Ad Hoc Networks 29 (2015) 15–31

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Efficient global optimization of multi-parameter network problems on wireless testbeds

Michael T. Mehari *, Eli De Poorter, Ivo Couckuyt, Dirk Deschrijver, Jono Vanhie-Van Gerwen, Daan Pareit, Tom Dhaene, Ingrid Moerman

Ghent University - iMinds, Department of Information Technology (INTEC), Gaston Crommenlaan 8 (Bus 201), B-9050 Ghent, Belgium

ARTICLE INFO

Article history:
Received 1 March 2014
Received in revised form 21 July 2014
Accepted 25 January 2015
Available online 4 February 2015

Keywords:
Wireless experimentation
Optimization
Testbeds
Surrogate modeling
Outlier detection

ABSTRACT

A large amount of research focuses on experimentally optimizing the performance of wireless solutions. Finding the optimal performance settings typically requires investigating all possible combinations of design parameters, while the number of required experiments increases exponentially for each considered design parameter. The aim of this paper is to analyze the applicability of global optimization techniques to reduce the optimization time of wireless experimentation. In particular, the paper applies the Efficient Global Optimization (EGO) algorithm implemented in the SUrrogate MOdeling (SUMO) toolbox inside a wireless testbed. Moreover, to cope with the unpredictable nature of wireless testbeds, the paper applies an experiment outlier detection which monitors outside interference and verifies the validity of conducted experiments. The proposed techniques are implemented and evaluated in a wireless testbed using a realistic wireless conferencing scenario. The performance gain and experimentation time of a SUMO optimized experiment is compared against an exhaustively searched experiment. In our proof of concept, it is shown that the proposed SUMO optimizer reaches 99.79% of the global optimum performance while requiring 8.67 times less experiments compared to the exhaustive search experiment.

1. Introduction

Wireless networks are utilized in many application domains. For example, if a home user is wirelessly connected, he can move around with his laptop or mobile device, while staying connected to his peers. Wireless sensor networks can be used in applications as diverse as early-warning systems for forest fire and home automation. Body area networks attached to a patient for heath-monitoring purposes make the patient-doctor interaction more productive. These wireless innovations trigger the wireless research community to continuously introduce and validate novel wireless concepts. Such research problems often have several design parameters that can be changed. For example, Wi-Fi networks have parameters that can be tweaked at the physical layer (e.g. transmit power, channel, modulation), MAC layer (e.g. inter frame spacing, contention window), network layer (e.g. routing protocol, mobility, topology) and application layer (e.g. throughput, server configurations). Optimizing all or a subset of these parameters (a.k.a. multi-parameter optimization) in order to find the *optimum operating point* is time consuming since the design space grows exponentially for every investigated design parameter.

Often, these wireless networks are optimized using wireless network simulations. These simulators generate a number of interference and traffic patterns, create a propagation model of the wireless medium, execute the optimization algorithms and analyze a set of performance metrics. However, wireless network simulators also have

* Corresponding author. Tel.: +32 (0)93 313800; mobile: +32 484 418362.

E-mail address: michael.mehari@intec.ugent.be (M.T. Mehari).

http://dx.doi.org/10.1016/j.adhoc.2015.01.014
1570-8705/

a number of disadvantages. Results can be very different when executing identical experiments on multiple wireless network simulators. In [1], the accuracy of Opnet, ns-2, and GloMoSim simulators indicate significant differences when evaluating a single protocol problem. Another limitation of a wireless network simulator is its incapability to accurately model the underlying wireless transmission properties such as channel characteristics and antenna diversity. It is also very hard to model the hardware's imperfections and dissimilarities between devices of the same type [2], which often have a considerable impact on the overall network performance.

As a result, experimentally driven research is necessary to complement simulations [2]. Measurements and performance evaluations on a real-life testbed are gaining more attention as they account for hardware imperfections and dissimilarities. However, wireless testbeds also have limitations. They require more set-up overhead compared to their simulator counterparts before, during and after experimentation. Typical examples are resource management, turning on radio interfaces, message orchestration and output post processing. For example, when using the Orbit Management Framework (OMF) for experimentation control, an experiment having N wireless devices adds an average delay of 5.17*N ms on a single message orchestration [3]. In addition, experiments on real-life testbeds can not be artificially speed up, which is possible when using simulations. In order to mitigate the time overhead, efficient optimization algorithms can be used that are best fitted to wireless testbeds. Two of their most widely used approaches are selective sampling of the design space and sensitivity analysis on the design parameters. In this paper, we investigate the selective sampling approach of Efficient Global Optimization (EGO) [4] implemented in the SUrrogate MOdeling (SUMO) toolbox [5]. EGO uses Kriging approximations to find optimal operation point(s) of a complex problem while minimizing the number of experiments needed. This way, the overall experimentation time is kept to a minimum [6]. In a nutshell, this paper examines the strengths of the SUMO optimizer by applying it to a network problem in a wireless testbed having multiple design parameters.

This paper presents the following novel contributions.

– Integration of the SUMO toolbox in a wireless testbed.
– Definition of a wireless conferencing scenario which involves multiple design parameters and performance objectives.
– A simple mechanism for detecting outliers during Wi-Fi experiments.
– Repeatability analysis of Wi-Fi experiments.
– Sensitivity analysis of global optimization to the choice of the initial sample experiments.
– A generic stopping criteria that can be used in a variety of optimization problems.

The remainder of this paper is organized as follows. Section 2 explores the related work on multi-parameter optimization in wireless networks. The principles of SUMO optimization and modifications to the SUMO toolbox are explained in Section 3. In Section 4, the SUMO optimizer is experimentally validated by optimizing a wireless conference network problem. The results of the experiment optimization process are presented and analyzed in Section 5. Finally Section 6 proposes future work and Section 7 concludes the paper.

2. Related work

Solutions of wireless network problems often involve multi-objective optimizers in order to optimize multiple design parameters. In literature, a wide range of multi-objective optimization algorithms exist. The effectiveness of such algorithms greatly depends on the methodology behind their implementation as measured by time, processing power, memory and performance. During the optimization process, optimizers carefully investigate two aspects. These are exploration and exploitation [7]. Exploration refers to the phase in which an optimizer understands the dynamics of a problem by selecting as few random sample points as possible. These random sample points have to be selected carefully in order not to waste valuable experimentation time. On the other hand, the exploitation phase locates local optimums starting from the explored design space. If the problem has been explored very well, the exploitation phase guarantees to locate global optimums. Therefore, the question of predicting global optimums in a short period of time creates the *exploration vs exploitation trade off* [8] which all multi-objective optimizes target.

Exhaustive search approaches evaluate all operating points of a solution to select optimum settings from the design space. A generic numerical calculation approach using MATLAB is presented in [9]. This algorithm exhaustively searches the design space and determines the optimum point to give the highest performance objective.

Genetic Algorithms (GA) [10] are heuristic algorithms that mimic the process of natural selection. Starting from an initial population (that consists of so-called chromosomes), new generations are produced, which hopefully contain better (i.e. fitter) chromosomes than the previous generation. The optimization process selects new offsprings according to a fitness function and the evolutionary iterations continue until a predefined stopping criterion is met.

A Particle Swarm Optimization (PSO) [11] algorithm optimizes a problem by exchanging information with neighboring particles such that a single particle with given position and velocity parameters searches an optimum setting. PSO works based on a mathematical formula optimizing a population of solutions (i.e. particles). Finally the optimization process stops when the improvement is below a given limit.

Differential Evolution (DE) [12] algorithm, similar to GA, starts from a given population and a fixed number of randomly initialized vectors. In every iteration, a newer generation is produced by randomly combining the vectors in order to create a mutation. The newer generation mixed with the target vector is evaluated against an objective function and the selector decides whether or not it should be accepted to compose the next generation.