Onur Tan received the B.S. degree in Electrical and Electronics Engineering from Middle East Technical University, Ankara, Turkey in 2007 and the M.S. degree in Electrical and Electronics Engineering from Bilkent University, Ankara, Turkey in 2010, respectively. From September 2007 until June 2010, he was a Research&Teaching Assistant in the Department of Electrical and Electronics Engineering, Bilkent University. During that time, he also worked in a research project funded by the Scientific and Technological Research Council of Turkey (TUBITAK) in cooperation with Bilkent University and Meteksan Company. He joined the Centre Tecnólogic de Telecomunicacions de Catalunya (CTTC) in November 2011. Since then, he has been pursuing a Ph.D. degree at the Department of Signal Theory and Communications, Universitat Politécnica de Catalunya (UPC), Barcelona, Spain. From September 2013 to February 2014, and from October 2014 to January 2015, he was a visiting Ph.D. Scholar at the Department of Electrical and Electronic Engineering, the Intelligent Systems and Networks Research Group, Imperial College London, London, U.K. His primary research interests lie in the areas of wireless communications and information theory with special emphasis on smart meter privacy, demand-side energy management and smart grids.

Abstract

The smart grid (SG) is the enhancement of the traditional electricity grid that allows bidirectional flow of electricity and information through the integration of advanced monitoring, communication and control technologies. In this thesis, we focus on important design problems affecting particularly two critical enabling components of the SG infrastructure: smart meters (SMs) and wireless sensor networks (WSNs).

SMs measure the energy consumption of the users and transmit their readings to the utility provider in almost real-time. SM readings enable real-time optimization of load management. However, possible misuse of SM readings raises serious privacy concerns for the users. The challenge is thus to design techniques that can increase the privacy of the users while maintaining the monitoring capabilities SMs provide. Demand-side energy management (EM), achieved thanks to the utilization of storage units and alternative energy sources, has emerged as a potential technique to tackle this challenge.

WSNs consist of a large number of low power sensors, which monitor physical parameters and transmit their measurements to control centers (CCs) over wireless links. CCs utilize these measurements to reconstruct the system state. For the reliable management of the SG, near real-time and accurate reconstruction of the system state at the CC is crucial. Thus, low complexity delay-constrained transmission strategies, which enable sensors to accurately transmit their measurements to CCs, should be investigated rigorously.

To address these challenges, this dissertation investigates and designs privacy-preserving EM techniques for SMs and delay-constrained transmission strategies for WSNs. The proposed EM techniques provide privacy to SM users while maintaining the operational benefits SMs provide. On the other hand, the proposed transmission strategies enable WSNs to meet low latency transmission requirements, which in turn, facilitate real-time and accurate state reconstruction; and hence, the efficient and robust management of the SG.

First, we consider an SM system with energy harvesting and storage units. Representing the system with a discrete-time finite state model, we study stochastic EM policies from a privacy-energy efficiency trade-off perspective, where privacy is measured by information leakage rate and energy efficiency is measured by wasted energy rate. We propose EM policies that take stochastic output load decisions based on the harvested energy, the input load and the state of the battery. For the proposed policies, we characterize the fundamental trade-off between user's privacy and energy efficiency.

Second, we consider an SM system with a storage unit. Considering a discrete-time power consumption and pricing model, we study EM policies from a privacy-cost trade-off perspective, where privacy is measured by the load variance as well as mutual information. Assuming non-causal knowledge of the power demand profile and prices, we characterize the optimal EM policy based on the solution of an optimization problem. Then, assuming that the power demand profile is known only causally, we obtain the optimal EM policy based on dynamic programming, and also propose a low complexity heuristic policy. For the proposed policies, we characterize the trade-off between user's privacy and energy cost.

Finally, we study the delay-constrained linear transmission (LT) of composite Gaussian measurements from a sensor to a CC over a point-to-point fading channel. Assuming that the channel state information (CSI) is known by both the encoder and decoder, we propose the optimal LT strategy in terms of the average mean-square error (MSE) distortion under a strict delay constraint, and two LT strategies under general delay constraints. Assuming that the CSI is known only by the decoder, we propose the optimal LT strategy in terms of the average MSE distortion under a strict delay constraint.

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