Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 7 (4): 581-590, 2014
ISSN 1992-1454 / DOI: 10.3923/ajsr.2014.581.590

Adaptive Retry Time Based MAC Layer Spectrum Sensing for Cognitive Radio Networks

S. Varalakshmi and S. Shanmugavel
Department of Electronics and Communication Engineering, Anna University, Chennai, India

Corresponding Author: S. Varalakshmi, Department of Electronics and Communication Engineering, Anna University, Chennai, India

ABSTRACT

Spectrum sensing is an important issue for dynamic spectrum sharing in cognitive radio networks. The physical layer senses the availability of the primary user's channels whereas the MAC layer decides how often, at which time duration and in which order to sense the availability of those channels. In this study, an adaptive retry time algorithm is proposed for spectrum sensing and a modified optimal channel sequencing algorithm to reduce average Channel Switching Latency (CSL) and improve the channel utilization among the Secondary Users (SUs). The retry time of spectrum sensing is varied in accordance with the number of channels and sensing time in the physical layer. The modified optimal channel sequencing algorithm reduces the number of channel switching by arranging the primary user channels based on the descending order of their idle probability and T_{OFF} duration. This adaptive retry time and modified channel sequencing algorithm reduce the number of channel switching, the average channel switching delay by 43.4-65.11% and improves the secondary user channel utilization from 6.9-28.21% compared to the existing algorithm. The performance of the MAC layer adaptive spectrum sensing is verified using MATLAB.

Key words: Cognitive radio network, adaptive spectrum sensing, adaptive retry time, modified optimal channel sequencing, channel switching, channel utilization

INTRODUCTION

To overcome the problem of spectrum scarcity in wireless networks, 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 allocation (FCC, 2002). The dynamic spectrum allocation requires the enhancement of current PHY and MAC protocols to adapt spectrum-agile features. The Secondary Users (SUs) can access the idle spectrum of the Primary Users (PUs) without causing any harmful interference to the PUs. For this, the SUs should monitor each PU channel's usage pattern to identify and exploit spectrum availability.

Usually, spectrum sensing is considered as a two layer mechanism. In the PHY layer, sensing focuses on efficiently detecting the PU's signal to identify the availability of the channel. The most common PHY layer sensing techniques are energy detection, matched filter detection and feature detection, etc., that were proposed by Cabric *et al.* (2004), Tang (2005) and Shankar *et al.* (2005). In the case of MAC layer sensing, it decides when SUs can sense which channels and in which order.

In this study, the main focus is to improve the performance of adaptive MAC layer sensing by reducing the channel switching delay. For that, an adaptive retry time is proposed for spectrum sensing and a modified channel sequencing algorithm along with the two issues of MAC layer sensing proposed by Kim and Shin (2008). The two issues are: (1) How to maximize the overall discovery of opportunities in the licensed channels and (2) How to minimize the delay in locating an idle channel. The first is the sensing period optimization that maximizes the spectrum opportunities and optimizes the sensing overhead. The second is the optimal channel sequencing algorithm in which the channel switching delay is reduced and the channel utilization is improved. Along with this, this proposed adaptive retry time algorithm adaptively changes the retry time of spectrum sensing after some duration depending on the number of channels and the sensing time. This algorithm reduces the idle channel finding delay and the average channel switching latency much more. This, in turn, increases channel utilization among the SUs. This modified optimal channel sequencing algorithm for spectrum sensing arranges the primary user channels in descending order based on their probability of idle status and T_{OFF} duration. This, in turn, reduces the number of channel switching among the SUs and also reduces the average channel switching latency. This improves the channel utilization of secondary users.

There are a limited number of publications for MAC layer sensing compared to physical layer sensing of cognitive radio networks. Chou (2004) proposed a proactive sensing algorithm with non adaptive and randomly chosen sensing period. But maximization of discovery of opportunity is not considered. A cognitive MAC(C-MAC) protocol for distributed multi channel wireless networks was introduced by Cordeiro and Challapali (2007). A stochastic channel selection algorithm based on learning automata is proposed by Song *et al.* (2007), 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 is proposed by Jia *et al.* (2008) to optimize the spectrum sensing decision by formulating sensing as an optimal stopping problem. A decentralized cognitive MAC was proposed by Zhao *et al.* (2005). This DC MAC deals with reactive sensing with slotted time CSMA based channel access. Sankaranarayanan *et al.* (2005) proposed an Ad-hoc Secondary system MAC(AS-MAC), which ia a proactive scheme with slotted time based channel access. Zhao *et al.* (2005) and Sankaranarayanan *et al.* (2005), not consider about the tradeoff between sensing overhead and discovery of opportunities. Kim and Shin (2008) proposed an adaptive sensing period and channel sequencing algorithm to reduce the sensing time in the MAC layer. But the consecutive spectrum sensing time i.e., retry time is used as a fixed value, whereas in the proposed study, it is varied adaptively and the optimal channel sequencing algorithm is also modified to reduce the channel switching delay and channel utilization of SUs.

SYSTEM MODEL

Network topology: In this study, it is assumed that a group of SUs form a single hop wireless Secondary Network (SN) that provided within the transmission range and 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 that provided those channels which 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 given by Cordeiro *et al.* (2006) and Jain (2008). 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.

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) $f_{T_{ON}}(i)(y)$, $y>0$ similarly the p.d.f of the OFF period is $f_{T_{OFF}}(i)(x)$, $x>0$. The ON periods are independent and identically distributed (i.i.d) 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 $f_{T_{ON}}(i)(y)/f_{T_{OFF}}(i)(x)$, 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. Figure 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 as periodic manner or as on demand basis. In this study, 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(TOFF(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 $u(i) = E(T_{ON(i)})/(E(T_{ON(i)})+E(T_{OFF(i)})\}$, Kim and Shin (2008).

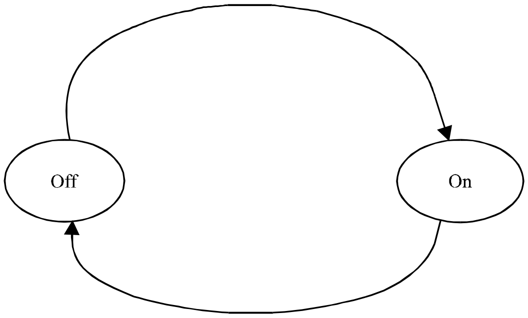

Fig. 1: State transition of semi Markov model

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, proposed by Shankar *et al.* (2005), Chou (2004) and Huang *et al.* (2011). 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) proposed by Chou (2004). 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.

ADAPTIVE RETRY TIME TO OPTIMIZE CHANNEL SWITCHING LATENCY

The retry time of spectrum sensing influences the spectrum sensing time, channel switching latency, channel utilization of SUs and throughput of the network. Therefore, in the proposed study, 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.

Adaptive retry time: The retry time is directly proportional to the new channel availability time which was proposed by Huang *et al.* (2011). 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 i.e., ($N\times T_I$). Therefore, the expression for retry time is given as follows:

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

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.

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

- Get the value for T_I and N and calculate T_{retry} value
- Use the value T_{retry} for spectrum sensing
- Change the value of T_{retry} when time duration elapses, else use previous value of T_{retry}

The adaptive retry time algorithm is given as flowchart in Fig. 2.

Channel Switching Latency (CSL) with retry time: The adaptive retry time not only influences the spectrum sensing time but also affects the channel switching latency. The channel

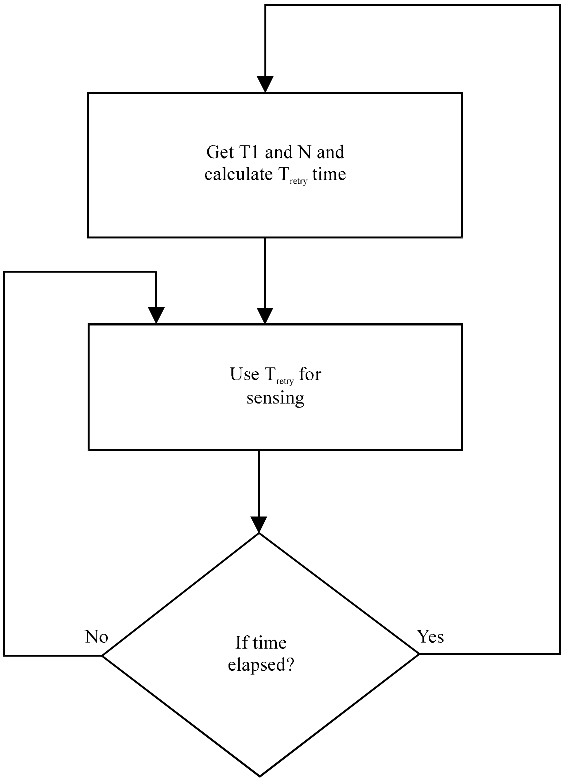

Fig. 2: Flow chart for adaptive retry time

switching latency depends on spectrum sensing time, number of channels and the consecutive channel search duration i.e., retry time. The expression for minimum value of channel switching latency is $T_{CSLmin} = \tau$ and the maximum value of CSL is $T_{CSLmax} = NnT_I+(n-1)T_{retry}+\tau$.

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

$$T_{CSLavg} = \frac{1}{N}\left\{\sum_{i=1}^{N}\{Nn\ T_I(i) + MT_I(i) + xT_{retry}(i) + \tau(i)\}\right\} \tag{2}$$

Where:

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

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 i.e., the identified PU's spectrum OFF duration but not used by the SUs, sensing time $T_I(i)$ and the average channel switching latency T_{CSLavg}. The expression for average channel utilization is given as follows:

$$\text{Avg.SU.u} = \frac{1}{N}\sum_{i}^{N}\{T_{OFF}(i) - [T_{idle}(i) + T_I(i) + T_{CSL avg}]/T_{OFF}(i)\} \tag{3}$$

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 of channel switching and channel switching delay, let us consider $P^i_{idle}(t)$, 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 $P^i_{idle}(t)$. But in this proposed study for the modified optimal channel sequencing algorithm along with the $P^i_{idle}(t)$, $T_{OFF}(i)$ parameter is also considered. In the modified optimal channel sequencing algorithm, the PUs channels are arranged in the descending order of both $P^i_{idle}(t)$ and $T_{OFF}(i)$ and sensed. The modified optimal channel sequencing algorithm is given as flowchart in Fig. 3.

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

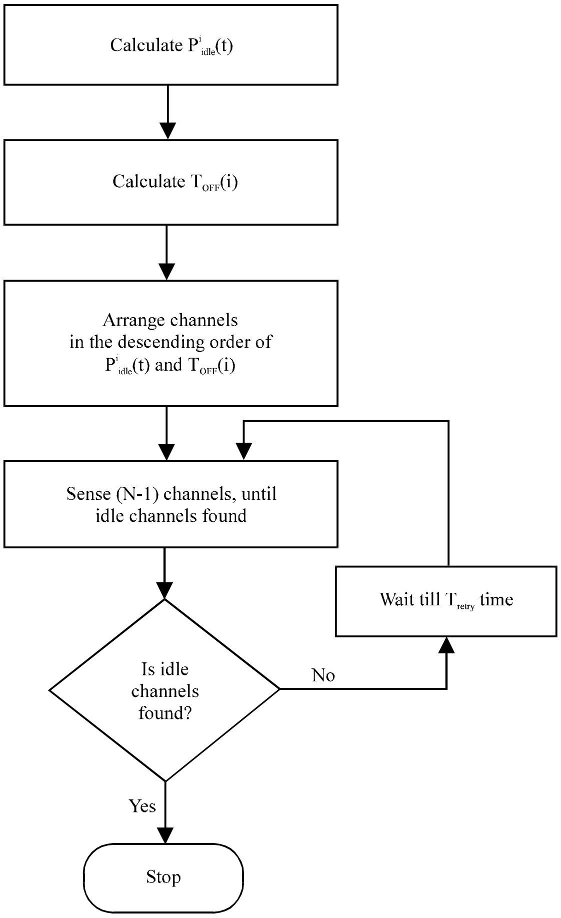

Fig. 3: Flow chart of modified optimal channel sequencing algorithm

- Calculate $P^{i}_{idle}(t)$
- Calculate $T_{OFF}(i)$ of idle channels
- Sense (N-1) channels in the descending order of $P^{i}_{idle}(t)$ 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 algorithm given by Kim and Shin (2008), 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 study, the T_{retry} time is adaptively varied in accordance with the variation of the number of channels and the 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.

PERFORMANCE EVALUATION

The numerical results obtained by MATLAB simulation are discussed here which demonstrate the improved performance of this proposed MAC layer adaptive spectrum sensing with the existing algorithm proposed by Kim and Shin (2008). The performance of the proposed scheme is measured in terms of Channel Switching Latency (CSL). The proposed scheme outperforms the existing scheme (Kim and Shin, 2008) because of the adaptive retry time and modified optimal channel sequencing algorithm. In the existing scheme, fixed retry time is used whereas in this scheme, the retry time is varied in accordance with the number of channels and spectrum sensing time. This reduces the number of channel switching, channel switching latency and improves the channel utilization of SUs.

We consider a total of 9 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) and nine channels (1, 2, 3,.., 9). The proposed scheme is comparatively evaluated with the existing schemes. The parameters used for simulation are tabulated in Table 1 and 2 and all the time values are in seconds.

Table 1: General parameters

Parameters	Proposed scheme
CSL test initial $T_P(i)$ (sec)	0.1
$T_I(i)$ (msec)	2.0
τ (sec)	0.1

Table 2: Channel usage pattern parameters

	Channels								
Parameters	1	2	3	4	5	6	7	8	9
$T_{OFF}(i)$	1.5	0.60	0.5	3.0	1.00	3.3	4.00	0.5	0.70
$T_{ON}(i)$	0.8	2.50	0.5	2.5	2.00	0.6	1.00	3.3	2.00
$T_{idle}(i)$	0.1	0.09	0.1	0.5	0.15	0.5	0.45	0.1	0.09

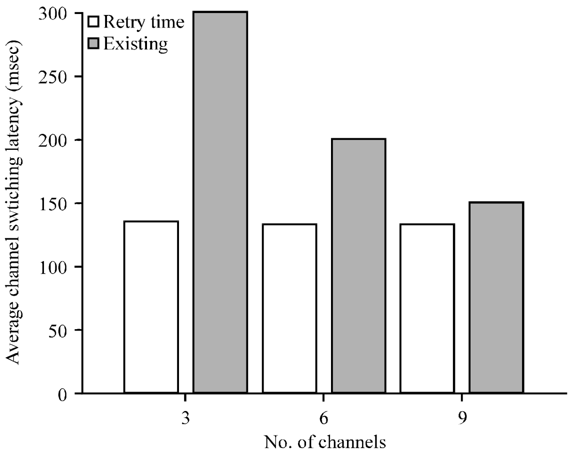

Fig. 4: Average channel switching latency with retry time

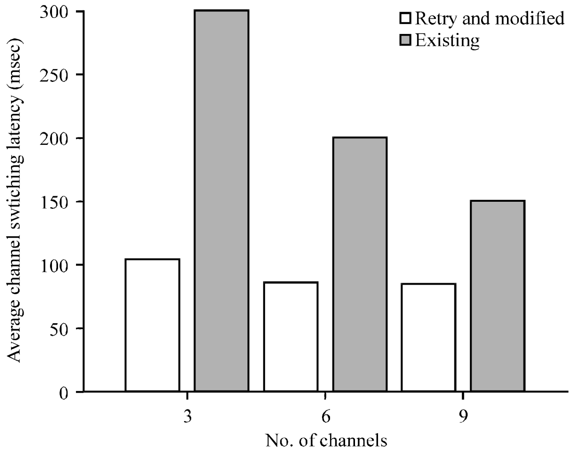

Fig. 5: Average channel switching latency with modified channel sequencing algorithm

In the existing scheme (Kim and Shin, 2008), the retry time was kept at fixed values and the corresponding CSLs were evaluated. But in the proposed scheme, the retry time has adaptively varied and it reduces the CSL and outperforms the existing scheme. The comparison is shown in Fig. 4. The average channel switching latency is reduced from 11.4-55%. In the second case, the average channel switching latency is reduced with adaptive retry time and modified channel sequencing algorithm. This performance is shown in Fig. 5. In this case, the average channel switching latency is reduced from 43.4-65.1% compared to the existing scheme proposed by Kim and Shin (2008).

The channel utilization of secondary users is also improved by using the adaptive retry time when compared with the fixed retry time. This comparison is shown in Fig. 6. The SUs channel utilization is improved from 1.8-23.82% compared to existing CSL given by Kim and Shin (2008).

As the CSL is reduced with adaptive retry time and modified channel sequencing algorithm, the SUs channel utilization is much more improved with modified channel sequencing algorithm. Figure 7 gives the comparison of SUs channel utilization between the existing scheme and the proposed study. The improvement of SUs channel utilization obtained in the proposed scheme ranges from 6.9-28.21%.

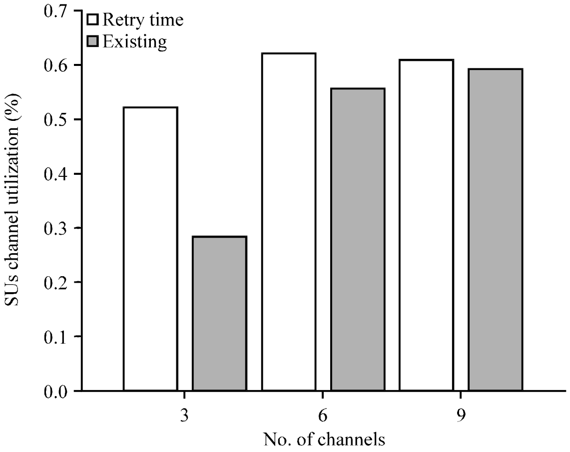

Fig. 6: Secondory User's (SU's) channel utilization with adaptive retry time

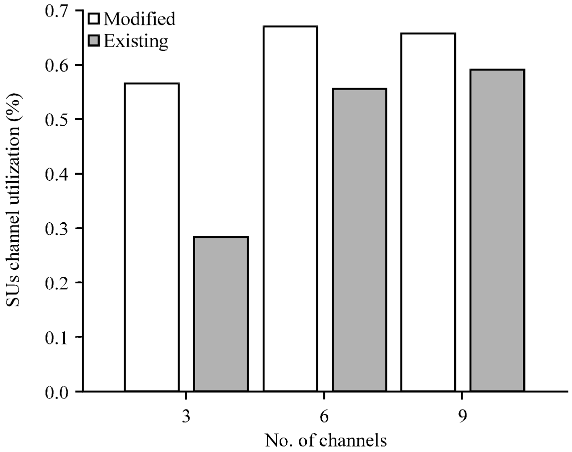

Fig. 7: Secondory User's (SU's) channel utilization with adaptive retry time and modified channel sequencing

CONCLUSION

The proposed adaptive retry time and modified channel sequencing algorithm 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 study, one may consider the energy of the secondary users along with the adaptive retry time to optimize the performance.

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