energies

Editorial

Wireless Rechargeable Sensor Networks

Chang-Wu Yu

Department of Computer Science and Information Engineering, Chung Hua University, 707, Sec. 2, Wufu Rd., Hsinchu 30012, Taiwan; cwyu@chu.edu.tw; Tel.: +886-3-5186413; Fax: +886-3-5186416

Citation: Yu, C.-W. Wireless Rechargeable Sensor Networks. *Energies* **2021**, *14*, 7895. https://doi.org/10.3390/en14237895

Received: 13 September 2021
Accepted: 12 November 2021
Published: 25 November 2021

Wireless sensor networks have attracted much attention recently due to their various applications in many fields. Due to limited power consumption, these sensor nodes may experience power shortages and thus lead to many problems including network disconnection. Most previous methods focused on providing energy-saving strategies to increase the lifetime of sensor networks. Recently, another aggressive but different approach is to wirelessly recharge the sensor nodes by using varying vehicles to increase the lifetime of the interested sensor networks.

This Special Issue, entitled "Wireless Rechargeable Sensor Networks", invited articles that address state-of-the-art technologies and new developments for wireless rechargeable sensor networks (WRSNs). Articles that deal with the latest hot topics in WRSNs are particularly encouraged, such as unmanned aerial vehicles (UAV) wireless charging, charging pad deployment, wireless charging scheduling, global energy transmission, flying ad hoc networks, machine learning based WRSNs, and WRSN with separable charger array. In addition, articles that discuss protocols, algorithms, and optimization in WRSN, were of particular interest.

For example, UAV wireless charging is usually done by one or multiple UAV(s) equipped with wireless chargers moving toward sensors demanding energy replenishing. Since the loading of each sensor in a WRSN can be different, their time to energy exhaustion may also be varied. Under some circumstances, sensors may deplete their energy quickly and need to be charged urgently. Appropriate scheduling of available UAV(s) so that all sensors in need of recharge can be served in time is thus essential to ensure sustainable operation of the entire network.

As a guest editor of this Special Issue, we were able to make certain that the fundamental issues of wireless energy transmission are now widespread among WRSN scientists and scholars. We hope this Special Issue can push the theoretical and practical research forward for a deeper understanding in the fundamental algorithm, modeling, and analysis techniques of WRSNs.

Hereafter, we provide a brief review of five papers published in this Special Issue. The first paper considers the charger deployment to provide extra energies to WRSNs. In order to efficiently extend the lifetime of the WRSNs, in [1], Lin et al. proposed a novel hybrid search and removal strategy of placing wireless chargers by considering the hot spot effect. Their proposed algorithm attempts to discover the minimum number of chargers required to cover all sensor nodes by adopting the dominating set technique. Their algorithm also considers the charging power of the wireless directional charger when arranging its placement to maximize the charging capacity in a power-balanced prerequisite.

The second paper [2] considers a localization method based on ray-tracing and fingerprinting techniques. The improvement in the technology related to radio localization and the rise in the data traffic demanded require a large number of base stations. This increase in the density of base stations causes a rise in energy consumption of cellular networks. As a result, energy saving and cost reduction is a significant factor in the development of future localization networks. In this paper, Del Corte-Valiente et al. presented a localization method based on ray-tracing and fingerprinting techniques. Simulation tools based on high frequencies are used to characterize the channel propagation and to obtain the ray-tracing data. Moreover, their fingerprinting technique requires a costly initial learning phase for cell fingerprint generation.

The third paper considers energy harvesting issues in WSNs. Since energy harvesting sensors can be the solution to enabling future applications, in [3], Zareei et al. analyzed the performance improvement and evaluation of energy harvesting sensors in various situations. They applied a clustering concept to energy harvesting sensor networks to study its effect on the performance of the network in different scenarios. Moreover, a dynamic and distributed transmission power management for sensors is proposed and evaluated in both networks, with and without clustering, to study the effect of power balancing on the network end-to-end performance.

The fourth paper considers how to balance traffic loads for power saving in WSNs. In [4], Yu et al. proposed a shortest path tree with energy balance routing strategy based on a forward awareness factor. In their work, two methods are presented, including the power consumption and the energy harvesting schemes to select the forwarding node according to the awareness factors of link weight. First, the packet forwarding rate factor is considered in the power consumption scheme to update the link weight for the sensors with higher power consumption and mitigates the traffic load of hotspot nodes to achieve the energy balance network. With the assistance of the power consumption scheme, hotspot nodes can be transferred from the irregular location to the same intra-layer from the sink.

The last paper considers designing genetic algorithms for wireless charging scheduling. Two essential criteria that need to be considered concurrently in such a problem are time (the sensor's deadline for recharge) and distance (from charger to the sensor demands recharge). Previous works have used a static combination of these two parameters in determining charging order, which may fail to meet all the sensors' charging requirements in a dynamically changing network. In [5], Cheng et al. proposed a genetic approach, which includes novel designs in chromosome structure, selection, cross-over and mutation operations, supporting multiple charging vehicles. Two unique features are incorporated into their algorithm to improve its scheduling effectiveness and performance, which include: (1) inclusion of EDF (Earliest Deadline First) and NJF (Nearest Job First) scheduling outcomes into the initial chromosomes; and (2) clustering neighboring sensors demand recharge and then assigning sensors in a group to the same mobile charger. By including EDF and NJF scheduling outcomes into the first genetic population, this work guarantees that both time and distance factors are taken into account.

Due to advances in wireless charging technology, it is now possible to recharge sensors to extend their network lifetime through vehicles/drones/pads equipped with a charger. However, in terms of the number of mobile chargers used in a WRSN, there can be one or multiple ones available. With either one charger or multiple vehicles, the optimal charging scheduling and its related problems frequently have been proven to be NP-hard problems, and only heuristic/near-optimal solutions can be obtained. A more fine-tuned combination of the three factors, including time, spatial and loading of sensors to improve the performance of related applications for WRSN, will be one direction of future research on WRSNs. It would be interesting to discuss how to apply the existing algorithms to charge scheduling in WRSNs with multiple mobile chargers or chargers with multiple charging capabilities. Additionally, improvements in charging efficiency may be possible in these contexts. Moreover, in reality, the power consumption of each sensor node may be dynamic, which means that the threshold does not need to be fixed. In the future, some scholars may explore the effects of adjusting this threshold according to the nodes' loading conditions. More attention will be paid to the characteristics of deployed pads and charger in a WRSN. In addition, scenarios using wirelessly charged vehicles combined with multiple drones will also be taken into account to increase the robustness of the proposed model under varying configurations and circumstances.

Acknowledgments: The author is grateful to the MDPI for the invitation to act as a guest editor of this Special Issue and is indebted to the editorial staff of *Energies* for constant helps and patience.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lin, T.-L.; Chang, H.-Y.; Wang, Y.-H. A Novel Hybrid Search and Remove Strategy for Power Balance Wireless Charger Deployment in Wireless Rechargeable Sensor Networks. *Energies* **2020**, *13*, 2661. [CrossRef]
2. Del Corte-Valiente, A.; Gómez-Pulido, J.M.; Gutiérrez-Blanco, O.; Castillo-Sequera, J.L. Localization Approach Based on Ray-Tracing Simulations and Fingerprinting Techniques for Indoor–Outdoor Scenarios. *Energies* **2019**, *12*, 2943. [CrossRef]
3. Zareei, M.; Vargas-Rosales, C.; Anisi, M.H.; Musavian, L.; Villalpando-Hernandez, R.; Goudarzi, S.; Mohamed, E.M. Enhancing the Performance of Energy Harvesting Sensor Networks for Environmental Monitoring Applications. *Energies* **2019**, *12*, 2794. [CrossRef]
4. Yu, C.-M.; Tala't, M.; Chiu, C.-H.; Huang, C.-Y. Joint Balanced Routing and Energy Harvesting Strategy for Maximizing Network Lifetime in WSNs. *Energies* **2019**, *12*, 2336. [CrossRef]
5. Cheng, R.-H.; Xu, C.; Wu, T.-K. A Genetic Approach to Solve the Emergent Charging Scheduling Problem Using Multiple Charging Vehicles for Wireless Rechargeable Sensor Networks. *Energies* **2019**, *12*, 287. [CrossRef]