CRESCENT: a Modular Cost-Efficient Open-Access Testbed for Cognitive Radio Networks Routing Protocols

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ABSTRACT

Cognitive Radio Networks (CRNs) provide a solution to increase the utilization of the scarce radio frequency spectrum. Building testbeds for CRNs is one of the main challenges that can affect the wide deployability of such networks. Many testbeds were proposed for testing CRN routing protocols, but most of them are either pure simulations or require high deployment cost for buying and maintaining the needed hardware devices on a large scale. We propose *CRESCENT*: a modular framework for testing CRNs routing protocols with cost-efficient and large-scale deployability. *CRESCENT* is based on general purpose computers without the need for any special devices leveraging their built-in Wi-Fi interfaces as the default interface. The framework is built on top of Click modular router to ensure the ease of the development of new routing protocols while providing new modules that are essential for cognitive radio protocols.

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*; C.2.2 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Protocols—*Protocol verification*

Keywords

Cognitive radio networks; Cognitive routing protocols; Emulation; Testbeds.

1. INTRODUCTION

The huge increase in wireless devices highlighted the problem of wireless spectrum scarcity in today's networks that are characterised by a static spectrum assignment policy. Spectrum utilization varies from 15% to 85% [1] distributed temporally and spatially. These variations and the current inefficient use of spectrum led to the emergence of cognitive radio networks (CRNs) as an important solution that allows dynamic spectrum allocation. This is achieved by giving secondary unlicensed users access to use the spectrum when the primary licence users are inactive.

CRN protocol designers are concerned with testing the behavior of their protocols with real environmental conditions [6]. Most of the current testbeds for CRNs protocols focus on the physical or MAC layers. Usually, they either use simulations, which may be limited in capturing the real channel conditions, or use high cost hardware per node, e.g. [4], which limits their scale. Even though these high cost testbeds may be needed to implement the details of the physical or MAC layers protocols, there are many cases in which this high complexity is not necessary. This is especially true for implementing routing protocols for CRNs, where the protocol designer may not be interested in implementing and managing the details of the physical or MAC layer protocols.

In this work we propose *CRESCENT*: a novel architecture with modular implementation for a large-scale and open-access testbed where the protocol designers can deploy and benchmark CRNs protocols using a powerful and easy-to-use GUI. CRESCENT is a modular low-cost testbed which uses commodity computers with off-the-shelf Wi-Fi cards with the ability to extend the RF-Frontend to use USRP and/or WARP boards.

The remainder of the paper is organized as follows: In Section 2, we present our system architecture and implementation. Finally, Section 3 presents a case study for a typical CRNs protocol on both our framework and ns-2.

2. SYSTEM ARCHITECTURE

CRESCENT represents our second generation CRN routing testbed architecture that extends our *CogFrame* architecture [5]. In particular, *CRESCENT* provides (a) more functionalities including emulation modules for PU behavior, mobility, and topology management; (b) remote testbed access for centralized control and management; (c) low-end hardware support, e.g. Raspberry Pi; (d) protocols library for easier deployment; and (e) enhanced GUI for configuration, management, animation, and analysis.

CRESCENT is built on top of the Click modular router [3]. This allows it to inherit Click modularity and extensibility and to facilitate the implementation of various routing pro-

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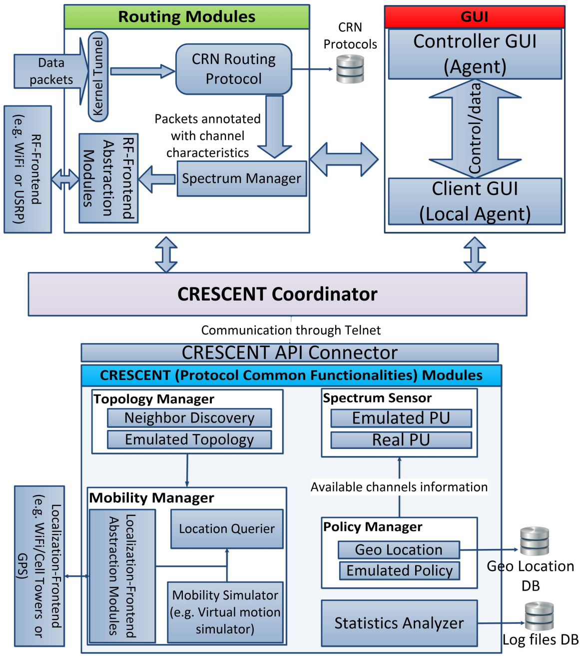


Figure 1: *CRESCENT* Architecture

tocols and nodes configurations while providing the common functionalities required by CRN protocols. *CRESCENT* is designed as a low-cost testbed that can be deployed on commodity computers with typical RF interfaces, without the need for attaching any other special hardware. In particular, *CRESCENT* makes use of the MAC and PHY protocols of conventional 802.11 cards, allowing the user to focus only on the implementation of the routing protocols, with integration with USRP and WARP boards if needed. *CRESCENT* also provides a set of common CRN functionalities, via an API, to separate the development of the protocol from the details of PHY and MAC layers.

Figure 1 depicts *CRESCENT* architecture. *CRESCENT* is composed of four main components: 1) Routing modules, 2) *CRESCENT* modules, 3) *CRESCENT* Coordinator and 4) *CRESCENT* Agent and GUI.

2.1 Routing Modules

The routing modules are built on top of Click modular router, they are responsible for routing the incoming packets and managing the spectrum. They consist of:

- Router elements: These are Click elements implemented by the protocol designer describing the behavior of the protocol. Developing a new protocol requires only the implementation of the protocol Click elements. This enables the user to test and compare different protocols together easily.

- Spectrum manager: This module is provided by *CRESCENT* to manage the spectrum by handling channel switching, transmission power and rate by interacting with the RF-Frontend abstraction module.

- RF-Frontend abstraction module: This module provides an abstraction layer for the users to handle different RF-frontend devices. No restrictions are made on the wireless interface hardware making it possible to use any RF interfaces ranging from conventional Wi-Fi cards to software defined radios, such as USRPs [4].

- Protocol database: *CRESCENT* provides a library of CRN protocols that can be used by CRN protocol designers. This significantly reduces the development time and overhead.

2.2 CRESCENT Modules

These modules are supported by *CRESCENT* to provide the common CRN functionalities hiding PHY and MAC layers details from the protocol designer. They can provide both emulated and real information through a unified API. *CRESCENT* provides emulated scenarios such as virtual primary users and virtual node motion. This allows it to model complex scenarios over limited hardware, if needed.

- Spectrum sensor: This module is responsible for providing spectrum information such as available channels, channels quality, and primary users existence. Spectrum sensing information can be sensed by Wi-Fi cards or USRP boards to provide real information about the spectrum, or it can provide emulated environment measurements by supporting virtual primary users allowing complex and extreme scenarios.

- Topology manager: This module is responsible for maintaining the topology of the participating nodes in the experiment. Two modes of operation are provided: (a) physical sensing of neighbors, where each node senses its surrounding and identifies its neighbors or (b) through enforcing a certain topology by emulating different channel qualities on the links between neighboring nodes.

- Policy manager: Policy manager provides the protocol designer with the available spectrum channels and transmission regulations which can be collected either from geo-location databases or by enforcing certain policy information.

- Mobility manager: *CRESCENT* provides different modes of mobility, either through mounting the nodes on robots moving in predefined paths, or by emulating mobility through virtual motion where motion parameters are defined at the beginning of the experiment (e.g. the velocity, acceleration and the direction of motion). Location determination can be done using different localization technologies (e.g. GPS, Wi-Fi, or cellular localization techniques) or through simulated localization. The mobility manager manages the mobility of certain nodes and provides the interface to query the location at any given instance of time.

- Statistics analyzer: It is responsible for the aggregation of the statistics files from each node with the collaboration of the *CRESCENT* agent and performs statistical analysis producing different CRN metrics used to evaluate the protocol. Big data can be analyzed through large-scale parallel computing paradigms and files can be stored in a distributed database.

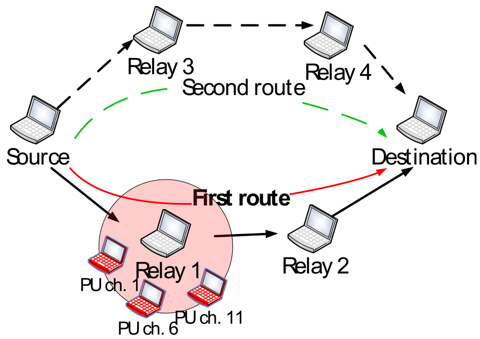


Figure 2: Experiment scenario with three primary users becoming active sequentially at Relay 1.

2.3 CRESCENT Agent and GUI

CRESCENT provides two graphical user interfaces to help the protocol designer configure and monitor the behavior of each node in the experiment.

1. Controller GUI: It provides a set of functionalities starting from the collection of nodes information (e.g. Ethernet IP and Hardware addresses), setting the network topology, visualizing the experiment statistical metrics, and animating the experiment dynamics.

   CRESCENT also provides an agent module that communicates with all the machines involved in the experiment to collect their information, distributes configuration files automatically, and aggregates their statistics files. The agent plays a crucial role to support large-scale deployment of *CRESCENT* as it enables the user to perform many complex tasks easily via the GUI.

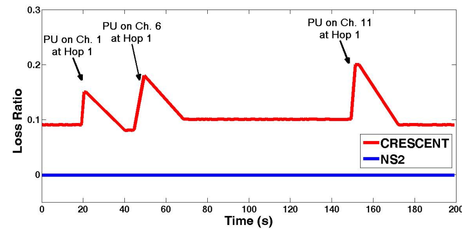
2. Client GUI: This module is run on all the nodes involved in the experiment and provides real-time information regarding each node including loss ratio, number of channel switches, primary user status, wireless interfaces information, among other protocol-specific information.

2.4 CRESCENT Coordinator

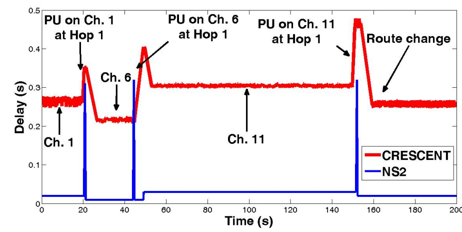
The routing modules and the controller GUI interact with *CRESCENT* modules through the Coordinator. The coordinator provides a unified API that facilitates the separation and abstraction of the common CRN functionalities supported by *CRESCENT* and the router elements written by the protocol designer.

3. CASE STUDY

We implemented a location-aided routing protocol for CRNs [2] over both *CRESCENT* and ns2. We had to implement only two modules to fully have a running version of the protocol on *CRESCENT*. We used the scenario shown in Figure 2 where there are three available channels (1, 6 and 11) corresponding to the non-overlapping channels of 802.11b. Figure 3 shows the results collected from *CRESCENT* and ns2. At the beginning, none of the PUs is active and the source selected Relay 1 as the next hop based on the routing protocol. Virtual PUs were scheduled to appear at Relay 1 on channels 1, 6 and 11 sequentially at different times, leading to interruption in service during channel switching on



(a) Loss ratio.



(b) End-to-end delay.

Figure 3: Performance comparison between CRESCENT and ns2 for the scenario in Figure 2.

the same route. After all PUs are active concurrently, the source decided to change the route to go through Relay 3.

The figure shows that *CRESCENT* provides more realistic results than ns2 that has instantaneous switching time.

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