A Probabilistic Routing Protocol Based on Priori Information for Cognitive Radio Sensor Networks

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Abstract. The cognitive radio technology has been adopted as a promised solution to deal with overcrowded problem in ISM band. In wireless sensor networks, the cognitive radio technology enables sensor nodes to occupy licensed band in opportunistic manner and introduces advantages of improving spectrum utilization and increasing system throughput. By considering the opportunistic spectrum access nature, in this paper, we aim to provide a stable path selection scheme for cognitive radio sensor networks. The proposed routing protocol utilizes priori delivery information and derives a novel routing metric for the optimal path selection. The routing metric is derived from naïve Bayes inference and used to indicate the path stability by means of delivery probability. We show through extensive simulations that the proposed routing protocol is efficient to find the most probable delivery path and increase the system throughput.

Introduction

Traditional wireless sensor networks (WSNs) operate in ISM 2.4GHz band by using less than 16 channels. Recently, the huge numbers of devices occupy the ISM band in various networks (i.e. WLANs, Mesh networks, body area networks, sensor networks, etc.). It introduces severe interference and overcrowded problems in the wireless sensor networks. Cognitive radio is a promised solution to solve these problems. In CRSNs (Cognitive Radio Sensor Networks), each sensor device is equipped with a dynamic spectrum sensing module. Therefore, the sensor device has capability to sense wide spectrum range, dynamically identify current available channels and intelligently access it [1]. CRSNs can operate in licensed bands and share the band with licensed users or primary users (PUs) who communicate with each other by specific allocated bands i.e., common cellular networks and TV broadcast networks. The duty of cognitive radio sensor devices is same with the traditional sensor network node to sense environment information. Because of high spectrum utilization CRSNs can be applied in many areas [2], i.e., indoor sensing applications, multimedia applications and real-time surveillance applications, where suffer with overcrowded problems in ISM band.

Cognitive radio sensor devices (CRSDs), also called secondary users, access licensed bands opportunistically and prudently with non-interfering manner. On the other hand, it also means that the communication in CRSNs is sensitive with PU's behaviors. CRSDs communicate with each other only when they have common channels. However, according to activity of PU, the link between CRSDs will be interrupted at any time, and the topology must be dynamically changed according to available channel set and located regions in CRSNs. Therefore, compared to the traditional WSN, CRSNs meet many unique requirements and challenges in network-layer [3]. In addition to conventional wireless sensor network routing metric, opportunistic channel access in CRSDs and minimization of interference on the PUs need to be taken in to account in routing in CRSNs.

In this paper we aim to provide a probabilistic routing protocol based on on-demand route discovery. The proposed routing mechanism is performed in distributed manner and just requires local available channel information. The objective of the routing mechanism is to minimize interrupt probability and maximize packet delivery ratio through a route. A novel routing metric is derived based on priori delivery information. Based on naïve Bayes inference, posterior delivery probability can be derived according to current physical and channel state. The probability can be regarded as the routing metric for selecting the most stable path. Finally, based on semi-Dijkstra algorithm the optimal path can be selected to the correspondents.

The rest of the paper is organized as follows. Section 2 revises the most relevant related works. Naïve Bayes inference based routing mechanism is proposed in Section 3. Section 4 validates the proposed scheme's performance. Finally, Section 4 contains the conclusion.

Related Work

Due to the opportunity channel access nature of cognitive radio technology, routing technique for traditional sensor network is hard to satisfy required performance in CRSNs. There already exist some routing techniques which are specifically designed for ad-hoc based cognitive radio networks (CRN). In [4] and [5], an AODV based spectrum aware routing protocol is proposed for CRN. In [4], end-to-end performance is guaranteed by integrating flow-based approaches with link-based one. The authors propose a routing metric which is based on available channels set. The other on-demand routing protocol which is proposed by Cheng *et al.*[5] is to select the best suitable spectrum for each node along the path. A new routing metric is proposed in their work which takes MAC layer delay into account and the best path is selected based on cumulative path and node delay. However, the proposed schemes in [4] and [5] do not model how the PUs' active behaviors impact on the routing. Pefkianakis *et al.* [6] present a routing solution which aims to provide long-term and short-term route according to spectrum availability, while in [7], multi-path based routing protocol is proposed. Although both of the solutions are specific to cognitive radio technology and select optimal path based on minimum hop-count, they are not clearly account for the possible dynamic topology changes of the networks.

By considering drawbacks of existing works, in this paper, we aim to provide a routing solution for predicting and minimizing PUs' interrupt and find the most stable path in CRSNs. Details about the proposed routing protocol will be described in the next section.

Proposed Scheme

In this section, we will introduce a novel routing metric which is based on naïve Bayes inference. We consider people-centric licensed networks e.g., common cellular network, TV broadcast network etc., where the path stability can be reflected by attributes such as time and region. Furthermore, due to the specific nature of CRSNs, priori information of channels with which packets have been successfully transmitted to destination are also needed to take into account to derive a novel routing metric. Then, we apply the routing metric into a modified Dijkstra algorithm to select the most stable path. Consequently, the proposed routing mechanism will elaborate with following two subsections.

A. Routing metric

Bayes rule is one of the most important theorems in probability theory. The Bayes rule enables us to calculate posterior probability with priori information. However, Bayes rule requires many parameters to obtain excellent estimate results and thus it is not practical in real environment. There is one more effective method which is called naïve Bayes inference. The naïve Bayes is derived from Bayes theorem and shows good performance in machine learning research domain [8]. The naïve Bayes can be presented as following equation:

$$P(X_1 ... X_n \mid C) = \prod_i P(X_i \mid C) \tag{1}$$

The proposed routing protocol cares for whether the packet can be successfully delivered to the destination and it is denoted by Y (delivered) and N (not delivered). Thus in Eq. 1 $C=\langle Y,N\rangle$. In order to give the delivery probability, we consider the priori information by means of current time slot $\{T_1...T_n\}$, node set $\{D_1...D_n\}$ and channel sets $\{Ch_1...Ch_n\}$. We assume the attributes $X_1=\langle T_1...T_n\rangle$ indicating the time slot that the packet was received by destination. The destination node belong to node set $X_2\in\langle D_1...D_n\rangle$, and the current available channel sets is defined by X_3 which is a subset of $\{Ch_1...Ch_n\}$. Then, we can obtain the prior delivery probability according to priori information i.e. $P(T_4,D_3,\{Ch_1,Ch_3,Ch_4,Ch_7\}|Y)$ which indicate that a node successfully transmitted packet to destination node D_3 at time slot T_4 with available channel set $\{Ch_1,Ch_3,Ch_4,Ch_7\}$. However, there is limitation for applying naïve Bayes inference. The reason is if there is very small priori information can be utilized, current state will not found in the information and lead to unreliable of the estimation results. The limitation will arise out that prior probability is equal to 0, and this is associated with another problem that the routing decision will not realistic. For these reasons, we introduce m-estimate of probability to derive prior probability more realistically. When we estimated $P(x_n|Y)$ by fraction $\frac{s_n}{s_n^{total}}$, according to m-estimate definition [8] the fraction convert into $\frac{s_n+mp}{s_n^{total}+m}$, where s_n^{total} is the number of training examples for $C=Y$, s_n is the number of these for which x_n is a specific attribute. The weight m means equivalent sample size and p indicates probability when attribute has uniform distribution, e.g. an attribute has n possible values then $p=\frac{1}{n}$.

Next, the nodes can derive posterior probability according to the considered attributes based on Eq. 2 as follow, where X_i^{new} means node's the current attribute.

$$P(Y|X_1^{new},X_2^{new},X_3^{new})=\frac{P(Y)\prod_i P(X_i^{new}|Y)}{P(Y)\prod_i P(X_i^{new}|Y)+P(N)\prod_i P(X_i^{new}|N)} \tag{2}$$

In the proposed routing protocol, we assume that the radio module occupy only one channel at a time by means the attributes in available channel set X_3 are independent. Therefore, the delivery probability must be derived cumulate with the each channel's delivery probability. In Eq. (2) the denominator is constant, not depend on attribute C, therefore the proposed routing index (RI) is defined as following (k means the number of available channel):

$$RI=\sum_{k=1}^{k}P(Y)\prod_i P(X_i^{new}|Y) \tag{3}$$

*B. **Optimal path selection***

In this paper, by considering the specific challenge of CRSNs, the proposed routing mechanism aim to provide most stable path to the correspondent with spectrum-aware manner. In order to find the path which has the highest delivery probability, we employ the RI information as routing metric. First, source broadcast route discover (RD) message through common channel. The message contains destination address and current available spectrum. If nodes have common spectrum with the source, in addition to the node id, they calculate and attach RI_{ab}, which means the routing index between node a and b, to RD message and broadcast it to the other neighbor nodes. Second, when the destination node receive RD message it can maintain local topology information. The topology can be

constructed with nodes identifier and the end-to-end RI information which are regarded as vertices and edges in Fig. 1. It is remarkable that the dentation node will receive multiple RD messages from different neighbor nodes, and only when there is new RI information include, the topology structure will be updated. Finally, each updated topology information will triggers Dijkstra based algorithm helps the node to find the highest end-to-end delivery path, then the source node sends packet to destination with the optimal path. The routing scenario is shown in Fig. 1.

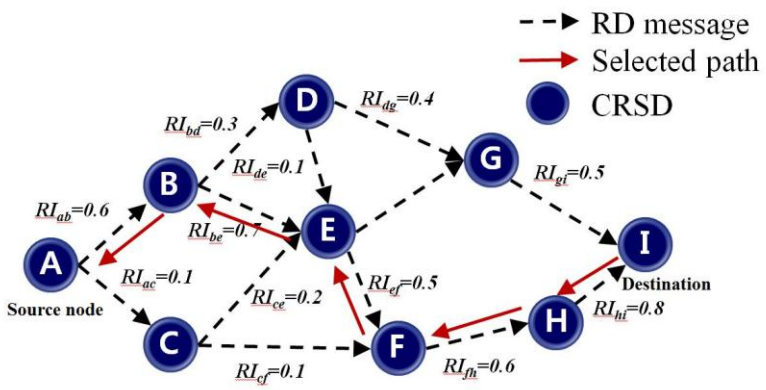

Figure 1. Routing scenario

Simulation Result

In this part, we evaluate the performance of the proposed scheme through simulation. We deploy 100 CRSDs in 100 m×100 m filed. There are 1 common channel and 10 licensed channels are available in the simulation environment. We assume the PUs randomly interrupt the communication links between CRSDs.

The proposed routing protocol compare with SAMER [5] which uses the minimum hop count as the route selection metric in Fig. 2. The proposed routing protocol shows higher performance in terms of packet delivery ratio than SAMER. The curve which shows the performance of SAMER is instability and stay in a lower level through simulation iterance. In the simulation results, SAMER cannot provide satisfactory performance, although it has benefits not only providing minimum hop routing but also low transmission delay. The simulation results show the randomly active behavior of PUs is significantly impact on the system throughput. However, the proposed routing protocol shows high performance of packet delivery ratio which converge into 85%. The performance keep stable in the simulation and it shows the proposed protocol is efficient to search stable path for the dynamic spectrum access environment.

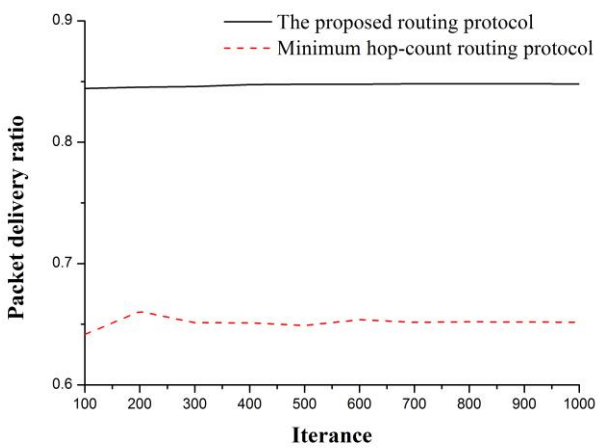

Figure 2. Simulation results

Conclusion

In this paper, we present a probabilistic based routing protocol to provide a routing solution for predicting and minimizing PUs' interrupt. We derive a novel routing metric based on combination of naïve Bayes inference and m-estimation. By utilizing the routing metric, optimal path which is the most stable in the topology is selected with semi-Dijkstra algorithm. Finally the performance is evaluated by the simulation, and the simulation results show the proposed scheme is effective for providing stable path and enhancing system throughput.

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