AN EFFECTIVE SPECTRUM HANDOFF SCHEME FOR COGNITIVE RADIO AD HOC NETWORKS

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Abstract

The increasing demands on higher data rates, as well as, the limited availability of radio spectrum have led to the development and continuous research of Cognitive Radio Networks (CRNs). The way radio spectrum is utilized nowadays through fixed licensing via governmental agencies seems to be inefficient and suboptimal. As a result, portions of the radio spectrum, which could be dynamically used to enhance network performance, or deploy more networks in the same geographical area, remain unutilized. To this end, cognitive radio networks using advanced Dynamic Spectrum Access (DSA) techniques are used to overcome fixed spectrum assignments disadvantages. The development of such dynamic networks is possible via the Cognitive Radio (CR), an intelligent network technology that can alter its transmission parameters based on the operating wireless environment. Nodes with CR radios, are Secondary Users (SUs), whereas the licensed Primary Users (PUs) have priority over SUs for accessing the radio spectrum

Introduction

The main functions of CRNs are: spectrum sensing, spectrum mobility, spectrum management and spectrum sharing. Active SUs scans the radio spectrum to find available spectrum portions, referred to as white spaces or spectrum holes. This procedure is known as spectrum sensing, and in specific cases is prompted via spectrum allocation databases, as defined in IEEE 802.22 WRAN and IEEE 802.11af WLAN standards. Due to the time-varying and geographic availability of spectrum, SUs maintains transmission links, by changing operating frequencies. This function is denoted as spectrum handoff, and is part of the spectrum mobility and management process. Two types of spectrum handoffs exist, namely the proactive and the reactive spectrum handoff. In the proactive spectrum handoff, the SU switches to another spectrum before a PU occupies the channel for transmission. Accordingly in the reactive approach the SU changes its operating frequency as soon as a collision with a PU is perceived.

Apart from the operating frequency, other transmission parameters can be altered as well, depending on the calculated channel Bit Error Rate (BER), the channel data rate estimation, Quality of Service (QoS) requirements and other similar factors. Such transmission parameters include the modulation scheme, coding scheme, transmission power etc. Spectrum Sharing is an important aspect of CRNs considered on Cognitive Radio Ad hoc Networks (CRAHNs). The decentralized nature of CRAHNs in conjunction with the absence of spectrum sharing amongst SUs can lead to greedy frequency selection by nearby SUs.

This subsequently results in increased number of SU collisions, affecting negatively network performance. In this thesis, we propose a hybrid handoff scheme for CRAHNs. More specifically we explore the possibility of using a scheme which can adapt to the varying PU traffic intensity. The two main characteristics of the hybrid scheme include the selective use of reactive or proactive handoffs based on PU traffic and the adaptive SU frame size. Extensive simulations of our scheme to evaluate its effectiveness are performed using NS- 3 simulator.

Cognitive Radio, Primary User and Secondary User

Cognitive Radio (CR) is one of the technologies that has the potential to alleviate the spectrum scarcity by improving the spectrum utilization and network performance. This is achieved by allowing the Secondary Users (SUs) to access the underutilized licensed spectrum opportunistically. PU scan preempt the SUs any time during the transmission, soon arrival of PUs, SUs have to vacate the current channel.

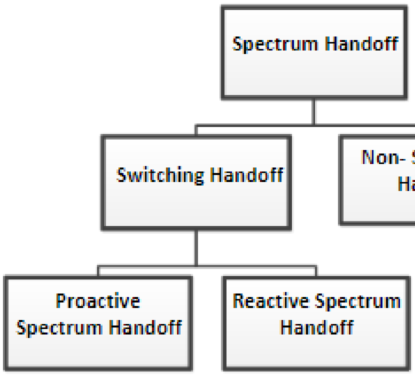

Fig. : Classification of Spectrum Handoff

Process and switch to another idle channel to resume its undone transmission. This process of channel switching is called spectrum handoff in cognitive radio network (CRN), but spectrum handoff in CRN does not always indicate channel switching by SU as there is another technique of spectrum handoff call non-switching spectrum handoff as shown in Fig. 1.1. Spectrum handoff is necessary to ensure that there will be no or minimal interference arises to the PUs from the SUs. If during the spectrum handoff processes the SUs do not find any vacant channel, then the ongoing transmission of the SU will be blocked for real-time traffic or suspended until any channel becomes vacant for non-real time traffic.

PU And SU Switching-Off

On the arrival of PU the SU either switch to another vacant channel in switching handoff technique or wait on the current channel till it becomes available again in the case of non-handoff or non-switching technique. Technique. Fig. 1.1 shows the classification of spectrum handoff in CRN. Innon-switching handoff technique, the SU keeps waiting onthe original channel till it becomes idle again to resume the undone transmission, instead of changing spectrum. The handoff latency in this technique is equal to the duration the SU waits on the original channel. Although channel switching delay can be ignored as the current and target channel is same. Spectrum Handoff in case of switching technique can be further classified as either reactive-switching spectrum handoff or proactive-switching spectrum handoff on the basis of decision timing to initiate spectrum handoff process and method to find target channel. In reactive-switching spectrum handoff the tar-get channel is searched on demand, after being interrupted by the PU. Therefore, SU stops its transmission and begin sensing for idle channel. SU gets an appropriate target channel due to the fact that the sensing is performed in the most relevant spectrum environment. Reactive-switching spectrum handoff includes channel sensing and switching delay but on the cost of accurate channel status, as sensing for target channel selections done in real time.

On the other hand proactive-switching Spectrum handoff the process for target channel selection is done in advance, before the actual arrival of PU on the basis of long term observation of PU traffic and usage statistics. The spectrum handoff modeling techniques can be categorized into slot-based or connection-based. Both techniques different triggering factors to initiate spectrum handoff process. In slot-based modeling technique, beginning of each time slot is considered as a triggering factor to start a handoff process i.e. Channel selection process starts at the beginning of each timeslot. However, in the case of connection-based techniques, the arrival of PU will consider as a triggering factor to start spectrum handoff process and spectrum handoff process occurs in event driven manner.

Literature Survey

Dynamic Spectrum Access

Today's wireless networks are characterized by a fixed spectrum assignment policy. However, a large portion of the assigned spectrum is used sporadically and geographical variations in the utilization of assigned spectrum ranges from 15% to 85% with a high variance in time. The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. This new networking paradigm is referred to as Next Generation (xG) Networks as well as Dynamic Spectrum Access (DSA) and cognitive radio networks. The term xG networks is used throughout the thesis. The novel functionalities and current research challenges of the xG networks are explained in detail. More specifically, a brief overview of the cognitive radio technology is provided and the xG network architecture is introduced. Moreover, the xG network functions such as spectrum management, spectrum mobility and spectrum sharing are explained in detail. The influence of these functions on the performance of the upper layer protocols such as routing and transport are investigated and open research issues in these areas are also outlined. Finally, the cross-layer design challenges in xG networks are discussed.

Spectrum Admission Control

Spectrum handoff scheme with spectrum admission control (SAC). In the proposed scheme, the secondary users (SUs) make up secondary user groups (SUGs) to achieve appointed detection probability of primary user signals, and perform spectrum handoff to an available spectrum when the primary users (PUs) reuse the spectrum in cognitive radio networks (CRNs). A simple Markov model is adopted to analyze the performance of spectrum handoff in terms of blocking probability, forced termination probability and throughput of the cognitive radio system. Numerical results show that the new handoff strategy is suitable for multi-user cognitive radio systems, and that spectrum admission control and cooperative sensing can effectively increase the efficiency of spectrum handoff.

In this thesis, we have proposed a novel spectrum handoff framework with 'SUG', considering the SUG's cooperation and the spectrum admission control mechanism. We have obtained that the SUG's detection probability would greater than 95% under a constant SUG's false alarm probability with 'OR' rule when the SUG's size δ no fewer than 3 for a given $\gamma = -15$ dB, and then the numerical results have shown the performance of the scheme with the appointed δ. Our proposed scheme is suitable for multi-user CRNs to achieve steady throughput. Future works including considering spectrum sensing overhead and spectrum handoff overhead.

Optimal Channel Sensing Sequence Design

Optimal channel sensing sequence (CSS) design for spectrum handoff in an overlay multichannel cognitive radio network (CRNs). We study the frame structure for spectrum handoff in the Rayleigh fading channels and formulate the CSS design problem as a sequential decision-making problem. Considering the secondary link maintenance probability during a frame, we design the optimal CSS length to achieve the maximum energy efficiency/throughput or the minimum energy consumption. A dynamic programming approach is proposed to solve the CSS design problems. Finally, the performance of the proposed design is examined and discussed using numerical examples.

In this letter, we have developed a frame structure and investigated the optimal CSS design for spectrum handoff considering the link maintenance probability constraint. The optimal length of an optimal CSS has been achieved in Rayleigh fading channels for the SU with adaptive modulation. Furthermore, the proposed CSS-maxη scheme can obtain the maximum energy efficiency with the tradeoff between throughput and overheads.

A Proactive Spectrum Handoff Framework

Cognitive Radio (CR) technology is a promising solution to enhance the spectrum utilization by enabling unlicensed users to exploit the spectrum in an opportunistic manner. Since unlicensed users are temporary visitors to the licensed spectrum, they are required to vacate the spectrum when a licensed user reclaims it. Due to the randomness of the appearance of licensed users, disruptions to both licensed and unlicensed communications are often difficult to prevent, which may lead to low throughput of both licensed and unlicensed communications. In this thesis, a proactive spectrum handoff framework for CR ad hoc networks, Prospect, is proposed to address these concerns. In the proposed framework, Channel-Switching (CW) policies and a proactive spectrum handoff protocol are proposed to let unlicensed users vacate a channel before a licensed user utilizes it to avoid unwanted interference. Network coordination schemes for unlicensed users are also incorporated into the spectrum handoff protocol design. Moreover, a distributed channel selection scheme to eliminate collisions among unlicensed users in a multiuser spectrum handoff scenario is proposed.

Proposed Method

In this thesis, we adopt the assumptions using common channel hopping. More specifically, we assume that K SU pairs try to opportunistically access M licensed channels. The co-ordination between the SUs for accessing the available channels is accomplished without the need of a dedicated common control channel (CCC) using common channel hopping. The Request to Send (RTS)/ Clear to Send (CTS) mechanism of IEEE 802.11 wireless networks is used by SUs to access the channels. Additionally, system channels are modeled as ON-OFF sources, where an “ON period” denotes a busy channel and an “OFF period” implies an available channel. The main components of the ad hoc CRN are described below.

Channel Hopping

The cognitive system is based on the principle of common channel hopping coordination scheme. More specifically, each SU follows the same channel sequence. In this way without the use of a dedicated CCC, SU nodes can communicate with each other for transmitter-receiver negotiations or for exchanging RTS/CTS messages on the current channel. Time synchronization among SUs is required, because the channel hopping sequence varies solely on time. SUs tune to the common channel, based on the hopping sequence, thus using only single-rendezvous co-ordinations. Multiple-rendezvous described in, are not considered in this thesis.

Co-ordination Time-Slot (COTS)

COTS is the basic and smallest timeslot of the CRN system. Its duration denotes the dwelling time on each channel. SUs may transmit mainly 2 types of messages during a COTS. The first one is the RTS/CTS message type, used primarily by SUs that want to gain access to the channel. It should be noted that only one pair of SUs can access the channel at a time, namely the one exchanging first the RTS/CTS messages successfully. The second message is the spectrum handoff message (SHM), exchanged amongst co-operating SUs.

Frame Time-Slot (FTS)

The SU data packet is transmitted during an FTS. Its transmission takes place after a co-ordination time slot. For system synchronization purposes, the frame timeslot (FTS) duration must be a multiple of the co-ordination timeslot size.

DYNAMIC SU FRAME TIME-SLOT

DYNAMIC SU FRAME TIME SLOT

In this section, we describe the dynamic SU FTS scheme proposed for CRAHNs. It has been noted that in cognitive systems, the optimal SU FTS size depends on PU activity and collisions. In particular, it is implied that when PU traffic is low, i.e. OFF periods are frequent and last longer, large frames increase the SU throughput. On the contrary in case of high PU traffic, large frames deteriorate SUs performance since the probability of collisions increases. Accordingly, smaller frames tend to have better probability to pass through the scarce white spaces that are available when PU traffic is high.

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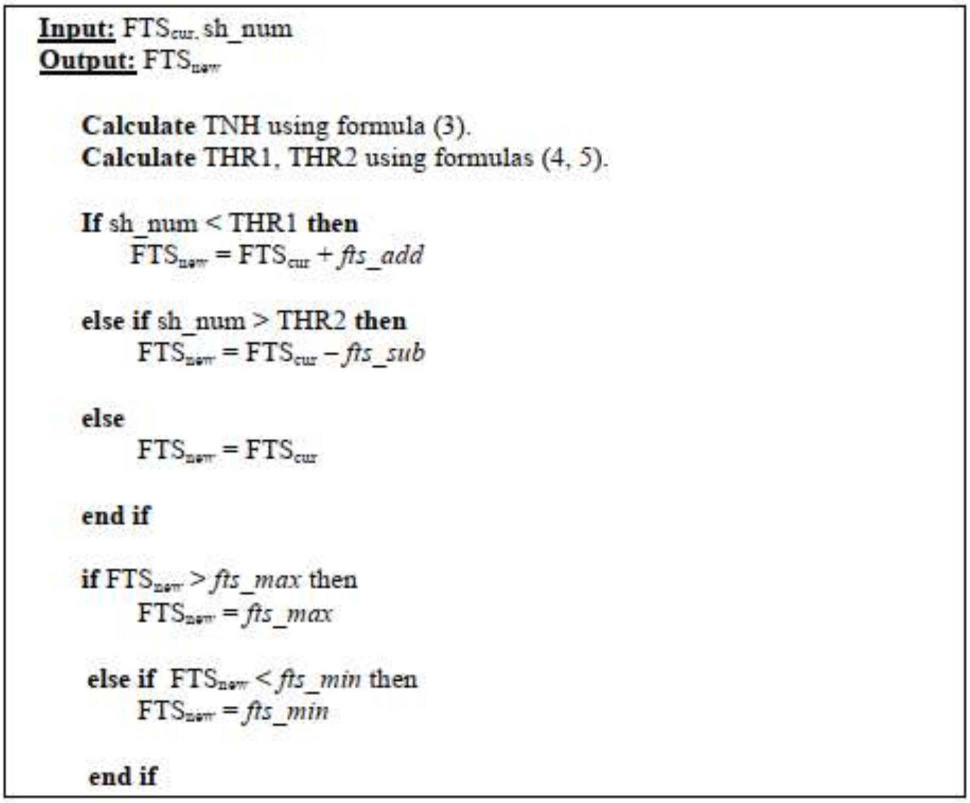
ALGORITHM 1 PSEUDOCODE

TABLE I ALGORITHM 1 PSEUDOCODE



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Input: $FTS_{cur}$, sh_num
Output: $FTS_{new}$

    Calculate TNH using formula (3).
    Calculate THR1, THR2 using formulas (4, 5).

    If sh_num < THR1 then
        $FTS_{new} = FTS_{cur} + fts\_add$

    else if sh_num > THR2 then
        $FTS_{new} = FTS_{cur} - fts\_sub$

    else
        $FTS_{new} = FTS_{cur}$

    end if

    if $FTS_{new} > fts\_max$ then
        $FTS_{new} = fts\_max$

    else if $FTS_{new} < fts\_min$ then
        $FTS_{new} = fts\_min$

    end if
```

The algorithm starts by calculating the theoretical number of spectrum handoffs (TNH) initiated in a history window size:

$$TNH = \frac{History\ Window\ duration}{\text{FTScur}} \quad \texttt{equation ------> (3)}$$

TNH implies the maximum number of spectrum handoffs that could be initiated in the history window and therefore is calculated assuming that there is a spectrum handoff after each FTS in the history window.

As follows, if the number of initiated spectrum handoffs in the history window is quite small, the FTS duration should be increased. To accomplish this, we define the THR1 threshold as follows:

$$THR1 = 0 + \frac{TNH}{x} \quad \text{equation ------> (4)}$$

Where x is 0,1,2,…

Accordingly, if the actual number of spectrum handoffs in the history window is smaller than THR1, the FTS size is increased by an fts_add value.

On the contrary, when the number of initiated spectrum handoffs is closer to TNH, the FTS size should be reduced. For this purpose, THR2 threshold is defined as follows:

$$THR2 = y * TNH \quad \text{equation ------> (5)}$$

where $y \in (0,1)$.

Similarly, if sh_num is higher than THR2, the FTS size is reduced by fts_sub value.

Furthermore in case the number of initiated spectrum handoffs is between the [THR1, THR2] interval the FTS size remains unchanged.

By increasing/decreasing constantly the frame timeslot through successive iterations of Algorithm 1 can led to quite large/small FTS sizes. Large FTSs will unavoidably collide too often with PU data while small FTS sizes introduce communication overheads. To this end we confine the FTS duration between an upper and a lower limit defined as fts_max and fts_min respectively.

Variables fts_max, fts_min, as well as fts_add and fts_sub should be multiples of the COTS duration so that the FTS size remains multiple of the COTS duration.

In conclusion Algorithm 1 adjusts the FTS size depending on the number of initiated spectrum handoffs within a predefined time interval. Accordingly, an increase number of spectrum handoffs specify the existence of high PU traffic load while less initiated spectrum handoffs denote low PU activity. Thus the FTS size varies based on the intensity of the PU traffic.

Simulation Result

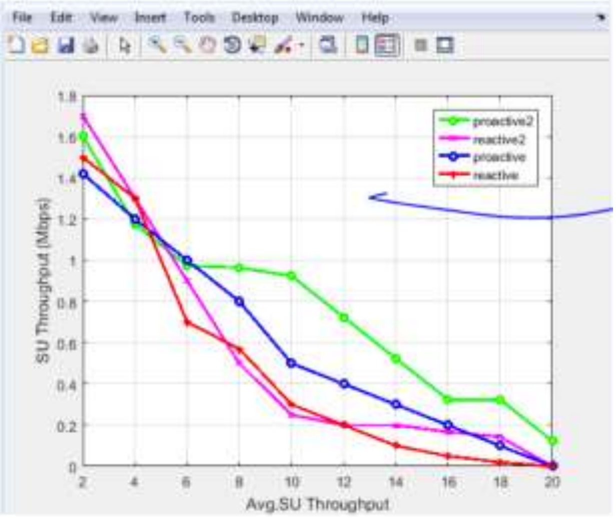


Fig.Avg. SU Throughput

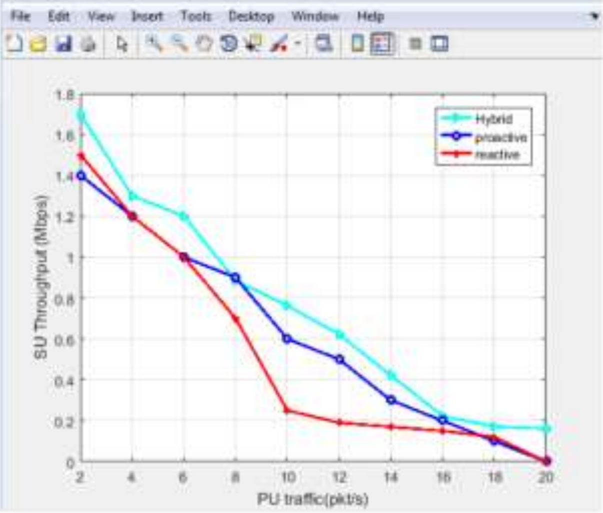


Fig.Avg. SU Throughput

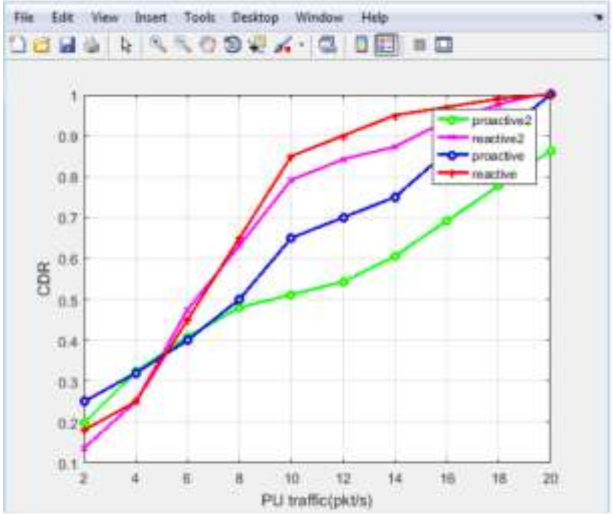
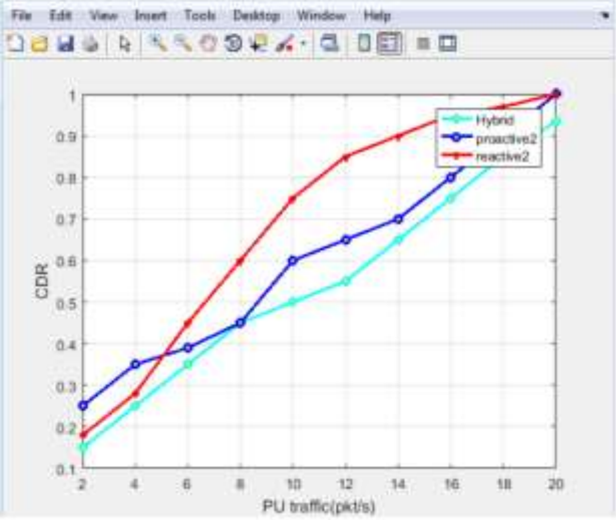


Fig. Communication Disruption Ratio



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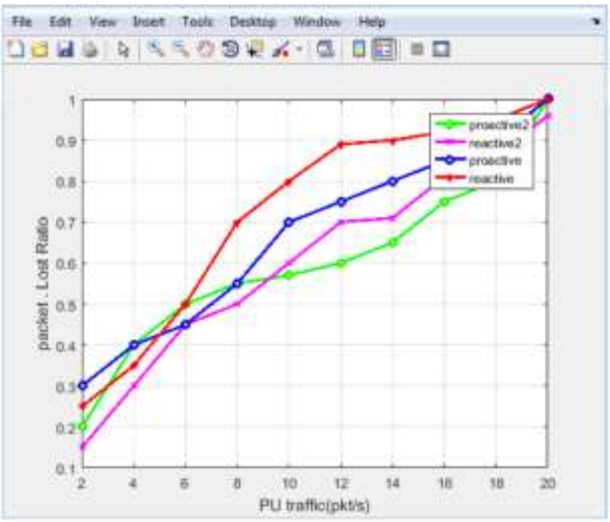
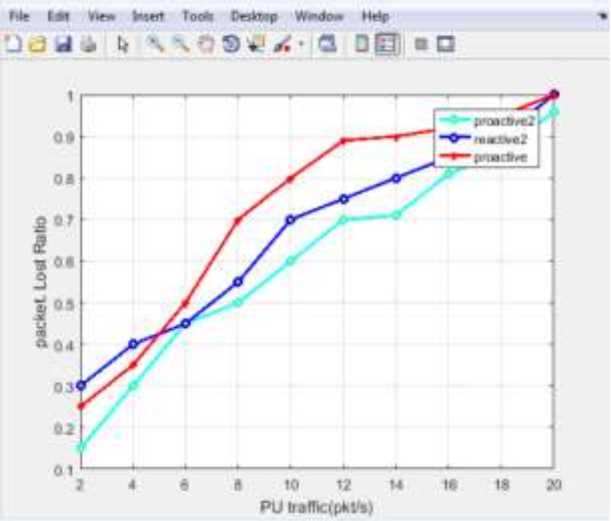


Fig: SU Packet Loss Ratio



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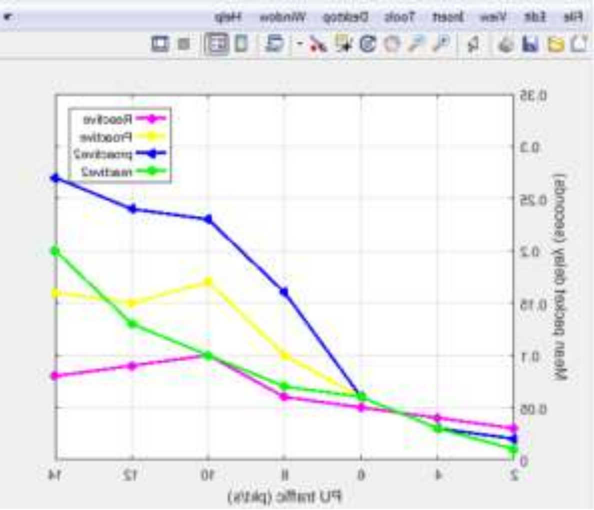

Fig. SU Mean Packet Delay

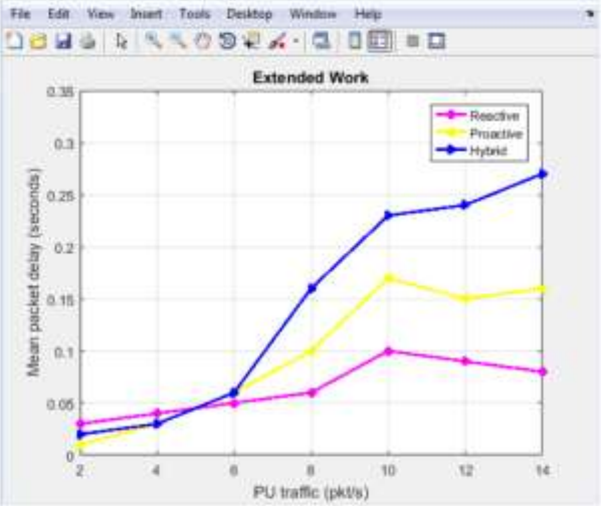

Fig. SU Mean Packet Delay

Conclusion

We propose a hybrid handoff scheme for CRAHNs which takes into account the varying PU traffic intensity. The proposed hybrid handoff scheme adaptively uses the best handoff scheme, i.e. reactive or proactive, as well as updates the SU frame timeslot periodically, considering the PU traffic intensity. Simulation results show that the new handoff scheme improves the achieved SU throughput, as well as minimizes communication disruption ratio. This makes spectrum handoff interruptions less noticeable to SU nodes. Also, the introduced network latency remains at an acceptable level, considering the increased PU traffic and the existing time varying spectrum opportunities.

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