Capacity Estimation and Adaptation in Cognitive Radio Networks: Demonstrating Software Defined Radios in Action

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ABSTRACT

In this demonstration we suggest to exhibit some key components for the future cognitive and adaptive radio networks that are enabled by low-cost software defined radios. In multi-hop cognitive radio networks estimation of available capacity is an important feature to go beyond simple sensing based Dynamic Spectrum Allocation. We demonstrate our capacity estimation engine, which is a part of the larger cognitive resource manager framework. The engine estimates available capacity of different routes in a dynamic cognitive radio network, which in our demonstration is build by using USRP and WARP software defined radios. The demonstration goes beyond the capacity estimation by showing the various types of MAC interferences and effects of those. The demonstration is fully dynamic showing our capability to chose different paths (or frequencies) between source and destination based on real-time capacity estimation of available radio links. Our tool demonstrates how the developed capacity estimation engine works, and its applicability for higher level applications such as routing, network provisioning and dynamic channel allocation. The demonstration has a graphical user-interface and we use video streaming as a test application to exhibit how the change of paths affects to achieved capacity and video quality.

1. INTRODUCTION

Nearly exponential growth of the number of wireless systems is pushing the wireless networking close to its capabilities. The last two decades have seen emergence of increasingly sophisticated physical layer techniques, which have nearly reached Shannon limit. More recently, the advances in microelectronics have finally made it possible to develop true Software Define Radios (SDR) that increase tremendously flexibility of execution platforms. Finally, cognitive radios have been suggested as a solution to enable *both* Dynamic Spectrum Access (DSA) and flexible cross-layer optimization of protocol stacks from radio hardware up to application layer. All this is directing us towards *cognitive radio networks*, which would enable efficient utilization of radio channels.

A number of problems solved for building efficient cognitive radio networks. A lot of work has been done especially to enable efficient DSA, but so far less focus has been paid for networking aspects. We are developing a general Cognitive Resource Manager (CRM) framework for overall optimization and control of cognitive radios[4]. This demonstration will exhibit with more details specific components and focus on a specific example scenario of cognitive radio network. The basic justification for the demonstration and developed technology is the insight that many higher layer applications should be able to chose the *automatically* maximum capacity radio links. This is important especially in multi-hop networks. However, simply using a link with maximum bandwidth or most aggressive modulation technique is not necessarily the most efficient approach. Similarly making dynamic spectrum allocation based on simple information of vacant spectrum or low SNR (Signal-to-Noise-Ratio) therein, is not guaranteed to lead to optimal decisions. For long-living flows it is more efficient to include into the infrastructure itself a capability to evaluate and estimate available capacity of end-to-end route[1].

First, we will show how a developed *capacity estimation engine* determines the available capacity of the routes in a dynamic cognitive radio network using USRP ("GNU Radios") and WARP based software defined radios[8, 7]. Second, we demonstrate different types of MAC interferences and how those affect to available capacity. We present our SDR-based interference monitoring module, and finally tie in all these aspects together to comprehensive demonstration where we use scheduling aware routing algortihm to choose between the best route over all the possible by taking concurrently in account interference, MAC-interactions and estimated capacity. In order to achieve this the system employs a two-phase measurement methodology, where in Phase 1 it computes a coarse-gained interference metrics through spectrum sensing. This interference metrics is shown interactively through our GUI. In Phase 2 the system finds out specific interference patters in a give spectrum.

[1]Note that a large part of the existing literature use the term bandwidth to denote capacity in the sense of bit per second. This is sometimes confusing in the wireless domain, where bandwidth also meands the bandwidth of communication channel measured in Hz. Thus we have chosen to refer data transfer capability as capacity (bit/s) and have reserved term bandwidth for its original wireless meaning.

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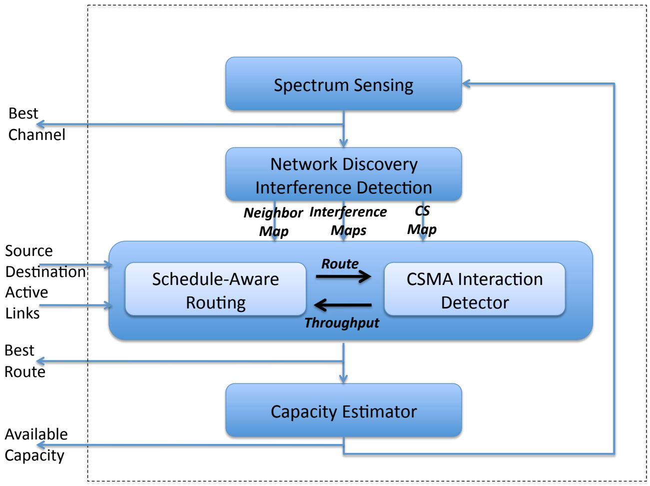

Figure 1: The basic blocks of interaction detection and capacity estimation engine (adopted from [2].

These modules are combined with popular bandwidth (capacity) estimation methodologies such as WBest.

The general functionality of our interference and capacity estimation engine is shown in Figure 1. The figure includes all the basic blocks of the tool, and our GUI is able to show the functionalities of all the functional blocks and input/output parameters in real-time. The spectrum sensing module is using USRP-radio to scan the 2.4 GHz frequency band for useful channels and records various interference metrics such as duty-cycle of the channel and power spectral density. This information is used to build interference maps and channel rating vectors for the best-channel ordering per node. The channel rating vectors are sent in the demonstration to central node (although also distributed operations could be supported), where the actual best-channel negotiation and decision between source-destination pairs is done. This coarse gained best channel selection triggers a further interference measurement protocol, which generated various interference matrices for actual computation of scheduling effectiveness[1, 6]. Although these basic modules are the real aim of our demonstration, we will also show a scheduling-aware of routing as a part of the system demonstration. The best available routes are calculated based on the channel rating vectors and interference matrices. The overall capacity estimation engine is the first fully functional implementation of these principles we are aware of. Although our demonstration is using specific hardware, we believe that the demonstration and techniques have a wider interested for the community, since in our implementation we have carefully avoided using any deep hardware specifics. Thus it should be quite straightforward to port these modules to almost any suitable SDR platform.

Overall the system demonstrates that capacity estimation can be done with a reasonable accuracy in cognitive radio networks. The key part of the demonstration is also to show how this information can be used to enhance operations of the network, and the chosen video-streaming application shows in real-time how perceived user quality of service is indeed affected by these choices. The system demonstration also shows pros and cons of interference and scheduling aware routing in Multi-Hop Wireless Networks. Due to inevitable limitations of time, space and regulations, we limit our demonstration to work in 2.4 GHz ISM-band. Thus we may comment some DSA issues and possibilities in a slideshow and material we would bring into workshop, we do not propose to make full-scale dynamic spectrum allocation with our SDRs.

2. BASIC IDEA, GOALS AND NOVELTY

The basic idea of the demonstration is to show that modern software defined radios are now capable for supporting efficient estimation of link capacities and measure interference graphs in a distributed manner. The goal of the demonstration is not only to prove this, but go beyond that by showing how this information can be used to develop scheduling-aware routing for multi-hop and multi-channel networks. The work is a part of our larger CRM Framework, and as such we have an added benefit that the demonstration is built to support heterogeneous SDR platforms. In the demonstration we use both USRP and WARP hardware and WiFi for control channel purposes. This enables us to show full flexibility of SDR in this context instead of being restricted, e.g. by the interfaces of commercial WiFi-cards. Also as far as we are aware of this is the only demonstrator based on heterogeneous networking technologies. This heterogeneity of network and technologies should also make a demonstration highly interesting for the audience.

The demonstration session is an ideal for our presentation, since we will be able to interactively show how developed modules are working. Moreover, we believe that for this sort of work, where a lot of implementation domain work has been done, demonstration or poster session is ideal, as it allows more free interaction with audience and allows us to explain in mode detailed fashion some of the implementation related complexities.

A part of the demonstration has been shown earlier in MobiHoc 2009 [3], but the current demo is a substantial extension of that work and we are planning to show more fully functional network in Beijing. The work itself and the extensions in this demonstration have not been yet published in other conference or journal papers.

2.1 Basic Scenario

The basic example application is the transfer of data over the wireless network, and as a specific visual application we show the use of video. Data packets are transferred over the network that is based on WARP-boards, which are configured to be OFDM-transceivers with high adaptivity. The channel sensing is performed by USRP-boards using GNU Radio software framework. This part of the network is doing passive sensing in 2.4 GHz frequency channel. Finally, we use IEEE 802.11 based protocol to implement control channel. In order to keep demonstration complexity reasonable there is a single central co-ordinator that coordinates the operations of nodes and runs GUI which is used explain demonstration to interested audience.

The basic premise of the scenario is to show how the system monitors different interference patterns and link qualities, and then selects the appropriate high capacity links. In this sense we welcome some interference from other possible wireless demonstrations and we do not require dedicated

Figure 2: A picture of one of the central control nodes with both USRP and WARP boards.

frequency channels. However, just being safe we will bring enough equipments to generate our own interference sources if necessary. Thus we are certain that we can demonstrate the CSMA interaction detection and capacity estimation under almost any conditions in the room.

3. REQUIREMENTS AND LOGISTICS

We have capability to scale our demonstration based on availability of space in the demonstration room. In maximum configuration we would bring in 8 laptops or Mac mini computers and set of 7 WARP and USRP radio boards. We would also bring in one IEEE 802.11 wireless router to build up a control channel for the demonstration (this channel does not need to be dedicated for us). All the radios will operate at 2.4 GHz ISM frequency below 100 mW transmission power and as such are also following Chine's frequency regulations. We would request from conference organizers a dedicated table for our demonstration, one wired internet connection (if possible), power extension cords (a total of 25 sockets). The demonstration area required is approximately 4 m $\times$ 2 m. If it were possible to locate some of the radios also other to parts of the demonstration area (extra table with power cords) we could increase spatial capabilities of the demonstration, but this is not absolutely necessary just a nice addition. Finally, if one large TFT-screen (20″ - 24″) could be provided by organizers to show GUI this would increase the user friendliness of our demonstration, otherwise we will use laptop screen.

As mentioned earlier, we do **not** require any dedicated WiFi channel, and in fact we hope to find some moderate interference in demonstration room to show how dynamics of our capacity and interference estimation engine.

Some of the authors are students, but they are not unfortunately currently ACM members, hence we are not currently eligible for the student demo competition. The practical development of the demonstration is based in large part to two M.Sc. theses [2, 5].

4. FINAL NOTES

In the case the demonstration is accepted, we are planning to ship equipments with air-freight (DHL) to Beijing and demonstration team comprises two (or more) persons. We have cleared from the funding agencies of our projects that support for travel would be available.

Furthermore, if the demonstration abstract were to be published in proceedings or other form, we are committed to polish it to acceptable publication level and to take into account any possible comments from demonstration TPC.

Acknowledgements

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5. REFERENCES

[1] M. Garetto, J. Shi, and E. Knightly. Modeling media access in embedded two-flow topologies of multi-hop wireless networks. In *Proc. of ACM MobiCom'05, Cologne, Germany*, pages 200–214, 2005.

[2] A. Greco. Scheduling-aware Routing in Multi-Hop Wireless Networks. In *Diploma (M.Sc.) Thesis, RWTH Aachen University, Department of Wireless Networks*, 2009.

[3] A. Greco, T. Milcher, V. Kolar, P. Mähönen, and M. Petrova. CSMA interaction detection and capacity estimation in cognitive radio networks. In *MobiHoc '09: Proceedings of the tenth ACM international symposium on Mobile ad hoc networking and computing*, pages 321–322, New York, NY, USA, 2009. ACM.

[4] P. Mähönen, M. Petrova, J. Riihijärvi, and M. Wellens. Cognitive wireless networks: Your network just became a teenager. In *Proceedings of IEEE INFOCOM 2006 (poster paper)*, 2006.

[5] T. Milcher. End-to-End Bandwidth Estimation in Cognitive Radio Networks. In *Diploma (M.Sc.) Thesis, RWTH Aachen University, Department of Wireless Networks*, 2009.

[6] S. Razak, N. Abu-Ghazaleh, and V. Kolar. Modeling of two-flow interactions under SINR model in multi-hop wireless networks. In *Proc. of Local Computer Networks, LCN 2008, Montreal, Canada*, pages 200–214, October 2008.

[7] Rice WARP-project. http://warp.rice.edu/.

[8] The GNU Radio Project. http://www.gnu.org/software/gnuradio.