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Adaptive Mac Layer Spectrum Sensing Algorithms For Cognitive Radio Networks

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Abstract-- In Cognitive radio networks, spectrum sensing is one of the major issues for dynamic spectrum access. The physical layer senses the spectrum availability of the primary users. The MAC layer sensing decides how often, at which time duration and in which order to sense the Primary user channels. In this paper, for the MAC layer, we propose an adaptive retry time algorithm and modified optimal channel sequencing algorithm to reduce the spectrum sensing period and channel switching latency (CSL) respectively. The proposed adaptive retry time algorithm adaptively changes the spectrum sensing period based on the number of channels and the physical layer sensing time. The modified optimal channel sequencing algorithm arranges the primary user channels in the descending order of their idle probability and T_{OFF} duration. These two algorithms reduce the number of channel switching, channel switching latency and improve the channel utilization of secondary users. The performance of these algorithms was verified with different techniques. The average channel switching latency has reduced from (35.65 - 65.11) % and the secondary user channel utilization has improved from 7.61% to 28.21 %.

Index Terms – Adaptive Spectrum sensing, Adaptive retry time, Cognitive Radio Network, Channel utilization, Modified optimal channel sequencing.

I. INTRODUCTION

In wireless networks, to overcome the problem of spectrum scarcity, the Cognitive radio networks serve as a framework for dynamic spectrum allocation. The spectral efficiency of dynamic spectrum allocation is significantly improved compared to static spectrum allocation [2]. The dynamic spectrum allocation requires the enhancement of currently available Physical and MAC layer protocols to adapt spectrum-agile features. The secondary users (SUs) can access the idle spectrum of the primary users (PUs) but the interference to the primary users should be minimum. To access the idle channels of PUs, the SUs should monitor each PU channel's usage pattern to identify and exploit the spectrum availability.

In general, spectrum sensing is considered as two layer mechanism. The PHY layer sensing mainly focuses on efficiently detecting the PU's signal to identify the availability of the channel. The most general PHY layer sensing techniques are energy detection, matched filter detection and feature detection etc, [3], [4], [5],[15],[16]. In the MAC layer sensing it decides when the SUs can sense which channels and in which order.

In this paper, our main focus is to improve the performance of adaptive MAC layer sensing by increasing the discovery of opportunities and decreasing the channel switching delay. To improve the MAC layer sensing performance, in this paper we propose two algorithms:1.Adaptive Retry time algorithm to minimize the spectrum sensing time and 2.Modified optimal channel sequencing algorithm to arrange the primary user channels in the descending order to reduce the channel switching delay. In [1] Kim proposed sensing period optimization and optimal channel sequencing to reduce the sensing period and channel switching delay respectively. In the existing work [1] the duration between two consecutive sensing is fixed and the channel sequencing algorithm is based on the descending order of idle probability. But in the proposed work, the adaptive retry time algorithm adaptively changes the sensing period based on the number of channels and physical layer sensing interval T_I and the modified optimal channel sequencing algorithm arranges the PU channels in the descending order of their idle probability and the OFF duration of the channels. The proposed work, reduces the idle channel finding delay and the number channel switching and average channel switching latency and improved the secondary user channel utilization when compared to the existing work [1]. The performance of the proposed work has verified with the existing work [1], fixed and random sensing period with no ordering of the channels.

The organization of this paper is given as follows: Section II describes about the related work, section III illustrates the system model of adaptive MAC layer spectrum sensing framework. Section IV explains about adaptive retry time algorithm of spectrum sensing and section V describes the minimum channel switching latency with modified optimal channel sequencing algorithm. Section VI describes about the performance of simulation results. Finally section VII concludes this paper.

II. RELATED WORK

For MAC layer sensing, there are a limited number of publications compared to physical layer sensing of cognitive radio networks. In [6] a proactive sensing algorithm with non adaptive and randomly chosen sensing period is proposed. But maximization of discovery of opportunity is not considered. A cognitive MAC(C-MAC) protocol for distributed multi channel wireless networks is introduced in [8]. A stochastic channel selection algorithm based on learning automata is proposed in [9], which dynamically adapts the probability of access of one channel in real time. The probability of successful transmission is maximized using the algorithm. A hardware constrained cognitive MAC was proposed in [10] to optimize the spectrum sensing decision by formulating sensing as an optimal stopping problem. A Decentralized cognitive MAC had proposed in [11].This DC MAC deals with reactive sensing with slotted time CSMA based channel access. Shankaranarayanan et al. [12] proposed an Ad-hoc Secondary system MAC(AS-MAC), which ia a proactive scheme with slotted time based channel access. In [11] and [12], they did not consider about the tradeoff between sensing overhead and discovery of opportunities. Hyoil Kim [1] proposed an adaptive sensing period and channel sequencing algorithm to reduce the sensing time in the MAC layer. But the consecutive spectrum sensing time ie Retry time is used as a fixed value, whereas in the proposed work it is varied adaptively and the optimal channel sequencing algorithm is also modified to reduce the channel switching delay and to increase the channel utilization of SUs.

III.SYSTEM MODEL

a. Network Topology:

In this work, it is assumed that a group of SUs form a single hop wireless secondary Network (SN) provided that within the transmission range, there are no other SNs interfering with that SN. In a practical Cognitive radio network scenario, the interference among adjacent SNs should be solved with internetwork coordination of channel sensing and allocation. The proposed scheme can coexist with any coordination scheme. It can dynamically adapt to the pool of available channels for SNs provided that those channels are not used by other SNs simultaneously.

It is assumed that each SU in the SN is equipped with a single antenna and it can be tuned to any combination of licensed channels. This is performed with orthogonal frequency division multiplexing (OFDM).When each SU is equipped with more than one antenna it will cause severe interference among its antennas and degrade its performance. To avoid this, it is assumed that each SU is equipped with a single antenna and it works as a transceiver as well as a sensor in its SN.

The main role of spectrum sensing is to determine the presence /absence of PUs on a channel. Energy and feature detectors are the most commonly used sensing techniques. As energy detector detects the energy alone, feature detector can be used. But the feature detector increases the sensing time. So to avoid this, IEEE 802.22 introduced the concept of quiet period in [13] and [14]. During this time all the SUs suspend their transmission so that any SU monitoring the channel may observe the presence/absence of the PU signals without interference. It is assumed that a channel is sensed within the quiet period.

b. Channel Usage Model:

In Spectrum sensing the channel availability of the PU's can be modeled as ON/OFF usage pattern. So that the SUs can utilize the spectrum when it is OFF (idle) without causing any interference to the PUs.

Let us assume that there are i channels for the PUs in the cognitive radio system. The ON period is modeled as a random variable $T_{ON(i)}$ with probability density function (p.d.f) ( ) (y), y>0 similarly the p.d.f of the OFF period is ( ) (x), x>0.The ON periods are i.i.d (independent and identically distributed) and we assume that the ON and OFF periods are independent of each other.

Let $Z^i(t)$ denote the state (ON/OFF) of channel i at time t. $Z^i(t)$, $t \geq 0$ becomes a semi Markov process in which the process enters ON/OFF state and the next state transition is governed by the p.d.f ( )(y)/ ( ) (x) since there are only two states, the process can be analyzed using the theory of alternate renewal processes and can be represented with semi Markov model. Fig.1. shows the state transition model of this semi Markov process.

Spectrum Sensing is a sampling procedure of the given channel process { $Z^i(t)$, $t \geq 0$} to discover its state at each sensing instant. A sample from an ON/OFF period corresponds to the value 1/0. Sensing produces a binary random sequence for each channel.

Spectrum sensing is performed either periodic manner or as on demand basis. In this work, periodic sensing is considered. For periodic sensing with sensing period $T_P(i)$ and sensing time $T_I(i)$ the value of $T_I(i)$ is predetermined by the required quality of physical layer sensing and it is small relative to $E[T_{OFF(i)}]$ and $E[T_{ON(i)}]$.The channel utilization u(i) is defined as the fraction of time in which channel i is in ON state and it is given as $u(i) = E[T_{ON(i)}]/\{ E[T_{ON(i)}]+E[T_{OFF(i)}]\}$.

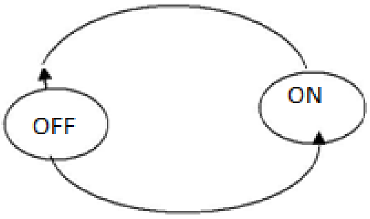

Fig.1. State Transition diagram of semi Markov model

c. Opportunity Usage Model:

Opportunity represents a spectrum hole (an OFF period) in a licensed channel. This is discovered by sensing the channel. $T_I(i)$ is the ith channel spectrum sensing time in the physical layer. During sensing, if an opportunity is discovered in a channel the channel is merged with a pool of available channels where the pool of available channels is called as logical channel. A logical channel can include 0- N licensed channels depending on their availability at that instant. The logical channel is treated as a single channel by using OFDM technique with selective allocation of subcarriers to the channels to be utilized [5], [6], [7]. These logical channels can be used by the SUs. The logical channels which are used by the SUs are termed as home channels. A channel which is not in the logical channels is called as foreign channel.

To share the logical channels among the SUs, we assume the following medium access model: 1. SUs with packets to transmit compete with each other to gain access to the logical channel, 2. When a SU is transmitting, other SUs keep silent, 3. The SU who has gained access to the channel should listen the medium before transmission (to detect the return of PUs) [6]. The detection of PUs return should be done with short duration of time so that the interference to the PUs can be reduced and the channel can be vacated by SUs. To vacate the channel for the PUs, OFDM should reconfigure the subcarriers to exclude the channel from usage. When the channel to be vacated to the PU is the only member of logical channel, then the SU has to vacate the current channel immediately and switch its transmission to other idle channel.

IV. ADAPTIVE RETRY TIME TO OPTIMIZE CHANNEL SWITCHING LATENCY

The Retry time of spectrum sensing influences the idle channel finding delay, number channel switching, channel switching latency, channel utilization of SUs and throughput of the network. Therefore in the proposed, work the retry time of spectrum sensing is varied adaptively in accordance with the variation of the number of channels and spectrum sensing time T_I after some predefined duration.

a. Adaptive Retry Time:

The Retry time is directly proportional to the new channel availability time [7].The minimal value of new channel availability time is a single channel sensing time (T_I), whereas the maximum value of new channel availability time is the time required to sense all the N channels ie,(N x T_I). Therefore the expression for Retry time is given as follows,

$$T_{retry} = 5(N+1)T_I \quad (1)$$

In the above expression T_{retry} is multiplied by a factor of 5 because the retry time should be greater than the data transmission duration.

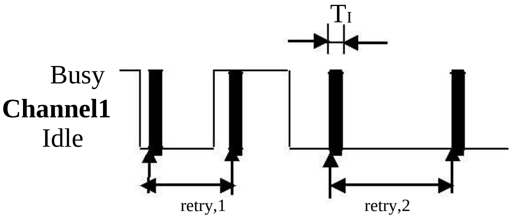

Fig.2.Timing diagram for sensing interval and Retry time for a channel.

Fig.2 Gives the timing diagram for sensing interval T_I (ie the physical layer sensing duration) and two different sensing periods ie adaptive retry time T_{retry} for a channel. The adaptive retry time algorithm is given as flowchart in fig.3.

The algorithm for the adaptive retry time is given as follows,

1. Get the value for T_I and N .Calculate T_{retry} value.
2. Use the value T_{retry} for spectrum sensing.
3. Change the value of T_{retry} when time duration elapses else use previous value of T_{retry}.

b. Channel Switching Latency (CSL) With retry time:

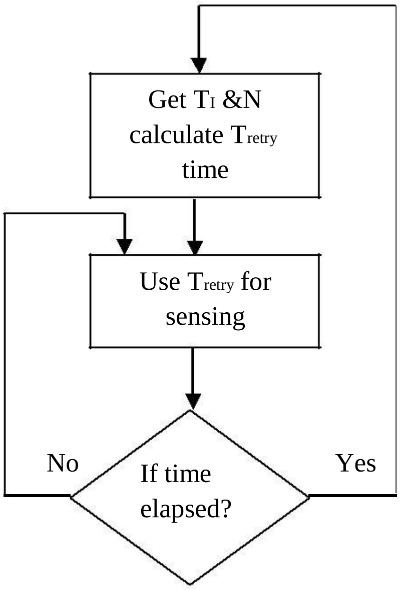

Fig. 3. Flow chart for Adaptive Retry time algorithm.

The adaptive retry time not only influences the spectrum sensing time but also affects the channel switching latency. The Channel Switching Latency depends on spectrum sensing time, number of channels and the consecutive channel search duration ie, Retry time. The expression for minimum value of channel switching latency is $T_{CSLmin}=$ and the maximum value of CSL is $T_{CSLmax}= NnT_I + (n-1)T_{retry}+$.

The average value of channel switching latency for N number of channels is given as follows,

$$T_{CSLavg}= {}^{1} \{\sum_{=1} \{ \quad (i)+MT_I(i)+ xT_{retry}(i)+ \quad (\ )\}\} \tag{2}$$

Where,
n- Number of complete search of N channels.
$M < N$.
If $M=0$ then $x = n-1$, else $M \neq 0$ then $x = n$.
T_{retry} -Time duration between two consecutive channel searches.
-Network switching delay from one channel to other.

Channel switching latency is a function of the number of channel switching and idle channel finding delay. It is given as follows,

$$T_{CSL}= f (N_{CS}, T_{idelay}) \tag{3}$$

Where N_{CS} – Number of channel switching
T_{idelay} - Idle channel finding delay time.

For the proposed adaptive sensing algorithms the number of channel switching is a function of spectrum sensing time T_I, Adaptive retry time T_{retry} and the switching delay in the network and it is given as follows,

$$N_{CS,\ adapt} = f (T_I, T_{retry}, \tau) \tag{4}$$

For the case of fixed retry time based sensing, N_{CS} is given as follows,

$$N_{CS,fixed} = f (T_I, T_P ,\tau) \tag{5}$$

Tp - fixed sensing period.

The number channel switching for the fixed case is more when compared with adaptive algorithms, because $T_{retry} <T_P$.

The expression for idle channel finding delay T_{idelay} for the proposed adaptive algorithm and the fixed case are given as follows,

$$T_{idlay,\ adapt}= f\{T_I,T_{retry}\ P_{idle}(i),T_{OFF}(i)\} \tag{6}$$

$$T_{idelay,\ fixed} = f\{T_I, T_P\} \tag{7}$$

For the proposed adaptive sensing algorithms the idle channel finding delay is less compared to the fixed, random and Kim [1], because in equation (7) it is a function of TI and Tp only. But in equation (6) it is a function of $P_{idle}(i)$ and $T_{OFF}(i)$. Therefore the idle channel finding delay is less for the case of adaptive sensing compared to the fixed algorithms. As the number channel switching and ilde channel finding delay are less for the adaptive sensing algorithms, the Channel Switching Latency (CSL) is also less.

c. Secondary User Channel Utilization:

The channel utilization of secondary users depends on the OFF duration $T_{OFF}(i)$ of PUs and T_{idle} of SUs (ie. the identified PU's spectrum OFF duration but not used by the SUs), Sensing period Tp(i) and the average channel switching latency T_{CSLavg}. The expression for average channel utilization is given as follows,

$$Avg.SU.u={}^{1} \sum \{ T_{OFF}(i)[T_{idle}(i)+T_I(i)+T_{CSLavg}]/ T_{OFF}(i)\} \tag{8}$$

V. MINIMUM CHANNEL SWITCHING LATENCY BY MODIFIED OPTIMAL CHANNEL SEQUENCE OF SENSING

The SUs should try to minimize the time required to find an idle channel when they are in a need to switch the current channels to some other channels because of the PUs demand for the channels. So that the SUs must sense (N-1) foreign channels one by one until they can find an idle channel. In a simple search sequence, the channels may be arranged in an ascending order of channel utilization (u^i), which is not an optimal solution.

To optimize the idle channel finding time and to reduce the number channel switching and channel switching delay, let us consider (t) the probability that the channel i would be idle at a certain time t and $T_{OFF}(i)$ the idle duration of ith channel. For the optimal channel sequencing algorithm the channels are arranged in descending order of (t) in [1]. But in this proposed work, for the modified optimal channel sequencing algorithm, along with the (t), $T_{OFF}(i)$ parameter is also considered. In the modified optimal channel sequencing algorithm the PUs channels are arranged in the descending order of both (t) and $T_{OFF}(i)$ and sensed. The modified optimal channel sequencing algorithm is given as flowchart in fig.4.

a. Modified Optimal Channel Sequencing algorithm for Sensing:

The complete modified optimal channel sequencing algorithm is given as follows:

1. Calculate(t).
2. Calculate $T_{OFF}(i)$ of idle channels.
3. Sense (N-1) channels in the descending order of (t) and $T_{OFF}(i)$.

In this proposed algorithm the channels are arranged in the descending order of idle probability of channels and maximum T_{OFF} duration of channels whereas in the existing

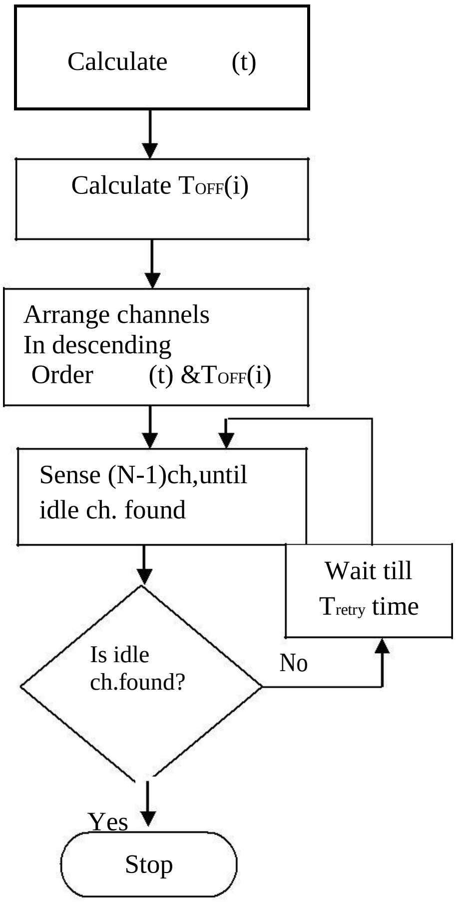

Fig.4.Flow chart of Modified Optimal channel sequencing Algorithm.

algorithm given in [1] the channels are arranged in the descending order of idle probability of channels only. This reduces the number of channel switching and switching delay.

If no idle channel is found in a complete search of (N-1) channels and another search is performed within a short duration of time then there is a chance to get no idle channels. To avoid this, (N-1) channels to be searched again after T_{retry} seconds. In this work, the T_{retry} time is adaptively varied in accordance with the variation of number of channels and physical layer sensing time $T_I(i)$. A new idle channel will be found either by research or by periodic sensing. Once a new idle channel is found, SUs complete the channel switching procedure and resume their communication in a new channel.

VI. PERFORMANCE EVALUATION

This section provides the numerical results obtained by MATLAB simulation demonstrating the improved performance of our proposed MAC layer adaptive spectrum sensing with the existing algorithm [1] and fixed, random retry time with no channel sequencing. The performance of the proposed scheme is measured in terms of the idle channel finding delay, Number of channel switching, Average channel switching latency and channel utilization of secondary users.

We consider a total of 12 heterogeneous channels for the simulation. The channels are assumed to have exponentially distributed ON/OFF periods. The different channel conditions are tested by changing the number of channels to be sensed as three channels (1,2,3), six channels (1,2,…6), nine channels (1,2,3..9) and twelve channels(1,2,3..12).

The proposed scheme has comparatively evaluated with the existing schemes. The parameters used for simulation were tabulated in table 1and 2 and all the time values are in seconds.

parameter	**Proposed Value**
Number of channels	3,6,9,12
T_{retry}	40,70,100,130 msec
$T_I(i)$	2 msec
	0.1sec

Table.1. General parameters.

Ch.id	**Ch1**	**Ch2**	**Ch3**	**Ch4**	**Ch5**	**Ch6**
$T_{OFF}(i)$	1.5	0.6	0.5	3.0	1.0	3.5
$T_{ON}(i)$	0.8	2.5	0.5	2.5	2.0	0.6
$T_{idle}(i)$	0.18	0.17	0.18	0.58	0.23	0.58
Ch. id	**Ch7**	**Ch8**	**Ch9**	**Ch10**	**Ch11**	**Ch12**
$T_{OFF}(i)$	4.0	0.5	0.7 5	1.5	3	2.5
$T_{ON}(i)$	1.0	3.3	2.0	0.3	0.2	0.15
$T_{idle}(i)$	0.53	0.18	0.17	0.28	.53	0.38

Table.2.Channel usage pattern parameters.

In the proposed scheme the idle channel finding delay was reduced when compared with the other three schemes (ie. fixed, random and Kim). This performance is shown in fig.4. For the proposed adaptive sensing, the idle channel finding delay ranges from 18 to 15 m sec which is very less compared with other schemes.

The proposed scheme reduced the number of channel switching as shown in fig.5.For the proposed scheme the number of channel switching ranges from 3 to 4 which is less compared with other algorithms.

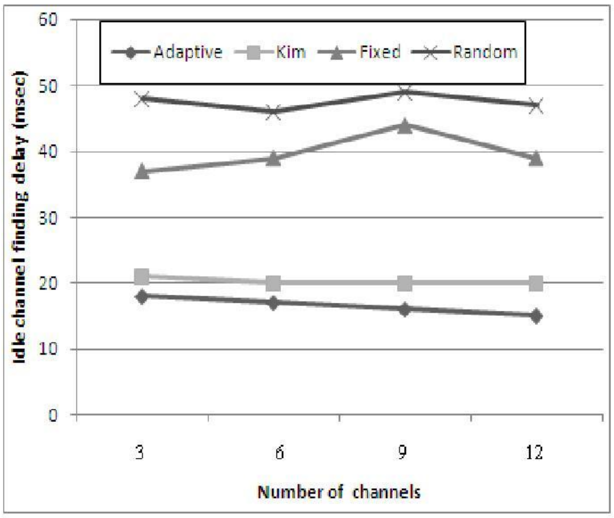

Fig.4. Number of channels Vs Idle channel finding delay.

The proposed adaptive sensing algorithms have reduced the average channel switching latency when compared with Kim [1], fixed and random retry time. This performance is shown in fig.6. and fig.7.The channel switching latency was reduced from 35.65 to 65.11% (compared with kim[1]).

The channel utilization of secondary users of the proposed scheme is better when compared with the other three schemes. The channel utilization of the proposed scheme ranges from 56.54 to 69.74 % and it ranges from 28.33 to 62.13 % in Kim[1] and it is lesser for the other two schemes as shown in fig.8. In the proposed scheme, the obtained channel utilization of secondary users ranges from 7.61 to 28.21%.

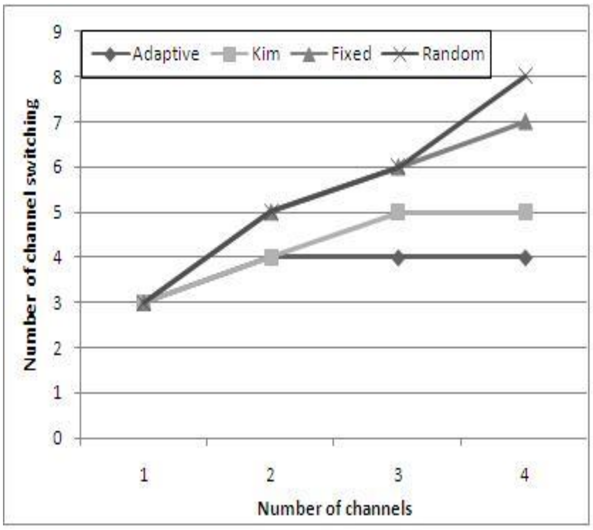

Fig.5. Number of channels Vs Number of channel switching

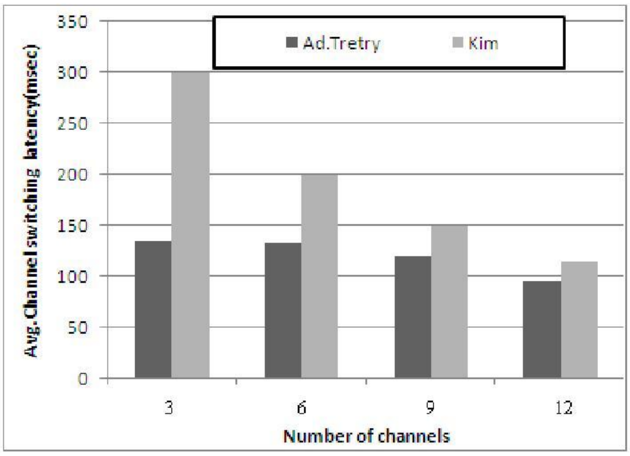

Fig.6. Average channel switching Latency with Adaptive Retry time.

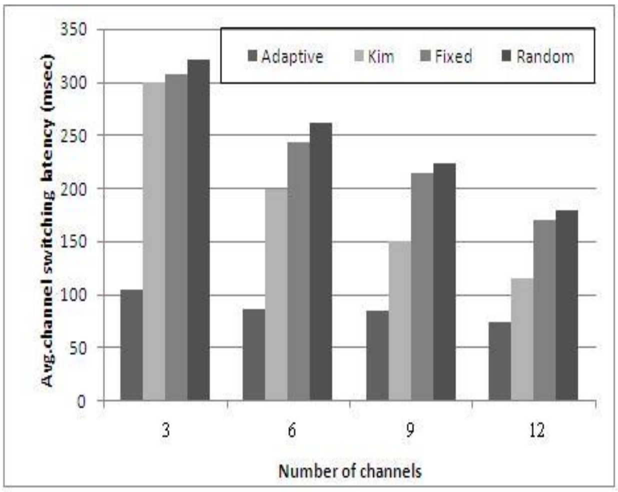

Fig.7. Average Channel switching latency comparison with other three algorithms.

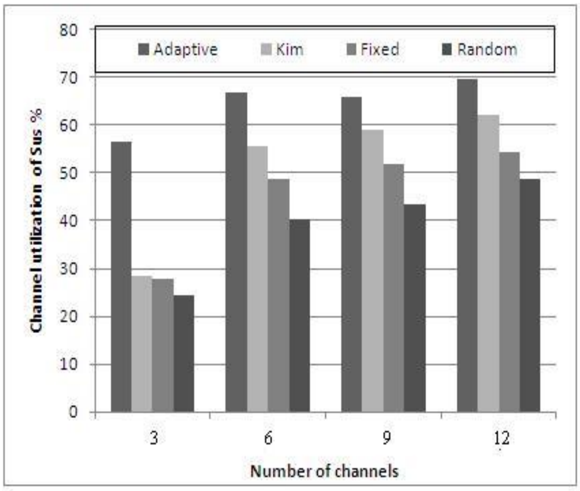

Fig.8. comparison of Channel utilization of secondary users with other techniques.

In the proposed adaptive sensing scheme the idle channel finding delay, number of channel switching, average channel switching latency were reduced and channel utilization of SUs were improved when compared with the other three algorithms.

VII. CONCLUSION AND FUTURE WORK

The proposed adaptive Retry time and modified channel sequencing algorithms improved the performance of MAC sensing framework, by reducing the number channel switching, the channel switching latency and increasing the SUs channel utilization. The simulation results have shown that the merits of the proposed scheme such as adaptive retry time, lesser channel switching, switching latency and improved channel utilization of SUs.

In the future work, one may consider the energy of the secondary users along with the adaptive retry time to optimize the performance.

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