

$$\underline{T_P}^* = \arg\max_{\underline{T_P}} \left\{ \sum_{i=1}^{N} \{(1-u^i) - SSOH^i(\underline{T_P}) - UOPP^i(T_P^i)\} \right\} = \arg\min_{\underline{T_P}} \left\{ \sum_{i=1}^{N} \{SSOH^i(\underline{T_P}) + UOPP^i(T_P^i)\} \right\}$$

UOPP: unexplored opportunity
SSOH: Sensing overhead
u: channel busy ratio

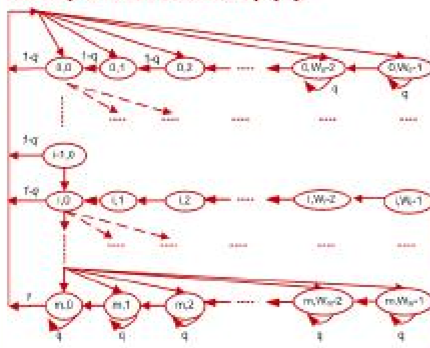


Alternating renewal theory can be used to estimate the channel occupancy probabilities of channels. Thus, channels are sensed in decreasing order with the highest probability of being idle channel sensed first.

Two-Dimensional Markov Chain Analysis

Kim and Shin's work is quite outstanding since provides an optimal solution, however it suffers from large MAC delays since provides a contention based medium access.

We first provide a theretical analysis of the proposed scheme. Applying the classical Markovian analysis by *Bianchi* [3] MAC delay is calculated by (3).

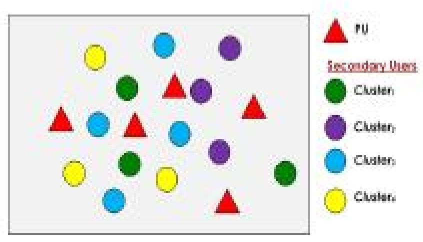


$$D_{MAC} = \frac{(1-2q)\cdot(W+1) + qW\cdot(1-(2q)^m)}{2\cdot(1-2q)\cdot(1-q)} \quad (3)$$
$$q = 1-(1-\tau)^{M-1} \quad (4)$$
$$\tau = \sum_{i=0}^{m} b_{i,0} = \sum_{i=0}^{m} \frac{1-(q)^{m+1}}{1-q} b_{0,0} \quad (5)$$

b(t) and s(t) denote stochastic processes of the backoff time counter and the backoff stage of a node at time t, respectively. Then, {b(t); s(t)} is a discrete-time Markov chain.

Proposed Clustered Approach

In a contention based MAC protocol, delay is dependent on the number of contenders. Hence, instead of forming a single logical channel a set of sub-logical channels can be formed. Then, secondary nodes are clustered into groups and each SU contends with the elements in the same cluster. The clustered-approach facilitates a better allocation of the spectrum opportunities between the competing secondary nodes.



$$D^{\prime}_{MAC} = \frac{1}{C}\sum_{i=0}^{C} D^{i}_{MAC}$$

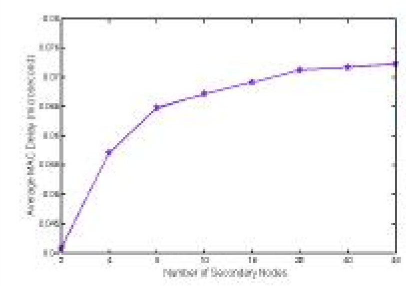
C: # of clusters
M : # of SU
Assuming uniform dist, # of SU in a cluster M/C

How to cluster?

Although we assumed a black-box clustering scheme and did not focus on it, there are possible clustering approaches, e.g. traffic prediction based clustering. This scheme clusters nodes according to their "on" times such that in each class collision will be minimized.

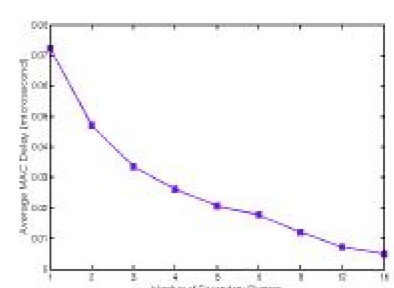
Initial Results

We modeled the system using OPNET Modeler 14.0 [4].



With increasing number of secondary users, the average MAC delay increases

In this scenario, network traffic is low, therefore the network throughput is linearly proportional to the network size.



Change in average MAC delay with increasing number of clusters

In the simulations, we did not consider the extra cost due to cluster assignment.

Conclusions

MAC delay is strongly dependent on number of users in the network. We used a two-dimensional Markov chain to model the opportunistic access scheme of the secondary network. By a set of simulations, we verified that the bigger the network size in terms of users, the longer the MAC delay. Hence, instead of forming a single high bandwidth logical channel, it is more efficient to form lower bandwidth sub-channels. In the proposed cluster-based approach secondary users have a more fair access to the spectrum opportunities.

References

[1] R. Tandra, M. Mishra, A.Sahai, *"What is a spectrum hole and what does it take to recognize one?"*, University of California at Berkeley Tech. Report, August 31, 2008.
[2] H. Kim and K. G. Shin, "Efficient Discovery of Spectrum Opportunities with MAC-Layer Sensing in Cognitive Radio Networks," *IEEE Transactions on Mobile Computing*, vol. 7, no. 5, pp. 533–545, May 2008.
[3] G. Bianchi, "Performance analysis of the IEEE 802.11 Distributed Coordination function", *IEEE Journal on Selected Areas in Communications*, Vol. 18, Issue 3, pp:535 – 547, Mar 2000.
[4] OPNET Modeler, Optimizaing Network Technologies, www.opnet.com.

WOMEN OF SPACE

Valentina Tereshkova (1937, Russia)
First woman in space
2.95 days in 1963
Vostok-6 Space flight
For more women in space:
http://www.astronautix.com/articles/womspace.htm

WOMEN OF COMPUTING

Barbara Liskov (1939 - , USA)

2009 ACM Turing Award Winner
Second women to win this prize (first was Frances Allen, she won award in the 41th year of the prize, 2006)

The first woman in the United States to receive a Ph.D. from a computer science department.

WOMEN ENGINEERS GROUP

We are a group of women working (seeking for a job or retired) in technical fields that came together to build solidarity and fight against gender discrimination in professional/daily life in Turkey.
Web site is in Turkish but if you are interested in more about the group:
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Kadın Mühendisler