Demo Abstract: WNOS: Software-defined Generation of Distributed Optimal Control Programs for Wireless Networks

Zhangyu Guan, Lorenzo Bertizzolo, Emrecan Demirors, Tommaso Melodia
Department of Electrical and Computer Engineering
Northeastern University, MA 02115, USA
Email:{zguan, bertizzolo, edemirors, melodia}@ece.neu.edu

***Abstract*—We demonstrate *Wireless Network Operating System (WNOS), a radically different approach to software-defined networking (SDN) for infrastructure-less wireless networks.* Departing from well-understood approaches inspired by OpenFlow, WNOS provides the network designer with an abstraction hiding (i) the lower-level details of the wireless protocol stack and (ii) the distributed nature of the network operations. Based on this abstract representation, the WNOS takes network control programs written on a centralized, high-level view of the network and automatically generates distributed cross-layer control programs based on distributed optimization theory that are executed by each individual node on an abstract representation of the radio hardware. We prototype WNOS on software-defined radio devices and test its effectiveness by considering specific cross-layer control problems. We demonstrate how the global network behavior can be controlled by modifying a few lines of code on a centralized abstraction.**

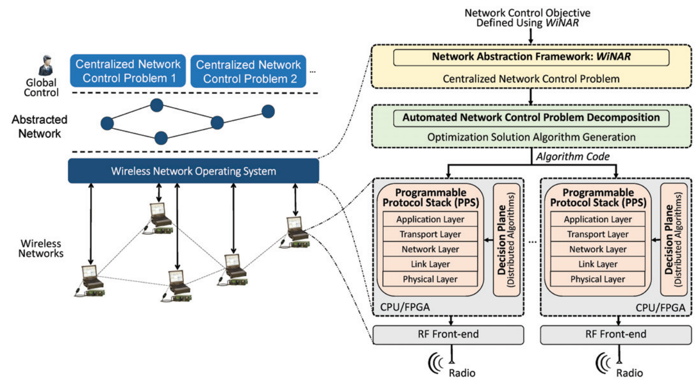

Fig. 1: Architecture of the wireless network operating system.

I. Introduction

Most existing wireless networks are inherently hardware-based and rely on closed and *inflexible architectures* that delay adoption of new wireless networking technologies [1], [2]. Moreover, it is very challenging to control large-scale networks of heterogeneous devices with diverse capabilities and hardware. Quite the opposite, software-defined radios provide a vast degree of flexibility. At the same time, software radios today lack appropriate abstractions to enable prototyping of complex networking applications able to leverage the cross-layer interactions that characterize wireless operations. To use an analogy from computer systems, trying to build a complex networked application on software radios is today as hard as trying to build a complex piece of enterprise software by writing bare-metal code in a low-level programming language.

In this research, we ask the following questions: is it possible to *automatically generate distributed wireless network control programs* that are *defined* based on a centralized abstraction of the network that hides low-level implementation details; and in this way *bridge the gap between software defined networking and distributed network optimization/control?* Can we, in this way, keep the benefits of distributed network control (where decisions are taken close to the network/channel/interference state without the need for collecting information at a centralized decision making point); and at the same time be able to define the network behavior based on a centralized abstraction? Can we, by answering these questions, develop a *principled approach* to software-defined wireless networking based on cross-layer optimization theory? We attempt to provide a preliminary answer to these compelling questions by designing and demonstrating *Wireless Network Operating System (WNOS)*.

This work is based upon work supported in part by ONR grants 0014-16-1-2213 and N00014-17-1-2046, ARMY W911NF-17-1-0034, and NSF CNS-1618727.

II. WNOS Design and Prototyping

We propose WNOS, an optimization-based wireless network operating system. The architecture of the proposed WNOS is illustrated in Fig. 1. At a high level, the WNOS comprises three key components: network abstraction, network control problem decomposition, and programmable protocol stack (PPS). Please refer to [3], [4] for more details of WNOS.

A proof of concept of WNOS has been designed and deployed over a network with 21 USRP software radios, as shown in Fig. 2. The prototyping diagram is illustrated in Fig. 3, which follows a hierarchical architecture with three tiers. At the top tier of the hierarchical architecture is the WNOS control host, based on which one can specify the network control objective using the provided network abstract

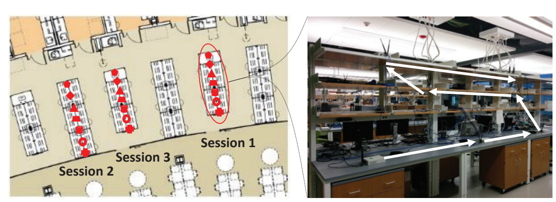

Fig. 2: WNOS SDR Testbed.

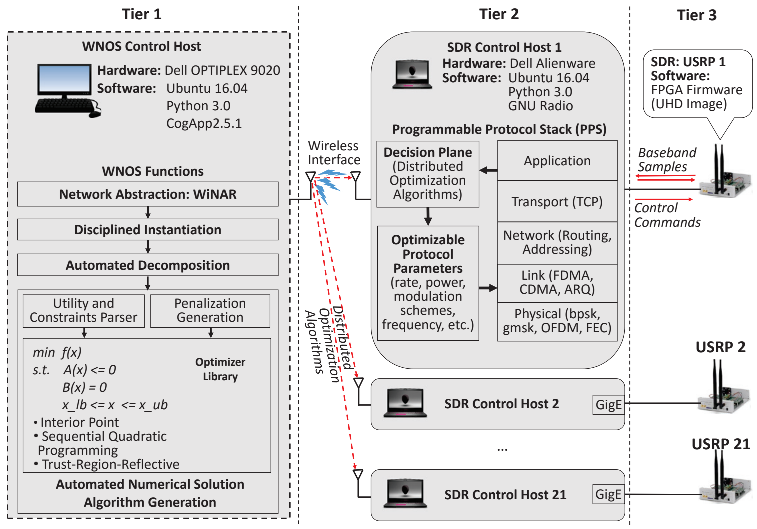

Fig. 3: Prototyping diagram of WNOS.

framework, which we refer to as *WiNAR*. The output of this tier is a set of automatically generated distributed solution algorithms, which will be sent to each of the SDR control hosts. At the second tier, the programmable protocol stack (PPS) is installed on each of the SDR control hosts. The distributed optimization algorithms received from the WNOS control host are stored at the decision plane of the PPS. At run time, the PPS will be compiled to generate operational code to control the SDR front-ends of the third tier. Finally, each of the SDR front-ends (i.e., USRP) receives the baseband samples from its control host via Gigabit Ethernet (GigE) interface and then sends them over the air with transmission parameters dynamically specified in the control commands from the SDR control hosts.

III. Demonstration

Over the developed SDR testbed, we will demonstrate the following properties of WNOS: *effectiveness, flexibility* as well as *scalability*.

Effectiveness. We will demonstrate the effectiveness of WNOS by considering a specific network control problem, where the control objective is to maximize the sum utility of two sessions by jointly controlling the transmission rate at the transport layer and the transmission power at the physical layer. For each session, the utility is defined as the logarithm of the achievable end-to-end throughput. We will show that, with the network abstract provided by WNOS, the network control objective can be defined using two lines of code only:

nt.make_var('wos_x', [ntses, ssrate], [all, None]),

expr = mkexpr('sum(log(wos_x))', 'wos_x').

We will demonstrate that WNOS-based network optimization outperforms non-optimal or purely locally optimal (greedy) network control. Five schemes will be considered in performance comparison: (i) WNOS-T-P: transport and physical layers are jointly controlled using the optimization algorithms automatically generated by WNOS; (ii) WNOS-T: only the transport layer rate is controlled by WNOS; (iii) WNOS-P: only the physical layer power is controlled by WNOS; (iv) neither transport or physical layer are controlled by WNOS; and (v) Best Response: maximum rate and power are used at the transport and physical layers, respectively.

Flexibility. We will demonstrate the flexibility of WNOS in modifying the global network behavior by changing control objectives and constraints. Specifically, we will show that, to achieve different desired network behaviors, one only needs to change the centralized and abstract control objective or modify the constraints while WNOS generates the corresponding distributed control programs automatically. For example, if the desired network control objective is to maximize the sum throughput (i.e., maximize $\sum x$) of all sessions instead of sum log throughput (i.e., maximize $\sum \log(x)$), this can be accomplished by rewriting one line of code only: *expr = mkexpr('sum(wos_x)', 'wos_x').*

Scalability. We will illustrate the sacalbility (as well as the flexibility) of WNOS by deploying code over a large-scale network and by considering two sharply different network control objectives: sum-log-rate maximization and sum-power minimization. Again, with WNOS, the network control objective of sum power minimization can be defined using a few lines of code only:

nt.make_var('wos_x', [ntlk, lkpwr], [all, None]),

expr = mkexpr('sum(wos_x)', 'wos_x'),

where the first line states the transmission power of all the active links in the network as control variables, while the second line defines the *sum of the transmission power* as the utility function to be minimized.

References

[1] M. Abolhasan, J. Lipman, W. Ni, and B. Hagelstein, "Software-Defined Wireless Networking: Centralized, Distributed, or Hybrid?" *IEEE Network*, vol. 29, no. 4, pp. 32–38, July/August 2015.

[2] M. A. Hassan, Q.-T. Vien, and M. Aiash, "Software Defined Networking for Wireless Sensor Networks: A Survey ," *Advances in Wireless Communications and Networks*, vol. 3, no. 2, pp. 10–22, May 2017.

[3] Z. Guan, L. Bertizzolo, E. Demirors, and T. Melodia, "WNOS: An Optimization-based Wireless Network Operating System," Dec. 2017. [Online]. Available: https://arxiv.org/abs/1712.08667

[4] http://www.ece.neu.edu/wineslab/wnos/wnos.avi.