Self-tuned distributed monitoring of multi-channel wireless networks using Gibbs sampler

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Abstract

Wireless side monitoring employing distributed sniffers has been shown to complement wired side monitoring using Simple Network Management Protocol (SNMP) and base station logs, since it reveals detailed PHY and MAC behaviors, as well as timing information. Due to hardware limitations, wireless sniffers typically can only collect information on one channel at a time. Distributed algorithms are desirable to determine the optimal channel allocation of sniffer nodes to maximize the information collected. In this paper, we propose Gibbs sampler based algorithms for robust distributed monitoring of multi-channel wireless networks. Among several variants of the base Gibbs sampling approach, we find that most algorithms suffer from high sensitivity to parameter selection. In contrast, Gibbs sampling using a thermodynamic schedule is self-tuned and can adapt to different network configurations. Simulation studies show that the proposed algorithms can achieve faster convergence rate and have higher chance of reaching global optima than traditional Gibbs sampler algorithm.

1. Introduction

Deployment and management of wireless devices and networks are often hampered by the poor visibility of PHY and MAC characteristics, and complex interactions at various layers of the protocol stack both inside a managed network and across multiple administrative domains. Accurate and timely estimates of network conditions and performance characteristics are vital to efficient network operations and beneficial to many applications like network resource management and network diagnosis.

Passive monitoring is a technique where a dedicated set of hardware devices called sniffers are used to monitor activities in wireless networks. These devices capture transmissions of wireless devices or activities of interference sources in their vicinity, and store packet level or PHY layer information in trace files, which can be analyzed distributively or at a central location. Wireless monitoring [1–6] has been shown to complement wired side monitoring using SNMP and base station logs since it reveals detailed PHY (e.g., signal strength, spectrum density) and MAC behaviors (e.g., collision, retransmissions), as well as timing information (e.g., back off time), which are often essential for wireless diagnosis.

In practice, due to hardware limitations, wireless sniffers typically can only collect information on one channel at a time [6]. Further, since most, if not all infrastructure networks utilize multiple contiguous or non-contiguous channels or bands, an important issue is to determine...
which set of frequency bands each sniffer operate on, in
order to maximize the total amount of information gathered.
This is called the sniffer-channel assignment problem or
channel assignment problem for short. It is a challenging
problem since monitoring resource is limited, and thus it
is infeasible to monitor all channels at all locations all the
time due to hardware limitations.

In [7], we introduce a quality of monitoring (QoM) metric
defined by the average number of active users moni-
tored, and investigate the problem of maximizing QoM by judiciously assigning sniffers to channels based on
the knowledge of user activities in a multi-channel wireless
network. Two capture models are considered. The first one, called the user-centric model assumes frame-level cap-
turing capability of sniffers such that the activities of dif-
ferent users can be distinguished. The second one, called
the sniffer-centric model only utilizes binary channel infor-
mation (active or not) at a sniffer. For the user-centric
model, we show that the implied optimization problem is
NP-hard, but a constant approximation ratio, can be
attained via polynomial complexity algorithms. When the
network size is large, it is desirable to have a distributed
solution to the sniffer channel assignment problem utiliz-
ing only local information.

Annealed Gibbs sampler is a sampling method for stoch-
astic search [8]. It is a special form of simulated anneal-
ing, where only local information is exchanged in each step. Annealed Gibbs sampler was first applied to solve dis-
tributed power control, channel assignment and user asso-
ciation problems by Kauffmann et al. in [8]. In this paper, we
propose Gibbs sampler based distributed algorithms for
the sniffer-channel assignment problem under the user-
centric model. We consider several techniques to
accelerate the speed of convergence and improve the opti-
mality of the baseline scheme, including parallel execution,
distorted objective function, and thermodynamic cooling
schedule. Among these variants, we find that most algo-
rithms suffer from high sensitivity to parameter selection.
Furthermore, there is little guideline as to how to tune
parameters such as the initial temperature and cooling fac-
tor given by specific objective functions. In contrast, Gibbs
sampling using thermodynamic schedule is self-tuned and
can adapt to different network configurations. Simulation
results using both synthetic traces and real-world mea-
surements demonstrate the superior performance of these
variants.

The rest of the paper is organized as follows. In Sec-
tion 2, we give an overview of existing work on wireless
side monitoring and Gibbs sampler-based algorithms for
wireless resource management. The problem formulation
is presented in Section 3. The annealed Gibbs sampler,
the proposed distributed algorithm, and several of its vari-
ants are detailed in Section 4. We evaluate their perfor-
mance in Section 5 through extensive simulation and
conclude the paper in Section 6.

2. Related work

Wireless side monitoring (a.k.a. wireless monitoring) is
an active area of research that has received much attention
from several perspectives. There has been much work done
on wireless monitoring from a system-level approach, in an
attempt to design complete systems, and address the inter-
actions among the components of such systems [9,10,1–4].
The authors have argued both qualitatively and quantita-
tively the need for wireless side monitoring. The work in
[9,10] uses AP, SNMP logs and wired side traces to analyze
WiFi traffic characteristics. Passive monitoring using mul-
tiple sniffers was first introduced by Yeo et al. in [1,2],
where the authors articulated the advantages and chal-
enges posed by passive measurement techniques, and dis-
cussed a system for performing wireless monitoring with
the help of multiple sniffers, synchronization and merging
of the traces via broadcast beacon messages. The results
obtained for these systems are mostly experimental. Rod-
rig et al. in [3] used sniffers to capture wireless data, and
analyzed the performance characteristics of an 802.11 WiFi
network. One key contribution was the introduction of a
finite state machine to infer missing frames. The Jigsaw
system, which was proposed in [4], focused on large scale
monitoring using over 150 sniffers.

The optimal allocation of monitoring resources for max-
imizing captured information is well studied. In literature,
the optimal monitoring is formulated as maximum cover-
age problem with group budget constraints, which was
previously studied by Chekuri and Kumar in [11]. Shin
and Bagchi consider the selection of monitoring nodes
and their associated channels for monitoring wireless
mesh networks [12]. Shin et al. proposed the solutions
for optimal monitoring of a multi-channel network, includ-
ing a greedy approach and two LP rounding approaches
[13]. A similar LP rounding approach is also proposed by
Chhetri et al. [7], where only channel assignment to the
sniffers is considered. All these approaches in [12,14,13,7]
are centralized and achieve sub-optimal results.

In contrast, in this paper (and [15]), we propose a fully
distributed solution based on Gibbs sampler for the channel allocation problem. Annealed Gibbs sampler with
logarithmic cooling schedule was proven to achieve opti-
mality (at the cost of slow convergence). Empirically, we
have shown in this paper that the annealed Gibbs sampler
with properly tuned cooling schedule and self-tuned ther-
dynamic cooling schedule can in fact converge to optimal
solutions in tens of iterations. Another distributed
algorithm is proposed by Shin et al. [16], which guarantees
an approximation ratio of $(1 - \frac{1}{3})$ and has polynomial time
complexity. In comparison, our algorithm can guarantee
optimality, but may not converge in polynomial time (in
the worst case).

The proposed algorithm runs only once during the boot-
strapping phase of the network. However, in practice, as
the network condition changes, the sniffer-channel assign-
ment needs to be adjusted online. One simple solution is to
periodically run our algorithm, so as to reallocate the mon-
itoring resource. Alternatively, we can adopt the mecha-
nism proposed in [16] to trigger the execution of the
proposed algorithm when the amount of information falls
below a predefined threshold. The work by Arora et al.
[14] considers the sequential learning of network parame-
ters together with the channel assignment decisions. Here,
we assume the network parameters have been learned and
provided as input to the algorithm.
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