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Editorial

Editorial for special issue: System and theoretical issues in designing and implementing scalable and sustainable wireless sensor networks

The recent advances in embedded software/hardware design have enabled large-scale and cost-effective deployment of wireless sensor networks (WSNs). Such a network consists of many small sensor nodes with sensing, computing, communicating, and control capabilities. The wireless sensor networks have a broad spectrum applications ranging from wild life monitoring, battlefield surveillance, to border control and disaster relief, and have attracted significant interests from both academy and industry in the last decade. A wireless sensor node generally has limited communication and computation capabilities, as well as severely-constrained power supplies in most applications, and the networks often operate in harsh unattended environments. Successful design and deployment of large scale wireless sensor networks thus call for technology advances and integrations in diverse fields, including embedded hardware design, data processing, and wireless communications and networking across all layers.

Although many great efforts have been put forward in the study of wireless sensor networks, one of the key challenges that remain critical in WSNs is to develop a sustainable and scalable system that achieves longer network lifetime and predictable services. Nodes that are capable of harvesting environmental energy have been designed and used in many WSN systems. The benefits of using rechargeable batteries by harvesting environmental energy to prolong sensor network lifetime have been well recognized. However, how to balance the cost of system and reliability remains a challenge here.

This special issue aims to summarize the latest development of hardware and software for WSNs, as well as deployment experiences. The special issue is devoted to cover the following topics: novel transport, network, and MAC protocol design; smart in-network processing and control; disruption-tolerant/opportunistic mobile sensor networking; cross layer design and optimization, duty cycle management; channel and network modelling and performance evaluation; measurements and experience from experimental systems and test-beds; new and novel methods for harvesting environment energy; hardware design, and novel applications and architectures.

This special issue is organized by Prof. Xiang-Yang Li from Illinois Institute of Technology, Prof. YunHao Liu from HongKong University of Science and Technology (and now of Tsinghua University), Prof. WenZhan Song from Georgia State University, and Prof. My Thai from University of Florida.

We received total 35 submissions. Each accepted paper has been reviewed by at least three reviewers or guest editors. We believe that accepted papers provide a good balance of the application of algorithms and theory to different networking problems in large scale wireless sensor networks. After rigorous reviews of all papers, due to space limit, we can only accept 13 papers out of all high quality submissions.

Several papers focus on the MAC protocol design, and efficient data collection and gossiping.

Energy constraints pose great challenges to wireless sensor network (WSN) with battery-powered nodes. But the reduction of energy consumption often introduces additional latency of data delivery. In paper "*Distributed Self-learning Scheduling Approach for Wireless Sensor Network*", Niu and Deng presented a new distributed self-learning scheduling approach (SSA), which can reduce the energy consumption and can achieve low latency for WSN. This approach, extending the Q-learning method, enables nodes to learn continuous transmission parameter and sleep parameter through interacting with the WSN. They compare SSA with S-MAC protocol and DW-MAC protocol using simulations. The results show that the SSA can make nodes to learn the optimal scheduling policy gradually. The results under different workloads also exhibit that SSA performs much better than S-MAC protocol and DW-MAC protocol by reducing the energy consumption and improving the throughput. With regard to latency and maximum queue length, SSA also outperforms the other two MAC protocols in the scenarios where the collision is serious and the work load is heavy.

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Due to the large-scale ad hoc deployments and wireless interference, data aggregation is a fundamental but time consuming task in wireless sensor networks. The paper "*Near Optimal Scheduling of Data Aggregation in Wireless Sensor Networks*" focuses on the latency of data aggregation. Previously, it has been proved that the problem of minimizing the latency of data aggregation is NP-hard. Many approximate algorithms have been proposed to address this issue. Using maximum independent set and first fit algorithms, Wang et al. designed a scheduling algorithm, Peony-tree-based Data Aggregation (PDA), which has a latency bound of $15R + \Delta - 15$, where R is the network radius (measured in hops) and Δ is the maximum node degree. They theoretically analyze the performance of PDA based on different network models, and further evaluate it through extensive simulations. Both the analytical and simulation results demonstrate the advantages of PDA over the state-of-art algorithm, which has a latency bound of $23R + \Delta - 18$.

IEEE 802.15.4 as a standard for low rate wireless personal area networks (LR-WPAN) is an applicative choice for implementation of wireless sensor networks. Due to the advantages of this standard and its capabilities for more specification to wireless sensor networks, we need resolve some of its proven weaknesses in such environments. The slotted CSMA/CA method utilized in beacon enabled mode of 802.15.4 causes unacceptable level of energy consumption and throughput in conditions like high loads. To overcome these issues, in paper "*An adaptive CSMA-TDMA hybrid MAC for energy and throughput improvement of wireless sensor networks*", Hossein et al. proposed an adaptable CSMA/TDMA hybrid channel access method by applying some modifications to the 802.15.4 standard. The energy and throughput improvement is achieved by dedicating a part of the contention access period to a time division medium access protocol (TDMA). To evaluate the proposed method in comparison with 802.15.4, they developed a simulation in OMNeT++. Analysis of the simulation results indicates general improvement of energy consumption and throughput. As a sensor network grows more populated or the load increases, the proposed method shows a better performance in comparison with IEEE 802.15.4 standard.

Almost all existing broadcasting algorithms assume an ideal physical layer, in which a successful transmission is guaranteed if the distance between communicating nodes is less than a certain threshold, e.g., a transmission range. However, wireless communication links normally suffer from the characteristics of realistic physical layer, which significantly reduce the reliability of broadcasting among the nodes. The work "*Efficient Broadcasting in Multi-hop Wireless Networks with a Realistic Physical Layer*" addresses the minimal broadcasting problem in multi-hop wireless networks with a realistic physical layer. Given a probability p^*, the problem is to design a distributed broadcasting algorithm such that each node in the network receives the broadcasting packet with probability no less than p^* and the number of retransmissions is minimized. Wong et al. show that this problem is NP-hard and propose a distributed greedy algorithm which maximizes the gain cost ratio at each node. They prove that the proposed algorithm guarantees that each node receives the broadcasting packet with probability no less than p^*, and analyze upper bound on the number of total retransmissions in the network. Simulation results show that our algorithm can provide near 100% coverage to the wireless network with a realistic physical layer, and reduce the number of retransmissions compared with modified traditional flooding schemes k-Flooding (pure flooding with multiple times) and ACK-Flooding (pure flooding with acknowledgement).

Gossiping, which broadcasts the message of every node to all the other nodes, is an important operation in multi-hop wireless networks. Interference-aware gossiping scheduling (IAGS) aims to find an interference-free scheduling for gossiping with the minimum latency. Previous work on IAGS mostly assumes that nodes are always active, and thus is not suitable for duty-cycled scenarios. In paper "*On interference-aware gossiping in uncoordinated duty-cycled multi-hop wireless networks*", Jiao et al. investigate the IAGS problem in uncoordinated duty-cycled multi-hop wireless networks (IAGSUDC problem) under protocol interference model and unbounded-size message model. They prove that the IAGS-UDC problem is NP-hard. They then propose two novel algorithms, called MILD and MILD-R, for this problem with an approximation ratio of at most $3\beta^2(\Delta + 6)|T|$, where $\beta = \lceil \frac{2}{3}\alpha + 2 \rceil$, α denotes the ratio of the interference radius to the transmission radius, Δ denotes the maximum node degree of the network, and $|T|$ denotes the number of time slots in a scheduling period. The total numbers of transmissions scheduled by both algorithms are at most three times as large as the minimum total number of transmissions. Extensive simulations are conducted to evaluate the performance of our algorithms.

In the paper "*Three Dimensional Greedy Routing in Large-Scale Random Wireless Sensor Networks*", Wang et al. investigate how to design greedy routing to achieve sustainable and scalable performance in a large-scale three-dimensional (3D) sensor network. Several 3D position-based routing protocols were proposed to seek either delivery guarantee or energy efficiency in 3D wireless networks. However, recent results showed that there is no deterministic localized routing algorithm that guarantees either delivery of packets or energy efficiency of its routes in 3D networks. In this paper, they focus on design of 3D greedy routing protocols which can guarantee delivery of packets and/or energy efficiency of their paths with high probability in a randomly deployed 3D sensor network. In particular, they first study the asymptotic critical transmission radius for 3D greedy routing to ensure the packet delivery in large-scale random 3D sensor networks, and then propose a refined 3D greedy routing protocol to achieve energy efficiency of its paths with high probability. They also conduct extensive simulations to confirm our theoretical results.

Wireless sensor networks (WSNs) introduce new challenges to topology control due to the prevalence of lossy links. In paper "*Localized and Configurable Topology Control in Lossy Wireless Sensor Networks*", Xing et al. propose a new topology control formulation for lossy WSNs. In contrast to previous deterministic models, their formulation captures the stochastic nature of lossy links and quantifies