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## Editorial

# Theoretical and Algorithmic Foundations of Wireless Ad Hoc and Sensor Networks

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Wireless ad hoc and sensor networks have attracted much attention in the past few years due to their widely potential applications such as airport, conference, hospital, battlefield, rescue, and monitoring scenarios. The ad hoc and sensor networks have their unique characteristics such as infrastructureless, self-organized, self-configured, and supporting interactions with environments, which make them different from classic computer networks and infrastructure-based wireless networks. While much work has been done in protocol and system design, simulation, and experimental study for wireless ad hoc and sensor networks, the theoretical research, however, falls short of the expectation of the future networking deployment.

Recent research in mobile ad hoc networks and wireless sensor networks raises a number of interesting, and difficult, theoretical and algorithmic issues. The objective of this special issue is to gather recent advances in the areas of wireless ad hoc and sensor networks, with a focus of theoretical and algorithmic aspect. In particular, it is devoted to distributed algorithms, randomized algorithms, analysis and modeling, optimizations, and theoretical methods in design and analysis of networking protocols for wireless ad hoc and sensor networks.

In this special issue, we selected 19 papers from 54 submissions. The selected papers may be classified into five categories: (1) coverage and localization in wireless sensor networks; (2) energy efficiency in wireless sensor networks;

(3) link layer and physical layer issues; (4) performance optimization; (5) tracking, data gathering tree, and transport layer in wireless sensor networks. A detailed description of the corresponding selected works in each category is given below.

## 1. Coverage and Localization in Wireless Sensor Networks

The first paper, entitled “*Perimeter coverage scheduling in wireless sensor networks using sensors with a single continuous cover range*” by Hung and Lui, studies the perimeter coverage problem in sensor networks, where the perimeter of an object needs to be monitored by multiple sensors, but each sensor can only cover a single continuous portion of the perimeter. The authors first show that the problem of finding optimal scheduling of sensors such that the network lifetime is maximized is NP-hard. They further identify the sufficient conditions for a scheduling algorithm to be a 2-approximation solution to the general problem and propose a simple distributed 2-approximation solution with a small message overhead.

The second paper, “*Characterizing the path coverage of random wireless sensor networks*” by Noori et al., investigates the path coverage of a randomly deployed sensor network, which aims to monitor a circular path and discover any

intruder trying to cross it. Using results from geometric probability, the authors determine the probability of full path coverage, distribution of the number of uncovered gaps over the path, and the probability of having no uncovered gaps larger than a specific size. They also derive a tight upper bound for the number of nodes guaranteeing the full path coverage with a desired reliability.

In the third paper, “*Collaborative event-driven coverage and rate allocation for event miss-ratio assurances in wireless sensor networks*,” Ozgur Sanli and Cam propose a joint coverage and rate allocation (CORA) protocol to exploit ideal correlator radius via cooperation between event-based scheduling and rate allocation for event miss-ratio assurances in wireless sensor networks. Both uniform event distribution and nonuniform event distribution are considered, and the notion of ideal correlation distance around a clusterhead is introduced for on-duty node selection.

In the fourth paper, entitled “*Range-based localization for UWB sensor networks in realistic environments*,” Shen et al. study the Nonline of Sight (NLOS) problem of localization in Ultrawideband (UWB) sensor networks. They first review the existing localization methods in UWB sensor networks under NLOS conditions and then propose a new localization algorithm to handle the NLOS problem by introducing an NLOS node identification and mitigation approach through hypothesis test.

## 2. Energy Efficiency in Wireless Sensor Networks

In the first paper, “*An energy-efficient MAC protocol in wireless sensor networks: a game theoretic approach*,” Mehta and Kwak apply the concept of incomplete cooperative game theory to model an energy-efficient MAC protocol in wireless sensor networks and propose an improved backoff algorithm which leads to a suboptimal solution for the energy-efficient MAC protocol.

The second paper, entitled “*Energy-efficient query management scheme for a wireless sensor database system*” by Nan and Li, proposes an energy-efficient query management framework that copes with multiple queries in a sensor network. The proposed method aims to reduce common tasks in a collection of queries through merging and aggregation, according to query region, attribute, time duration, and frequency, by executing the common subqueries only once.

In the third paper, “*An information-theoretic approach for energy-efficient collaborative tracking in wireless sensor networks*,” Arienzo studies collaborative tracking of mobile nodes in wireless sensor networks, where target tracking is combined with node selection procedures in order to select informative sensors to minimize the energy consumption of the tracking task. The author formulates the node selection problem as a cross-layer optimization problem with the aim of maximizing the total utility and proposes a greedy algorithm to solve it.

The fourth paper, “*Energy efficiency optimization of cooperative communication in wireless sensor networks*” by Wang and Nie, studies the energy consumption of cooperative communication compared with direct transmission.

The authors derive the energy efficiency of the two schemes and reveal that the direct transmission is more energy efficient than cooperation for the small transmission distance. The relay location, packet size, and modulation level have important effects on energy efficiency. They also propose a two-dimensional discrete optimization algorithm to find the maximum of energy efficiency for cooperative communication by optimizing the packet size and modulation level jointly.

## 3. Link Layer and Physical Layer Issues

The first paper, “*Performance analysis of a cluster-based MAC protocol for wireless ad hoc networks*” by Alonso-Zárate et al., analyzes the performance of the *distributed queuing medium access control protocol for ad hoc networks* (DQMANs), which is comprised of a dynamic clustering mechanism and a distributed queuing MAC protocol. The authors present a theoretical model of DQMAN under nonsaturation conditions for single-hop networks and provide analytical analysis on the performance of a DQMAN network in terms of throughput, average transmission delay, and average time spent in each of the modes of operation.

The second paper, “*A new iterated local search algorithm for solving broadcast scheduling problems in packet radio networks*” by Lin and Wang, studies a well-known NP-complete optimization problem, the broadcast scheduling problem (BSP), which aims to minimize the length of a time frame while avoiding packet collisions and minimizing the number of idle nodes. The authors propose a new iterated local search algorithm that consists of two special perturbations and local search operators to solve the BSP.

In the third paper, “*A precoded OFDMA system with user cooperation*,” Yu et al. propose a new cooperative approach for a two-user OFDMA system that combines linear interblock precoding and user cooperation. They show that the proposed scheme achieves the maximum available diversity for both users (full cooperation), or for the weak user (half cooperation) without increasing the number of antennas needed as compared to an energy-equivalent noncooperative OFDMA system that also uses interblock precoding.

In the fourth paper, “*Distributed transmit beamforming without phase feedback*,” Wang et al. propose a distributed transmit beamforming scheme which eliminates the inefficient feedback procedure. It utilizes the reciprocity of the signal propagation in space. By reversing the transmit sequence, the transmitting signals of the collaborative nodes “retrace their ways” and the phase shifts from the forward and backward path are automatically cancelled out so that they are in phase combined at the destination. The collaborative nodes synchronize to the reference signal simultaneously and independently.

## 4. Performance Optimization

The first paper, “*A stochastic multiobjective optimization framework for wireless sensor networks*” by He et al., utilizes

the concept of multiobjective optimization and provides a general framework for a specific class of applications in wireless sensor networks. They decompose the multiobjective optimization formulation through Lagrange dual decomposition and adopt the stochastic quasigradient algorithm to solve the primal-dual problem in a distributed way. They show theoretically that the algorithm converges to the optimal solution of the primal problem by using the knowledge of stochastic programming. They also illustrate how the general framework works by considering an example of the optimal rate allocation problem in sensor networks with time-varying channel.

In the second paper, “*On optimizing gateway placement for throughput in wireless mesh networks*,” Zhou et al. study the optimization problem of gateway placement in wireless mesh networks in order to maximize the aggregate throughput or the worst-case per-client throughput. They first derive a new performance metric called multihop traffic-flow weight (MTW) which takes multiple factors (such as numbers of mesh routers, clients, and gateways, traffic demand, locations of gateways, and interference) into account. Based on MTW, an iterative algorithm is proposed to determine the best locations of gateways which can significantly improve the throughput of wireless mesh networks.

The third paper, “*Flow oriented channel assignment for multi-radio wireless mesh networks*” by Ye et al., investigates the channel assignment problem in a multichannel and multi-radio wireless mesh network. They model the problem as a flow-based optimization problem and propose two iterative flow-oriented channel assignment heuristics for the conflict-free and interference-aware cases, respectively. To maximize the aggregate useful end-to-end flow rates, both algorithms identify and resolve congestion at instantaneous bottleneck link in each iteration. Then the link rate is optimally allocated among contending flows that share this link by solving a linear programming problem.

## 5. Tracking, Data Gathering Tree, and Transport Layer in Wireless Sensor Networks

The first paper, “*A decentralized approach for nonlinear prediction of time series data in sensor networks*” by Honeine et al., proposes a new approach to model physical phenomena and track their evolution with nonlinear functional learning. The new approach is based on a kernel machine but controls the model order through a coherence-based criterion that reduces spatial redundancy.

The second paper, “*Dynamic object tracking tree in wireless sensor network*” by Chen et al., investigates how to dynamically update the object tracking tree when the predefined mobility profiles do not match the real object movement behaviors. The authors propose a dynamic adaptation mechanism to improve and refine the object tracking tree with certain adaptation cost.

In the third paper, “*Determining localized tree construction schemes based on sensor network lifetime*,” Lee et al. study the network lifetime of different localized data gathering tree

formation algorithms by considering the communication overhead due to imperfect link quality. Via analysis, they show the tradeoff between link-quality-based schemes and minimum-hop-routing-based schemes in terms of network lifetime. They also present a guidance to design localized scheme for longer network lifetime.

The last paper, “*Internode distance-based redundancy reliable transport in underwater sensor networks*” by Liu et al., develops a new adaptive redundancy transport protocol (ARRTP) for underwater sensor networks. Due to high-bit error rate and large propagation delay in underwater communication, the design of transport protocols for underwater sensor networks is very challenging. The proposed ARRTP achieves the better tradeoff between reliability and energy consumption by using different redundancy schemes for different internode distances. The analysis and simulations show that ARRTP can increase the transmission reliability and provide better energy efficiency.

## 6. Conclusion

This issue of EURASIP JWCN offers an overview of the recent advances in several areas of the theoretical and algorithmic study for wireless ad hoc and sensor networks. We hope that this excellent collection of papers will help the interested readers to identify a number of key challenges and opportunities that lie within wireless ad hoc and sensor networks. We hope also that you enjoy and receive benefit from this special issue.

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