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A resource intensive traffic-aware scheme using energy-aware routing in cognitive radio networks

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HIGHLIGHTS

- New resource intensive traffic-aware scheme, incorporated into an energy-efficient routing protocol.
- Cognitive radio routing methodology for energy-efficient manipulation of the secondary nodes.
- The supported scheme by the framework enables nodes to have reliable transmission.
- The proposed scheme associates the backward difference traffic moments with the Sleep-time duration.
- The proposed framework is evaluated for the sharing efficiency using specified parameters.

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ABSTRACT

This paper proposes a resource intensive traffic-aware scheme, incorporated into an energy-efficient routing protocol that enables energy conservation and efficient data flow coordination, among secondary communicating nodes with heterogeneous spectrum availability in distributed cognitive radio networks. The proposed scheme associates the backward difference traffic moments with the Sleep-time duration to tune the activity durations of a node for achieving optimal energy conservation and alleviating the uncontrolled energy consumption of wireless devices. Efficient routing protocol operation, as a matter of maximum energy conservation, maximum-possible routing paths establishments and minimum delays is obtained, by utilizing a signalling mechanism, developed based on a simulation scenario that includes a number of secondary communication nodes. The validity of the proposed resource intensive traffic-aware scheme and the energy-efficient routing protocol is estimated and verified, by conducting experimental simulation tests and obtaining performance evaluation results. The simulation results validated the efficiency of the proposed scheme and the effectiveness of the routing protocol, in terms of minimizing the energy consumption and maximizing resources exchange between secondary communication nodes in a distributed cognitive radio network.

1. Introduction

Cognitive Radio (CR) technology [1] is an emerging communication paradigm that efficiently exploits radio spectrum resources to enable the deployment of future wireless networks. CR networks comprised communication nodes, capable of adapting their technical characteristics, based on interactions with the surrounding spectral environment. They can sense a wide radio spectrum range, dynamically identify locally unused/unexploited frequencies and efficiently access them. This capability opens up the possibility of designing new dynamic radio spectrum access policies with the

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purpose of opportunistically reusing under-utilized frequencies at local level, such as "television white spaces" (TVWS) [2]. TVWS comprise VHF/UHF radio spectrum portions that are either resulted by a switchover process from analogue to digital terrestrial television, or are completely under-utilized due to frequency planning principles ("Interleaved Spectrum") [3]. Therefore, introduction of CR networks in TVWS represents a disruption to the current "command-and-control" paradigm of TV/UHF spectrum management. The exploitation of CR technology is highly intertwined with the regulation models that would eventually be adopted [4,5] especially in future computing systems. The flexibility in radio spectrum access phase by CR networks caused new challenges along with increased complexity in the design of communication protocols at different layers. More specifically, the design and adoption of efficient routing schemes, is a vital process for such an emerging communication paradigm. CR networks are characterized by completely self-configuring architectures [6], where routing is challenging and different from routing in a conventional wireless network. A key difference is that spectrum availability in a CR network highly depends on primary communication nodes presence. Therefore, a fixed Common Control Channel (CCC) is difficult to be exploited, towards establishing a stable routing path between secondary communication nodes. The specific features of CR network architectures pose new requirements in handling energy efficient resources along with an underlying reliable routing scheme. To this end, this work considers the association of the routing mechanism utilized by CR systems with the traffic volume and the end-to-end mechanism for efficiently sharing the requested resources by nodes.

Energy conservation figures an important aspect for the high performance deployment in ad-hoc CR networks. On one hand, the Energy Conservation scheme has to be reactive so that the energy levels of wireless nodes will be tuned, according to the estimated parameters (i.e. capacity, traffic [7] of the nodes). On the other hand, an energy-efficient scheme has to take into consideration the bounded end-to-end delays of the transmissions. As the network lifetime is closely related to the transmission characteristics [8] of a source node to a destination node and the underlying routing protocol used [9], a mechanism that combines the temporal traffic-aware behaviour of the node [10] and the efficient routing scheme in an end-to-end path has to be investigated. In [8] the sleep-proxy nodes evaluate the duration of the activity periods of each node, according to the capacity and the estimated inter-cluster overall energy consumed within a time frame. Towards further investigating the scheme proposed in [8], this work has applied the traffic model and the characteristics of the volume of the traffic for a specified time window frame to CR systems, supported by the Backward Traffic Difference estimation. In order to minimize the energy consumption the Backward Traffic Difference measures the volume of the incoming Traffic that is destined for each one of the nodes within a time window frame. The Backward Traffic Difference [10,11] takes into consideration the repetition of the Traffic and estimates the Backward Difference for extracting the time duration for which the node is allowed to Sleep.

In this context, this paper elaborates on the design, development and experimental evaluation of a resource intensive traffic-aware scheme incorporated into an energy-efficient routing protocol for distributed CR network architectures. Moreover, the joint routing and traffic-aware methodologies were never combined in the past to offer energy conservation in CR systems. More specifically, a signalling mechanism combined with an energy efficient scheme is proposed, based on the Backward Traffic Difference estimation methodology initially stated in [7]. The goal of this work is to achieve energy usage that scales with loading. This is possible by using the incoming traffic aggregation for each node to adjust the volume of the traffic to the estimation of the activity time period assigned for each node. In addition, this paper elaborates to describe the development and assessment through simulation, of a novel solution for linear scaling adjustment of energy usage with all loads on each secondary node without any packet loss. The key idea is based on traffic aggregation via a traffic-aware mechanism. This mechanism occurs on each secondary node to obtain an estimation and maximization for the time slot when the interfaces of each node are put to sleep. Based on the underlying routing scheme and the volume of traffic that each node receives/transmits, the proposed scheme aims at minimizing the energy consumption, by applying an asynchronous, non-periodic Sleep-time assignment slot to the secondary wireless nodes. Following this introductory section, Section 2 elaborates on the related work and research motivation, while Section 3 presents the design and development of a novel green-aware routing protocol, offering energy efficient data transition, across secondary communication nodes with different TVWS availability. In order to achieve an energy-efficient methodology, the proposed framework uses a traffic-aware Backward Traffic Difference scheme for estimating the duration of the sleep time according to the nodal traversed traffic. The proposed scheme can efficiently determine the ON and OFF durations/periods of each node by adjusting the traffic onto the activity periods of each mobile node. The proposed scheme then effectively provides a reflection of the activity of the traffic to the overall energy consumed by nodes. Finally, Section 4 elaborates on the performance evaluation analysis of the proposed research approach, discussing experimental results and Section 5 concludes this paper by highlighting directions for future research.

2. Related work and research motivation

Conventional routing algorithms exploited in wireless ad-hoc networks, enable the optimization of network performance metrics, such as end to end delay, switching delay and backoff delay. A rich literature on conventional routing protocols is available based on network-wide broadcast messages, without using any local hops information. Such approaches are not suited for wireless CR networks, since there is no support for concurrently considering radio spectrum availability of secondary communication nodes, as well as the effect on other primary nodes that share spectrum resources. In a general context, several research approaches have been recently proposed in [12–15], towards addressing routing issues in CR networking environments. In addition, a routing protocol is proposed in [16], which is exploited to combine geographical routing and radio spectrum assignment, towards avoiding regions with high presence of primary communication nodes. It also determines optimum routing path channel combinations that reduce delays in the network. A spectrum aware data adaptive routing algorithm is proposed in [17], where the end to end route selection depends on the amount of data to be transferred. Furthermore, the proposed routing protocol in [18] builds a forwarding mesh, based on a set of available routes to the destination and opportunistically adapts during the forwarding process, according to the dynamic radio spectrum conditions. Moreover, a joint approach of on-demand routing and spectrum band selection is proposed in [19] for CR networking environments and a delay based metric is used to evaluate the quality of alternative routes. Most of the previous schemes are based on on-demand routing protocols and discover paths between source and destination communication nodes.

On the other hand, the routing mechanism has to be strictly associated with the Energy-Efficiency when the CR networking architecture hosts wireless nodes requesting spectrum, via which the traffic will be transferred. Therefore the routing mechanism in collaboration with an energy-efficient scheme should guarantee the end-to-end availability of requested resources, whereas it should be able to significantly reduce the Energy Consumption. In