

# Chapter 11

## Quantized Variational Filtering for Bayesian Inference in Wireless Sensor Networks

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### ABSTRACT

*The primary focus of the chapter is to study the Bayesian inference problem in distributed WSNs with particular emphasis on the trade-off between estimation precision and energy-awareness. We propose a variational approach to approximate the particle distribution to a single Gaussian distribution, while respecting the communication constraints of WSNs. The efficiency of the variational approximation relies on the fact that the online update and the compression of the filtering distribution are simultaneously performed. In addition, the variational approach has the nice property to be model-free, ensuring robustness of signal processing. We analyze the Bayesian inference issue for several specific but representative WSN applications to elaborate the quantized variational filtering method, which can be applicable to a wider class of problems.*

*Our contribution lies in the following aspects: (1) we investigate the impact of the choice of a fixed (in time) quantization level and uniform power on the quantized variational filtering (QVF) algorithm performances and propose an adaptive quantization scheme; (2) we jointly optimize the power scheduling to minimize the transmission energy consumption in WSNs; (3) we select the best candidate sensors that participate in data collection for tracking the target.*

*Simulation results demonstrate the significantly improved performance of our approach.*

## INTRODUCTION

A wireless sensor network (WSN) is a collection of a large number of sensor nodes, which provides access to information anytime, anywhere by performing high-level distributed sensing, processing and disseminating data. Each sensor node has a processing capability, multiple types of memory, various sensing units and actuators, a radio frequency (RF) transceiver as well as a power source. The configuration of sensors allows a random deployment in an ad-hoc fashion in some inaccessible terrains or during disaster relief operations. Because of the reliability, flexibility, cost-effectiveness and ease of deployment, WSNs promise to revolutionize our life in a wide range of application domains, including military, civil and ecological areas. With the unlimited applicability, WSNs have gained worldwide attention from both academia and industry in recent years. In spite of the diverse applications, WSNs face a number of unique technical challenges due to their inherent energy and bandwidth limitation, ad hoc deployment and unattended operation, etc.. Unfortunately, very little previous work on distributed systems can be applied to WSNs, since the underlying assumptions have changed dramatically. In addition, WSN protocols and algorithms must possess self-organizing and cooperating capabilities. Therefore, innovative energy-aware, scalable and robust algorithms for distributed signal processing in WSNs are highly required.

Foremost among the tasks performed by WSNs is the distributed sensing, which establishes parameterizations of physical phenomena and enables processing of information for inference and

estimation (Ribeiro, Giannakis & Roulmeliotis, 2006). The results of estimation or inference provide the base for decision making to manipulate the environment in return. This inference is generally based on models of what we expect to observe, where the models are designed to capture salient trends or regularities in the observed data with a view to predicting future events. Unfortunately, for the majority of real applications, the data are far too complex or the underlying processes not nearly well enough understood to design a perfectly accurate model. Therefore, the constructed model is a rough simplification of the reality, where inevitably some important aspects of the data, which cannot be exactly modeled, are considered as noise. In signal processing, the above ideas can be formalized using the concept of probability and the rules of Bayesian inference (Beal, 2003). We are concerned with data  $D$ , which are generated by a model defined by a set of unknown parameters  $\Theta$  (Smidl & Quinn, 2005). The beliefs about the data are completely expressed via the parametric probabilistic observation model,  $P(D|\Theta)$ . Given a specific set of observed data  $D$ , the learning of uncertainty/randomness of a process is solved by constructing a distribution  $P(\Theta|D)$ , namely, the *a posteriori* belief about the system. The simple prescription of Bayes rule reverses the order of the conditioning:

$$P(\Theta|D) \propto P(D|\Theta)P(\Theta) \quad (1)$$

which specifies how the prior belief, quantified by the *a priori* distribution,  $P(\Theta)$ , is updated according to the measured data  $D$ . The real-world

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