A Real-time Spectrum Handoff Algorithm for VoIP based Cognitive Radio Networks: Design and Performance Analysis

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Abstract. Secondary Users (SUs) in a Cognitive Radio Network (CRN) face unpredictable interruptions in transmission due to the random arrival of Primary Users (PUs), leading to spectrum handoff or dropping instances. An efficient spectrum handoff algorithm, thus, becomes one of the indispensable components in CRN, especially for real-time communication like Voice over IP (VoIP). In this regard, this paper investigates the effects of spectrum handoff on the Quality of Service (QoS) for VoIP traffic in CRN, and proposes a real-time spectrum handoff algorithm in two phases. The first phase (VAST-VoIP based Adaptive Sensing and Transmission) adaptively varies the channel sensing and transmission durations to perform intelligent dropping decisions. The second phase (ProReact-Proactive and Reactive Handoff) deploys efficient channel selection mechanisms during spectrum handoff for resuming communication. Extensive performance analysis in analytical and simulation models confirms a decrease in spectrum handoff delay for VoIP SUs by more than 40% and 60%, compared to existing proactive and reactive algorithms, respectively and ensures a minimum 10% reduction in call-dropping probability with respect to the previous works in this domain. The effective SU transmission duration is also maximized under the proposed algorithm, thereby making it suitable for successful VoIP communication.

1. Introduction
Cognitive Radio Networks (CRN) [1] aim to mitigate the problem of spectrum congestion by allowing opportunistic access of the licensed frequency bands by the unlicensed Secondary Users (SUs) in absence of the licensed Primary Users (PUs). In such a network, whenever a PU arrives in its default channel, the corresponding SU must vacate the channel and perform successful spectrum handoff to an available idle channel for resuming transmission. An efficient spectrum handoff algorithm must be in place to reduce the handoff delay and potential interference with the PUs [2]. Thus, spectrum mobility is a significant aspect of CRN, where two crucial aspects gain significance; i) intelligent decision mechanism to drop from the current channel without interrupting PU transmissions, and ii) efficient channel selection algorithm to perform handoff without incurring significant delay.

Existing works have primarily focused on designing proactive [2, 3] and reactive [4] handoff strategies, with the objective of decreasing the dropping probability [5] and interference with the PU [2]. While proactive algorithms efficiently reduce the channel selection time by obtaining a predetermined target channel sequence (T.C.S.) [4], their primary disadvantage stems from the fact that the channels in the T.C.S. may not be idle at the current time slot especially under varying network conditions.
conditions. Reactive handoff mechanisms solve this problem by selecting channels on an on-demand fashion, but at the cost of higher delay due to rise in channel selection and channel consensus time [5]. Therefore, it is observed from the literature survey that these algorithms fail to address Quality of Service (QoS) constraints (delay, loss, etc.) of real-time communication like Voice over IP (VoIP) [6].

This paper deals with this problem and proposes a real-time spectrum handoff algorithm to maintain the QoS requirements of VoIP calls. The first phase adopts a novel strategy to take dropping decisions based on adaptive tuning of timing parameters and the second phase performs efficient channel selection in real-time without incurring significant delay and call drop. Overall, the proposed algorithm maximizes the duration of successful communication for VoIP calls.

The paper is organized as follows. The proposed algorithm is explained in detail in Section 2 followed by its mathematical formulation in Section 3 and simulation results in Section 4. Finally, the paper is concluded in Section 5.

2. Proposed Algorithm

The proposed algorithm is comprised of two segments. The first segment, VAST (VoIP based Adaptive Sensing and Transmission) deploys adaptive sensing and transmission durations for SUs, and subsequently defines the conditions for dropping from the current channel. This is followed by the execution of the second segment, ProReact (Proactive and Reactive Handoff) which performs successful channel handoff to a new idle available channel, without degrading the QoS limits (delay, loss) of VoIP calls. Both these segments are depicted in Figure 1 and are described as follows.

2.1. VAST (VoIP based Adaptive Sensing and Transmission)

The VAST segment implements adaptive sensing and transmission durations for SUs, and also defines the conditions for dropping from the current channel. Two time intervals of high and low duration are considered each for channel sensing and transmission (denoted by $t_{ls}$, $t_{hs}$ for sensing and $t_{ld}$, $t_{hd}$ for transmission). If the channel is sensed idle during $t_{ls}$, SU transmits during $t_{hd}$ period. If the channel is busy, SU enters $t_{hs}$ period to re-sense the channel. At the end of every $t_{hs}$, SU starts transmission in $t_{ld}$ period if the channel is idle and resets its sensing duration to $t_{ls}$ for the next sense cycle.

Based on the four parameters ($t_{ls}$, $t_{hs}$, $t_{ld}$, $t_{hd}$), the decision to drop from the current channel is taken as per three rules; i) Cons_sense: drop from channel if sensed busy consecutively in two $t_{hs}$ intervals, ii) Cons_tx: drop from channel if SU performs transmission in two $t_{ld}$ intervals in consecutive cycles, iii) Alt_tx: drop from channel if no. of transmissions in $t_{ld}$ is greater than half the no. of transmissions in $t_{hd}$ for 10 CR cycles.

2.2. ProReact (Proactive and Reactive Handoff)

The ProReact segment is applied in the second phase, where it performs successful handoff to an idle channel. The SU performs proactive handoff based on a T.C.S. calculated by the Spectrum Broker through periodic sensing. The T.C.S. comprises of $n_{pro}$ no. of channels, such that the total time incurred by individual SU in sensing all the channels in the T.C.S. using energy detection technique is less than $t_{handoff}$.

In the worst case, if all channels in T.C.S are sensed busy, the SU performs reactive handoff by randomly and uniformly selecting any available channel for sensing. The total no. of channels that can be sensed reactively is limited by the total handoff time allowed and is denoted by $n_{react}$.

![Figure 1. Schematic Diagram depicting the Proposed Algorithm](image-url)
3. Mathematical Formulation
An analytical framework is designed to calculate the important call metrics for the proposed algorithm. Based on the exponential on-off traffic model for PU [2], the mathematical expression for channel idle probability during the Proactive phase of the ProReact algorithm is derived in (1), where $\beta_k$ = transition rate from idle to busy period for $k$th channel.

$$Pr_{idle,pro}(t_2) = e^{-(t_2)/(t_2/\beta_k)}$$ (1)

The probability of selecting the $k$th idle channel reactively from the list of available channels $l_{react}$ at time $t_2$ is derived in (2) using the Renewal Theory. The average spectrum handoff delay at time $t$ ($d(t)$) is derived in (3), where $Pr_{h-o}$, $p_{drop}$ = handoff and dropping probabilities at time $t$; $Pr_{idle,pro(2)}$, $Pr_{idle,react(t_2)}$ = probability of selecting idle channel $k$ from $n_{pro}$ and $n_{react}$ respectively at time $t_2$; $t_s$, $t_c$, $t_w$=channel sensing, consensus and switching time respectively.

$$Pr_{idle,react}(t_2) = (1-Pr_{busy}(t_2))^{n_{react}} \sum_{i=1}^{n_{react}} \prod_{A \in l_{react} \cap k} \left(1-Pr_{busy}(t_2)\right) \prod_{V \in A} Pr_{busy}(t_2)$$ (2)

$$d(t) = \frac{1}{Pr_{h-o}} \sum_{k=2}^{n_{pro}} \left(k \times Pr_{idle,pro(k)} \times Pr_{drop} \times t_s \times t_c + t_w\right) + \sum_{k=n_{pro}}^{N} \left(k \times Pr_{idle,react(k)} \times Pr_{drop} \times n_{pro} \times t_s + t_c + t_w\right)$$ (3)

4. Simulation Results and Discussion
The proposed algorithm is implemented by designing a model for VoIP based CRN in MATLAB. The total no. of channels is 30. PUs follow exponential on-off model, and the on-off rates vary randomly. Total handoff limit for VoIP SUs is kept at 2s, and the CR cycle parameters are defined as, $t_s=50$ ms, $t_h=100$ ms, $t_u=100$ ms, and $t_id=250$ ms. Further, $t_w=25$ ms, $t_c=100$ms, and $t_u=25$ ms. Based on previous works, three other cases are considered; i) React (Purely Reactive handoff [4]), ii) Pro-1 (Proactive Handoff to channel whose idle time is more than busy period [2]), and iii) Pro-2 (Variant of Pro-1:Proactive Handoff to channel whose idle time is 1.5 times more than busy period).

Two network scenarios are designed namely, i) best case: channel usage does not vary with time, and ii) worst case: channel usage varies drastically with time. It is observed from Figure 2(a) and (b) that the proposed algorithm selects maximum number of channels with higher idle probabilities, compared to other scenarios in the average and the worst case scenarios. Figure 2(c) shows maximum duration of successful transmission time for VoIP calls under the proposed algorithm, with a minimum 10% reduction in dropping probability, with respect to the other scenarios. Finally, as in Figure 3(a), VAST and ProReact segments ensure that handoff delay remains below 150 ms during proactive phase (40% lower than Pro-1 and Pro-2) and 600 ms in reactive phase (60% lower than React scenario).

Figure 2. Channel Busy Probability versus the sequence of target channels under the 4 algorithms with respect to (a) best/average case, and (b) worst case scenarios; (c) Successful SU Transmission Duration with respect to the CR cycles under the 4 scenarios.
5. Conclusion

Considering spectrum mobility as an integral part of CRN, this paper addresses the problem of spectrum handoff towards ensuring the QoS of VoIP users in the network. Accordingly, an efficient real-time spectrum handoff algorithm is proposed that not only guarantees successful handoff to the idle channels but also improves the QoS of existing VoIP calls. While the first phase of the algorithm (VAST) reduces call dropping probability by a minimum 10%, the second phase (ProReact) provides better channel selection mechanisms with higher idle probabilities. Overall, the proposed algorithm reduces the average handoff delay below the threshold limit of 200 ms, and maintains at least 100 ms of effective communication duration for VoIP calls. Further studies are being carried out to design suitable prediction mechanisms for efficient channel selection.

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