Journal of Artificial Intelligence and Data Mining (JAIDM), Vol. 9, No. 3, 2021, 383-402.

Shahrood University of Technology

Journal of Artificial Intelligence and Data Mining (JAIDM)
Journal homepage: http://jad.shahroodut.ac.ir

Review paper

A Mobile Charger based on Wireless Power Transfer Technologies: A Survey of Concepts, Techniques, Challenges, and Applications on Rechargeable Wireless Sensor Networks

Newsha Nowrozian and Farzad Tashtarian*

Department of Computer Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran.

Article Info

Article History:
Received 31 July 2020
Revised 21 April 2021
Accepted 21 May 2021

DOI:10.22044/jadm.2021.9936.2127

Keywords:
Wireless Charging Technology, Mobile Charger Vehicle, Rechargeable Wireless Sensor Networks, Wireless Power Transfer.

**Corresponding author: f.tashtarian@mshdiau.ac.ir (F. Tashtarian).*

Abstract

The battery power limitation of sensor nodes (SNs) is a major challenge for wireless sensor networks (WSNs), which affects the network survival. Thus, optimizing the energy consumption of SNs as well as increasing the lifetime of SNs, and thus, extending the lifetime of WSNs are of crucial importance in these types of networks. The mobile chargers (MCs) and the wireless power transfer (WPT) technologies have played an important long role in WSNs, and many researcher works have been done on how to use MCs enhance the performance of WSNs in the recent decades. In this paper, we first review the application of MCs and the WPT technologies in WSNs. Then, forwarding the issues, MC is considered in the role of power transmitter in WSNs and the existing approaches are categorized, with the purposes and limitations of the MC dispatching studied. Then an overview of the existing articles is presented, and in order to better understand the contents, tables and figures are offered that summarize the existing methods. We examine them in different dimensions such as advantages and disadvantages. Finally, the future prospects of MCs are discussed.

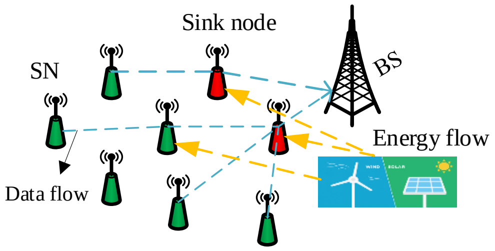
1. Introduction

Recently, Wireless Sensor Networks (WSNs) have been widely used in many healthcare and monitoring areas [1-4]. Given the small size and limited battery capacity of the sensor nodes (SNs) in WSNs, the battery power of SNs is limited, which is regarded as a major problem in the practical implementation of these networks. There are currently four main ways of energy management in WSNs [5-7]:

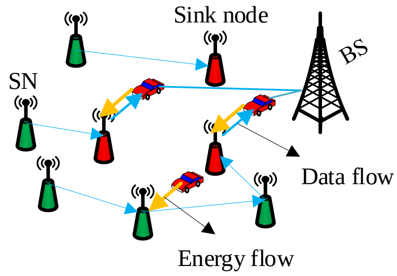
Energy conservation scheme: Although it cannot compensate the energy consumed by SNs, this scheme can only minimize the energy consumption of SNs by relying on a number of routing and protocols methods.

Battery replacement manually: This method is only suitable for small sensor networks whose SNs are tangible. Battery replacement will frequently increase the manpower and material costs. Energy harvesting technology: This technology has proposed energy extraction from the environment in order to compensate for the energy lost in SNs. Due to its dependence on its surroundings, this method inevitably imposes instability and uncontrollability in receiving energy for the network.

Wireless power transfer (WTP) technology: WTP is a new approach to overcome the limitations of the above designs [7, 8]. The main idea is to put a battery with enough power on a robot. Using this technology in [9], the robot has acted as a wireless mobile charger (MC) in order to charge SNs wirelessly. Based on this technology, they used an MC that utilized the wireless charging technology to charge a WSN. Among the WPT technologies, magnetic resonance coupling seems to be the most appropriate technology for WSNs. In [10], the researchers have conducted the first study on how to use the WPT technology in WSNs.



(a) Renewable energy form wind and solar in traditional network.



(b) Renewable energy from MC in WSNs.

Figure 1. Outline of the survey.

The WPT technology offers great benefits such as minimizing the charging latency, maximizing the system power and, maximizing the network life, which can be mentioned as primary targets for using MCs in WSNs. The Magnetic resonance couples [5] are one of the WPT technologies first proposed by Kruse et al. The authors considered the scenario of MCs, which periodically moved through WSNs and charged each SN. After each trip, MC returns to its service station (SS) or base station (BS), taking a break to start the next trip (Figure 1 shows the usage of MCs in WSNs). Given the recent advances in wireless energy transmission, based on the magnetic resonance coupling of an energy source, it is no longer limited to charging only one receiver per unit time. Reference [7] proposed the one-to-many WPT technology allowing charging of multiple receivers via a single source simultaneously, which is entirely based on the scalability problem in WSNs. It addresses WPT [8, 11].

In the present study, we present an integrated study on an MC vehicle as well as a static charger based on WPT as an energy deliverer in WSNs. We also discuss how they can solve the problem of energy constraint as SNs of small size with a limited capacity in WSNs. In order to gain a thorough understanding of the wireless chargers, in Session 2, we will first look at the WPT technologies and charging models. Then, we describe the taxonomy in the wireless charger from two viewpoints including the static charger and MC. We then focus on how MC extends in WSNs, and finally, based on our classification, we introduce the task of MC, issues of dispatching MC, classification of dispatching MC methods, and the objective of its dispatching in WSNs. Next, in Section 3, we describe our taxonomy of research topics in dispatching the MC method issues in two ways, periodic and on-demand.

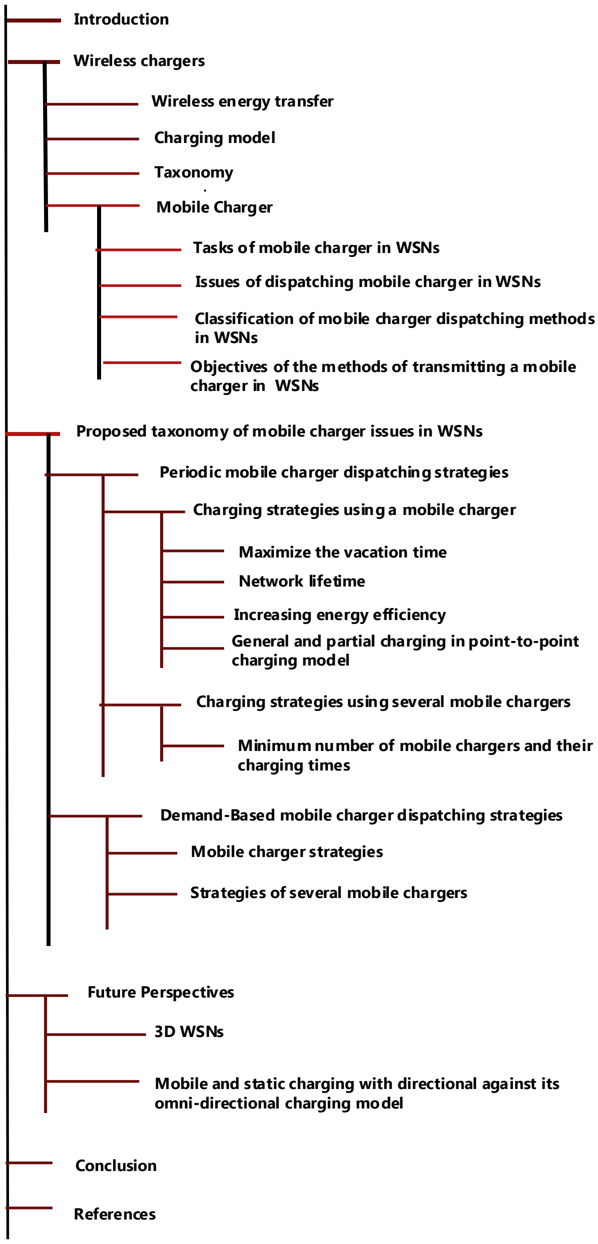


Figure 2. Display of the difference between energy deliveries.

Then, according to using one or several chargers, we cover all methods in each sub-division with respect to the MCs objectives. Also, we summarize the efforts on the MC in several figures and tables. In Section 4 and 5, we present a perspective on the future research work and conclude the paper. Figure 2 shows the structure of the survey.

2. Wireless Chargers

2.1. Wireless power transfer (WTP)

The power constraints are widely recognized as a major problem in wireless devices. In WSNs, the limited lifetime of the network, due to the limited capacity of the battery, is a major issue as well as an obstacle to its implementation on a larger scale. Recently, wireless power transmission has been proposed as a promising technology in order to address the energy bottleneck problem as well as the lifetime of the sensor network. Currently, the WPT technologies have been divided into three groups [5, 11, 12], which include the induction couples: it uses electromagnetic induction in order to transfer energy wirelessly, electromagnetic radiation: it operates on a radio frequency between 850 MHz and 950 MHz, which can be transmitted in two ways: directional radiation and omni-directional radiation, and magnetic resonance couples: it has been proposed by Korus and is widely used in WSNs. Table 1 summarizes the disadvantages and benefits along with several practical examples. In Figures 3 and 4, respectively, the WPT model and their applications are presented.

2.2. Charging Model

The experimental wireless charging model based on the well-known Friis free-space loss model was first formulated in [13]. Accordingly, the power received in a wireless sensor device is as follows:

$$P_r = \frac{(G_t G_r \gamma)}{L_p} \left(\frac{\lambda}{(4\pi(dis(M,s_i)+\beta))}\right)^{\chi} P_t \qquad (1)$$

P_t is the transfer power of the source, i.e. the transfer power of MC; P_r is the received power of the receiver, i.e. the power received from SN; $dis(M,s_i)$ is the Euclidean distance between SN s_i and MC M; G_t denotes the gain of the source antenna, G_r is the gain of the receiver antenna, L_p represents the polarization loss, λ denotes the signal wavelength, γ is the rectifier efficiency, and β equation for a short distance transmission (long distance). All values in the charging model are constant. In order to ease the description, equation (2) is re-written as follows:

$$\mathrm{P_r} = \frac{\alpha}{(dis(M,s_i)+\beta)^{\chi}} \qquad (1)$$

where

$$\alpha = \frac{(G_t * G_r * \gamma * P_t)}{L_p} * \left(\frac{\lambda}{4\pi}\right)^{\chi} \qquad (2)$$

Typically, χ is between 2 and 4, and χ is equal to 2. Generally, if R indicates the charging range, the power received P_r in a SN is as follows:

$$P_r = \begin{cases} \frac{\alpha}{(dis(M,s_i)+\beta)^{\chi}} & (dis(M,s_i) \prec R \\ 0 & (dis(M,s_i) \geq R \end{cases} \qquad (3)$$

In articles such as [10], [14-19], the Friis charge model has been used.

2.3. Taxonomy

The WPT technology has grown dramatically in the recent years with the development of WSNs. Generally, wireless chargers can be classified into two categories according to their charging behaviors and performance [18, 20]: static chargers [21-24] and MCs [25].

- **Static Charging (SC):** In this type, since static wireless chargers are fixed to charge the devices in predefined locations, the primary focus of most studies is to determine the ideal spot and minimize the spot for them. As noted previously, their effective coverage range is only a few m and maximum 10 m based on the magnetic resonance couples and electromagnetic radiation, respectively. Thus, they are only adequate for small areas. In addition, the cost of stationing omni-directional static chargers is expensive across a vast network. The current literature examines the strategies of stationary wireless charger deployment in three different scenarios [5]. Figure 5 shows an overview of them.

1- Point Supplying: SCs are stationed in order to support fixed SNs with the WPT capability.

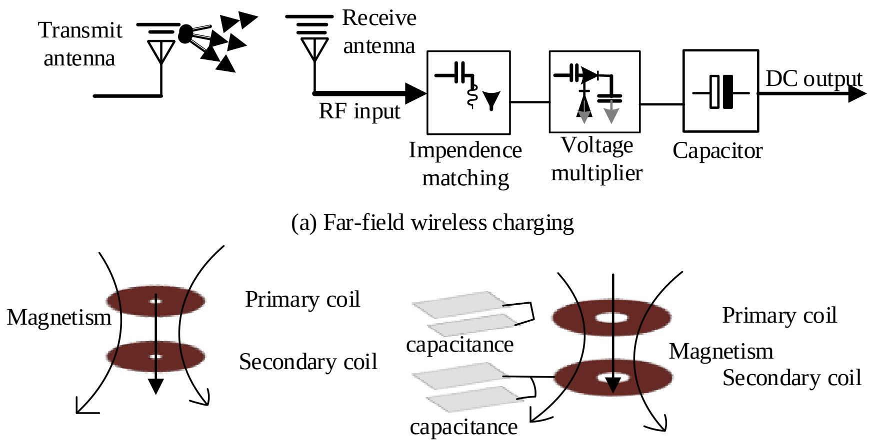
2- Path Supplying: The purpose of SCs is to deploy mobile or mobile nodes (for example, human-wearable or implanted sensors) on their journey.

3- Multi-Hop Supplying: Specifies places to place SCs in a static network, where devices with WPT are also active and can share energy with each other.

- **Mobile charger (MC):** The studies on MC emphasize both the problem of charging the SNs that is considered as a trip planning issue as well as scheduling a minimum number of MCs to compensate for the nodes' energy by moving around the network.

Table 1. Comparison of Technologies [7] and [8].

Wireless energy transfer technologies	Advantages		Disadvantages	Examples
Induction couples	Simple implementation, high efficiency charging from a few mm to a few cm		Short charge distance, requires precise alignment between chargers and devices	Electric toothbrush, charging pad for cell phones and laptops
Electromagnetic radiation	Omni-directional	Small-size receiver	Low charging efficiency over distance	Rechargeable WSNs for environmental monitoring (temperature, humidity, light)
	Directional	Efficient long-distance charging from several tens of m, up to several km	Need for line- of-sight charging and sophisticated tracking mechanisms, large scale devices	SHARP drone
Magnetic resonance couples	High-efficiency charging from a few cm to a few m, charging multiple devices simultaneously, no need for line-of-sight charging, insensitive to weather conditions		High efficiency in just a few m range	Charging mobile devices or electric vehicles, implantable devices and WSNs.



(a) Far-field wireless charging

(b) Inductive coupling

(c) Magnetic resonance coupling

Figure 3. Charging system models showing WPT technologies [7] and [8].

The sharp unmanned plane receives power beamed from the Erath

Electronic toothbrush

Haier HDTV is powered by wireless electricity

Intel WISP harvest power from radio signal

Cell phone and charger pad

Qualcomm halo electronic vehicle powered when stay at the charger point

(a) Electromagnetic radiation **(b) Magnetic resonance couples** **(c) Inductive coupling**

Figure 4.Illustrations of applications of WPT technologies [5] and [7].

2.4. Mobile charger (MC)

After a significant progress in the WPT technology, the researchers have found a greater determination to apply MC or multiple MCs as an efficient charging method in WSNs [26]. MC with a rechargeable battery, assuming the battery has enough power to charge all the SNs in the network, moves over the network and charges all the available SNs wirelessly. In addition, it will return to SS in order to recharge its battery if the battery is being completed [7]. The WPT technologies bring considerable profits such as minimizing the charging delays, maximizing the system power, and maximizing the network life. Thus they can be considered as the main reason for employing MCs in WSNs. In the following sub-sections, we first classify the different tasks of MC, and then discuss the issues of dispatching MC(s) and their goals for WSNs, and finally provide a classification on the approaches of dispatching of MC(s). According to various papers, three major roles are played by MCs, including: (Figure 6 (a-c)):

1- The role of aggregator (collection), gathering information or data from the relay nodes or SNs.

2- The role of the deliverer (delivery), the delivery of energy to SNs.

3- The hybrid role (combination), a combination of both the information gathering and the energy-delivering roles.

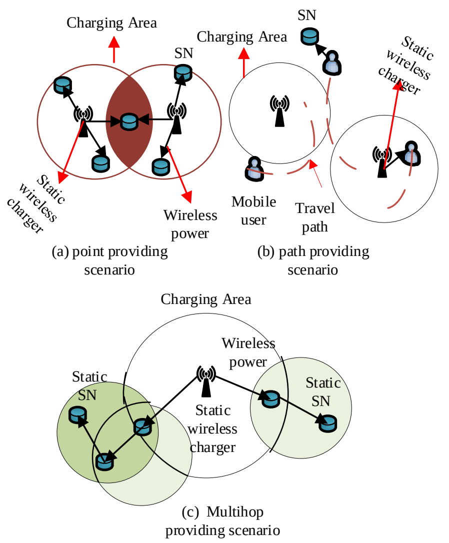


Figure 5. **View of static charger scenarios [5].**

2.4.1. Issues of Dispatching MC in WSNs

In this section, we first introduce the problem of dispatching an MC to WSNs as the problem of trip schedule of one or more MCs such that they visit and recharge a set of SNs. Also, one of its goals is usually to extend the network lifetime. Generally, five fundamental subjects must be considered in planning an MC trip including [10, 18, 27-29]:

1- Charging Location: The best charging locations to visit MC must be obtained by considering a number of distributed SNs and their locations so that MC can cover all SNs.

2- Travel Path: Depending on the number of charging locations, the MC is required to visit, an optimal travel route must be obtained to meet all locations by the MC so that specific goal(s) can be achieved.

3- Charging Time: Depending on the number of stop points (SP) for MC to visit, the optimal charging time for MC at each SPs should be obtained so that SNs are sufficiently charged.

4- Data Rate and Data Routing: Depending on the number of SNs, their locations and the required data flow, the best data rate, and the best data path for the SNs should be gained so the data collection performance is optimized.

5- Number of MCs: Supplying energy through cooperation of multiple MCs; they must set the minimum number of MCs in order to gain a specific target such as the lowest cost.

The above five topics are contemplated as the optimal variables to achieve some goals present in Section 2.4.3.

2.4.2. Classification of MC Dispatching Methods in WSNs

In WSNs, the task of the charging system is to guarantee the lifetime of the network nodes for a set time. The current MC scheduling strategies are, therefore, classified into five different aspects ranging from the demand response to demand-based, periodic-plan strategies. On the other hand, the strategies are categorized in terms of the number of MCs as single and multi-chargers. In addition to the charging model, both are classified as point-to-point and point-to-multi-point. Table 2 reports these classifications. In Figure 7, we present two typical model systems that have been proposed for scheduling portable charger delivery in the articles. View the strategies of using MC to charge SNs via wireless.

2.4.3. Objectives of Methods of Transmitting MC in WSN

Since the replacement of SNs is not economical, improving the network lifetime, where node charging technologies fail to work, is the first goal of the traditional network designers. Following this idea, with the advent of WTP and MCs, different concepts were raised such as energy efficiency, vacation time, latency, charging quantity, MC number, and rate number of live SNs [16, 29]. Then we summarize the goals of dispatching Table 3.

3. Proposed Taxonomy of MC Issues in WSNs

In this section, we have an overview of some of the dispatching MC methods in WSNs. Further, these methods are categorized into two groups: periodical and on-demand methods. In each sub-group, we first indicate the studies on the usage of MC and then proceed with several MCs. Note that it has been attempted to classify by the MC goals discussed in Section 2.4. The summarization of the existing methods as well as their disadvantages and advantages and the relationships between them are shown in Table 4 and Table 5.

3.1. Periodic MC Dispatching Strategies

MC employs a pre-determined path to charge SNs in periodic approaches [10, 14, 15, 30, 31].

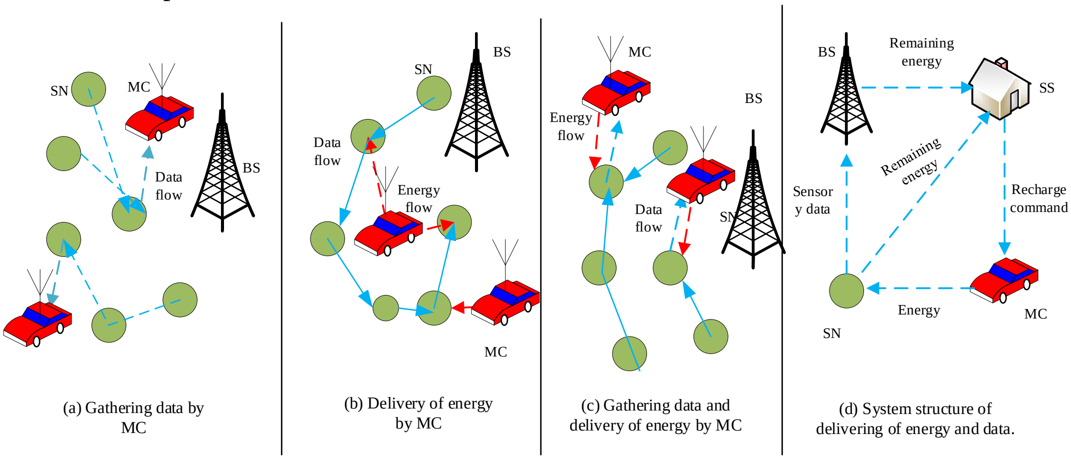


Figure 6. (a)-(c): The third of major roles of MC in WSNs, (d) Energy delivering system.

Table 2. Classification of MC delivery methods.

Charging cycle	Periodic	Charging time, travel route and charging sequence are specified in each round. MC(s) charges all the SNs in each round. The energy consumption rate of SNs is constant and the network topology is unchanged.
	On-demand	MC(s) will preferably charge the SNs that require the most charging per round. The charging schedule changes dynamically with the behavior of SNs in each round. The energy consumption rate of SNs is not constant and the network topology is dynamic.
Charging model	Point–to-point	It is suitable for the low-density node sensor networks or distributed nodes. MC(s) only charges one node.
	Point-to-multi-point	In WSNs high nodes density of distribution, clustering is applied. MC can charge multiple nodes in a range by selecting one node at a time.
MC number	Single	It is suitable for small WSNs with a simple network topology. All SNs are charged by MC.
	Multiple	The purpose of large-scale or ultra-large WSNs with complex network topology. Several MCs work together to charge SNs.
Route control	Centralized	Under a central entity the direction of motion of MC is determined.
	Distributed	The direction of movement is determined by the synergy between MCs.
How to charge the nodes	Full	The battery of the SNs is fully charged.
	Partial	The battery of the SNs is partially recharged several times as required.

Table 3. Goals of dispatching MC in WSN.

Network lifetime	The Duration of starting WSN operating to the death of the first SN.
Energy efficiency	Efficient use of energy (ratio of the energy received by SNs to the energy consumed by MC throughout the charging cycle).
Vacation time	Resting time of MC at BS (total time travel by MC to meet all SNs plus total charging time of SNs)
latency	Duration of the charging requests to recharging them. (it is in term of charging time plus waiting time and travel time for each SN)
Survival rate of SNs	Relationship between the rate of surviving SNs and the number of SNs.
Charging quantity	Total number of charged SNs.
MC number	Minimum number of MCs to achieve the above goals.

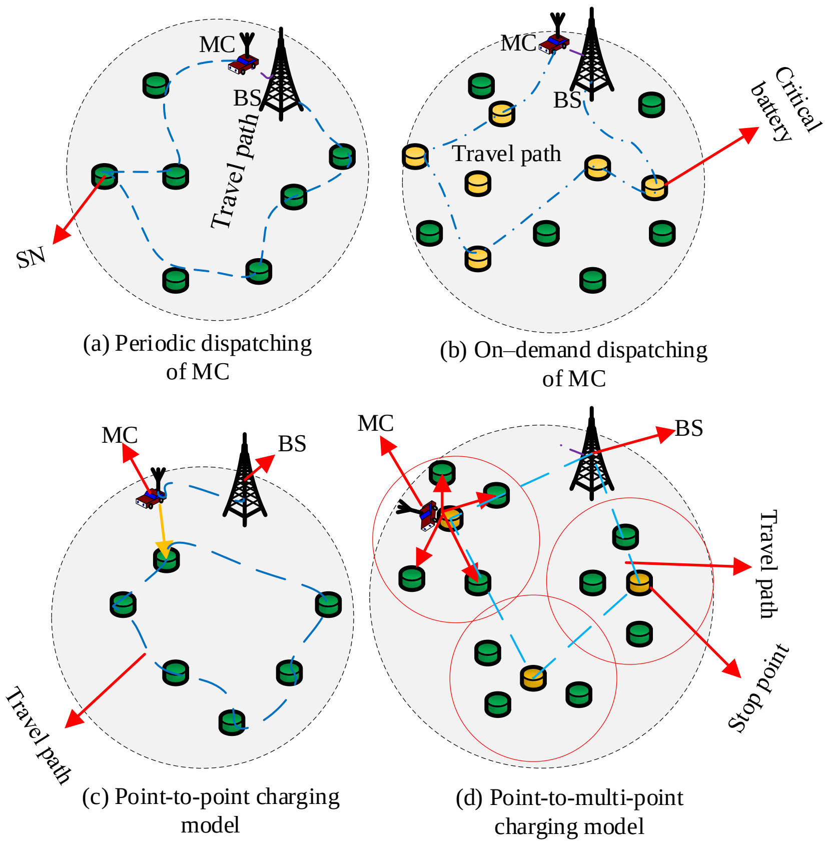


Figure 7: System of MC delivery: (a)-(b): Charging cycle model, (c)-(d): Charging model.

It is assumed that all SNs are required to be recharged, and MC will charge all SNs in each cycle along the specified path. These schemes are established on the point-to-point or point-to-multi-point charging model.

3.1.1. Charging Strategy Using MC

The intention of most single MC strategies [10, 14, 15, 30, 31] is to minimize the total charging time of the nodes, including the total traveling time for MC to meet the entire SNs coupled with the total charging time the whole node, along with other goals mentioned in Section 2.4.3.

- **Maximizing Vacation Time of MC**

The goal of the authors in [10] was to increase the rate of the vacation time of MC so that all SNs would have the least energy. The authors theorized that the optimal travel path for the MC to maintain the renewable energy cycle is the shortest Hamiltonian cycle (SHC) which is obtained by solving traveling salesman problem (TSP) [32]. Then, a non-linear optimization problem was formulated by considering the time of charge and routing of the data. This problem was NP-hard. They acquired a possible solution by adopting the piecewise linear approximation technique. Reference [17] is an extended form of [10] by considering a point-to-multi-point charging model. Reference [14] improved [10], where the static routing in [10] was considered, in contrast to the time-dependent dynamic routing applied in [14]. As in [28], the authors in [15] also presented a non-linear programming in order to optimize the total charge time where the SNs were charged within a very short time and received the maximum energy through synchronization between the angle and distance constraints (Figure 9). Their results revealed that if MC was arranged in a proper distance and angle from SN, the charging nodes would diminish by half. Their linear model was solved by simplex method.

The above-mentioned studies utilize a point-to-point charging model to charge SNs. Hereafter, we will review the articles that discuss the selection of charging locations along with the point-to-multi-point charging model [28, 30, 33, 34]. Reference [30] modified [10] by converting its energy model to point–to-multi-point.

Table 4. Classification of the existing methods and review from different dimensions.

Sources	Charging cycle		Charging model		Number of MCs		quantity of charge of nodes		The limitation of battery charging		Route control		Optimization variables		Targets										
	Periodic	On-demand	Point- to- multi point	Point-to-point	Multi	Single	General	Partial	Yes	No	Distributed	Centralized	Travel path	Data rate	Charging time	Stop location	Data flow routing	Vacation time of MC	A number of MCs	Scheduling of MCs	Energy efficiency	Lifetime network	Survival rate of SNs	Traveled distance	Charging value
(2019) [21]	+		+			+	+			+		+		+		+	+					+			
(2019) [35]		+		+		+	+			+		+	+								+		+		
(2019) [19]	+		+			+	+			+		+	+			+								+	
(2019) [69]		+	+			+	+			+		+				+									+
(2018) [68]		+	+		+		+			+		+			+					+	+		+		
(2018) [70]		+		+		+		+	+			+	+									+	+		
(2018) [35]		+	+			+	+			+		+	+		+	+		+							
(2018) [54]		+		+	+		+			+		+									+		+		
(2018) [67]		+	+			+	+		+			+	+			+					+				
(2018) [27]		+		+	+		+						+		+	+		+	+						
(2018) [73]		+		+	+		+						+		+	+			+						
(2018) [28]	+		+			+	+			+		+	+			+									
(2018) [48]	+			+		+		+				+	+		+								+	+	
(2017) [15]	+			+		+	+			+		+	+	+	+		+	+							
(2017) [71]		+		+		+	+			+											+		+		
(2017) [39]	+			+		+	+		+			+	+			+		+			+				

(2013) [33]	(2014) [43]	(2014) [14]	(2014) [45]	(2014) [44]	(2014) [47]	(2014) [47]	(2014) [72]	(2014) [58]	(2014) [57]	(2014) [56]	(2015) [34]	(2015) [30]	(2015) [51]	(2015) [74]	(2015) [64]	(2016) [55]	(2016) [43]	(2016) [62]	(2018) [18]	(2017) [62]	(2017) [29]
+	+	+	+	+	+	+					+	+	+				+		+	+	+
							+	+	+	+				+	+	+		+		+	
+	+		+	+			+	+			+	+	+					+	+		+
		+		+	+	+								+		+				+	
	+		+	+	+	+	+	+					+		+			+			
+									+	+	+	+		+	+	+			+	+	+
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+
																	+				
	+														+	+			+		
+		+	+	+	+		+	+	+	+	+	+	+	+				+		+	+
								+					+	+	+						
+	+	+	+	+	+	+	+		+	+	+				+	+	+	+	+	+	+
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+
+		+										+									
+		+			+	+	+		+	+		+	+	+	+		+		+	+	+
									+	+	+							+			
		+																			
+		+									+	+									
	+		+	+		+		+					+					+			+
	+																				
							+												+		+
															+	+	+				
+	+				+		+		+	+							+				
										+			+	+						+	

(2013) [10]	+			+		+	+			+		+	+	+	+		+	+						
(2013) [16]	+		+			+	+			+		+	+	+	+		+	+						
(2013) [49]	+			+	+		+			+		+	+						+	+				
(2011) [17]	+			+		+	+			+		+	+	+	+		+	+						
(2010) [40]	+		+			+	+		+			+	+				+					+		
(2010) [9]	+		+			+	+			+		+	+	+			+					+		
(2010) [36]	+		+			+	+			+		+	+		+						+			
(2010) [60]		+		+		+	+			+		+	+										+	

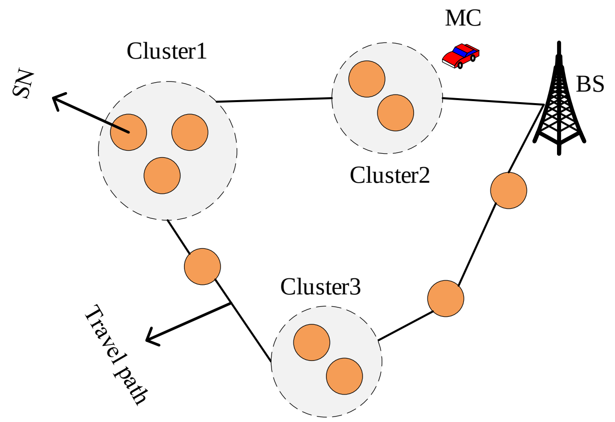


Figure 8. Clustering of SNs and determining the travel path of MC in [39].

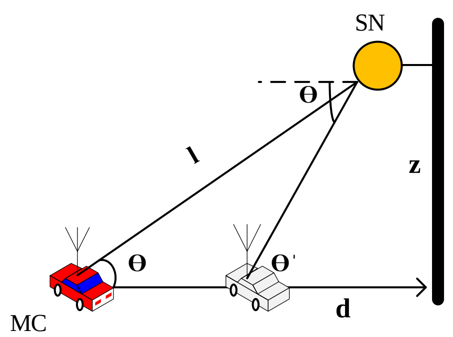


Figure 9. Concept of charging by considering of angle in [15].

They also formulated the issue of minimizing the vacation time of MC as a non-linear programming problem, and provided an optimal solution using discretization and a reformulation-linearization technique [35]. The authors in [16] developed the ratio of the vacation time of MC regarding the travel path, routing flow, and charge time of SNs by considering a hexagonal cells space so as to the MC pass away of central of all cell where inside SNs have the least energy level and charge them. Article [16] was developed based on the idea of article [36].The strategy proposed in [33] was simar to reference [16]. However, they considered SC as the travel path of MC, and provided the optimal path with one of solving TSP. In addition, they focused on the optimizing node charging time at each stop point, using dynamic routing solutions. In [34], a linear model was offered for optimizing the charge location of nodes and their charging time in order to achieve the maximum number of the charging nodes along with the minimum number of selective SPs in MC. They also reduced the search space in order to find the optimal solution using the smallest enclosed space method [37] as well as the Lloyd's k-mean clustering algorithm [38]. In [28], their goal was minimizing the charging stop point accompanied by the travel path of MC in order to gain the minimum energy consuming MC by considering the limitation of battery capacity of MC. This problem was known as the SHC problem, and the mate-heuristic genetic algorithm was applied to solve it. The goal in [19] was similar to [34], but in [19], they presented a new directional charging model with a foundation of angle and distance. They implemented the angle disconnection technique based on the charging model, and the k-means algorithm in order to limit the computational space of the problem and to obtain the minimum charge delay.

- **Lifetime of Network**

In [40], the authors jointly examined the routing and charge of SNs in order to seek the optimal flow path and delegation of the amount of energy to each SN with respect to the specified battery capacity of MC; thereby, they can obtain the maximized network lifetime. The authors' goal in [9] has been to extend the network lifetime, finding the optimal charge sequence by taking into account the charging time of each SN. Compared to [9], [40] has improved its performance by addressing the issues related to the charging schedule. In [41], they designed a charging strategy based on maintaining the balancing energy consumption in network along with finding a routing algorithm compatible with the feature of the nodes in the charging stage in order to promote the network lifetime.

- **Increasing Energy Efficiency**

The consumption of MC energy can be categorized into three types: moving the energy used up to move MC along the network. In addition, the energy that the MC loses due to the distance and duration of charging SNs, and finally, the energy of MC received by SNs. Improving the energy rate received by SNs to the total energy consumption of MC will enhance the charging energy efficiency, which will boost the performance of WSNs. As a result, one of the goals of MC [16, 18, 36] is how to strengthen the energy efficiency of networks. The authors in [36] have proposed a model in order to determine the best SPs with the optimization of the path and energy management in SNs, and considered the issue of prioritizing the charge of SNs in order to lower the cost of charging nodes with the MC in the network. In [39], their purposes were to find the effective SPs by the Welzl algorithm [37] and moving the path to increase the energy efficiency by applying two heuristic methods to find both the effective clustering of SNs and the shortest moving path for a limited battery MC based on the weighted edges algorithm (Figure 8).

- **General and Partial Charging in Point-To-Point Charging Model**

Most current methods suppose that the battery of each node is fully charged during the charging process by MC. In these methods, due to the restriction of the charging efficiency in the WTP technology, the work will take a long time to complete. In order to address this shortcoming, they suggested that SNs are charged partially in order to prevent the death while the travel distance of MC is minimized and the lifetime of SNs is elevated as much as possible in [42, 43].

In [42], they provided modules in order to allocate a suitable energy to SNs and find the best charging path while estimating the minimizing of the travel path cost and the highest SNs lifetime. Although their results have shown effective charging partially in the large and small–scale networks, it provides the rising of charge requests and the travel path for MC. In [43], the authors provided a similar model to the objectives of [42]. They formulated an optimal new scheduling model for charging SNs in the critical energy conditions. They proved that is NP-hard, and advanced an efficient scheduling algorithm to encounter the greatest SN charging tours.

3.1.2. Charging Strategy Using Several MCs

In the strategy of several MCs, visiting a set of target SNs is accomplished by sending MCs jointly from a SS or several distributed SS. In comparison to the issue of dispatching MCs, the concerns of dispatching multiple MCs focus more on the coordination between MCs. The strategic design of several MCs usually includes two discussions:

1- Minimizing the number of MCs in terms of needing a charge coverage [29, 44].

2- Optimal scheduling design, to dispatch in the minimum number of MC [45-49].

Most of the strategies of several MCs assess the point-to-point charging model. References [45-46] focus on mitigating a number of MCs in homogeneous and heterogeneous networks in order to maintain the network performance. In [45], the authors provided an optimal solution with linear complexity to the homogeneous SNs charge scenario in 1D space such as predetermined circular or linear path. In addition, they proposed a greedy algorithm for charging heterogeneous SNs. The authors in [44] had the same goal as [45], except that limitation of MCs' battery power was considered. The authors discussed various aspects of the problem, including charging SNs with MC as well as using a point-to-multi-point charging model and multiple MCs. The results obtained revealed the maximum energy rate required to charge SNs and the distance traveled. The dispatching strategy of the finite energy of several MCs in 2D space was addressed in [9],[47, 50].

Reference [9] examined the scheduling of a number of MCs on a 2D homogeneous network is NP-Hard. Two approximate algorithms as feasible solutions were proposed, whose outcome gave the optimal different answers. The authors in [47] aimed to minimize the total trip distance traveled by all MCs. The central idea was to apply the decomposition technique on a q-rooted TSP problem, finding the trees with the lowest cost and turning each tree into a closed tour.

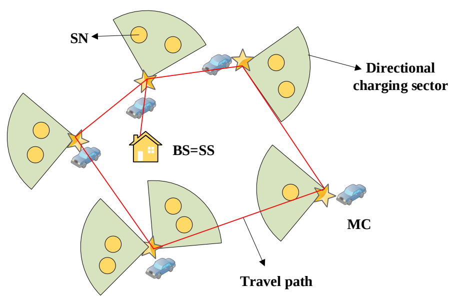


Figure 10. Charging model in [20] including marked stop points, charging direction sector, and determined path of the MC for charging SNs.

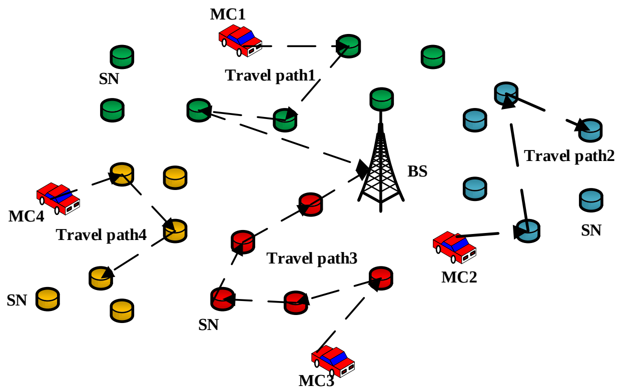


Figure 11. System architecture of WSN with four MCs [68].

In [50], they formulated at least the number of MCs, given the limited battery capacity of MCs, as the q-rooted TSP problem that was a classic TSP for planning multiple MCs akin to [47] with a provable equation of approximately five. Nevertheless, growing exponentially with a number of SNs is its disadvantage. The authors in [48] determined a time limit for the travel time of each MC in order to minimize the total cost of traveling of MCs that have considered as a traveling salesman problem multiple windows (TSPMTW) solving by a heuristic algorithm. Their goal in [46] was to seek the smallest number of MCs and the best scheduling of MCs, reducing to a distance constrained vehicle routing problem (DVRP) in a homogeneous network as the cost of network is affected by the number of MCs. The authors in [49] tried to minimize the network power consumption. The authors in [29] have studied how to diminish the total energy consumption in the network. They not only considered the least number of MCs under the limited capacity of MCs but also MCs could charge each other to boot the range of motion.

Note that in the strategies of using several of the above MCs, the route control has been centralized.

However, in [51], the strategy of several MCs is focused on the control distributed with local information. Their goal was to strike a balance between the benefits of node charging and the amount of information available. Four new protocols were proposed for efficient charging, which included two distributed protocols and two centralized protocols to establish a good cooperation between MCs and to provide the best way for moving them. The authors in [52] intended to provide a way to prevent radio interference so that MCs could be optimally timed to cover all SNs and minimize total node charging time, where each SN had minimal energy. Reference [52] modified [53]. In [53], For charge timing, a method was provided that calculated the amount of energy required by which SN and by which MC can be charged, and how much energy each MC gives them, resulting in an increase SNs; this became apparent, and the presence of radio frequency interference between moving chargers was overlooked. Article [52] revealed that there was no need for prior information such as reference [53], and solved the problem of these interactions.

In [54], a game theory model was introduced for the issue of charge timing with several moving chargers, taking into account the charge collisions and the point-to-multi-point charge model. Their goal was to enhance the energy efficiency and to minimize the number of dead SNs based on how MCs played in this model. In [55], the authors proposed the optimal speed control of MC as the main goal of designing and identifying an almost optimal solution.

3.2. Demand-Based MC Dispatching Strategies

Most of the articles presented in the previous section supposed that the MC operates based on general information in network. In practice, however, gaining general knowledge creates a lot of communication and energy consumption. In addition, in real-time systems where variety of requests is typically due to inherent network changes, periodic MC dispatching strategies lack compatibility and suffer significant performance degradation. To this end, on-demand charging strategies are designed. In on-demand strategy, the MC receive new charge requests at any time and charger only these requests in each period. Thus, the process of constructing and adjusting the travel path of MC will be based on demand. This approach is effective for networks with different energy consumption rates in nodes and increases the network efficiency and its lifetime [56]. In the following, we will review the articles related to on-demand the MC dispatching.

3.2.1. A Mobile Charger Strategy

In [56], the authors maximized charging throughput in both the periodic and on-demand charging strategies. For on-demand, they made the shortest tours of requests considering a time window. Then for periodic, they responded to the requests with the minimal processing time, which included the total travel time and the charging time for SNs. In [57], the authors designed an energy synchronized charging protocol making a series of a dynamic distributed TSP tours based on only the nodes with low remaining energy in order to reduce the travel path and the charging delay in the heterogeneous network.

The authors in [58-60] worked on the design of distributed control strategies. In [61], the first come first service (FIFS) was used that processed charge requests in terms of their time arrival. Nearest-job-next with preemption (NJNP) algorithm in [60] was suggested to overcome the constraint [61]. It replied to the service requests in terms of both the spatial and temporal features in such a way that MC would charge the next node if it had either charged the before SNs or the new request is entered. After that, it selected the nearest request to itself for recharging. Their goal was to magnify the charging throughput of MC as well as shorten the SN charging delay. The authors in [62], as in [60], were to increase the survival rate of SNs in a heterogeneous network. Their spatial dependent scheduling task (STD) algorithm made a right equilibrium between the charge requests, due to their distance to MC, and the necessity of these requests. In [62, 63], the authors formulated the charging utility maximization problem, taking into account the total travel distance in each tour and the time window of charge for each SN. Moreover, they modified reference [64] by considering the time window. The authors in [65] presented an approach that revealed a better performance than [60, 61]. This method aimed to minimize the charging latency for SNs with respect to the charging time of each SN, the travel time between SNs and the waiting time of each node to be charged. It used a gravitational search algorithm (GSA) in order to determine the optimal charging order. In [66], their goal was to optimize the maximum charge time of SNs at SPs considering finite the battery capacity of MC in order to prevent their early death. They used a combination of particle swarm and genetics algorithm to solve it. In [67], the charging schedule of MC was examined in order to maximize the charging efficiency and prevent the premature death of SNs concerning the concept of motion angle in order to create effectiveness and considering the time window, and limited the capacity of MC.

In [69], a new charging method has been given, aiming to devises an efficient charging scheme that involves all the network characteristics, such as the residual node energy, distance between the SN and MC, energy level of the neighboring SNs, and necessary charging for charging SNs. First, they used the entropy weighting method [70] in order to rank these features for a better decision-making, and then used the method in [26] to determine the travel path of MC. The simulation results showed that their method had a good performance compared to the methods in [60, 61] in the charging efficiency and survival rate of SNs. In [71], the charging schedule problem was developed in order to maximize the charging efficiency of SNs for large-scale WSNs. They claimed that although responses to the emergency requests in short-circuited (i.e. a Hamiltonian cycle) were always the best wok, it would be better to consider the closer SNs along the way in order to increase the overall efficiency. The simulation results showed its superiority in the mentioned criteria compared to the [60, 61] methods. In [70], their ultimate goal was to prolong the lifetime of the network and the survival rate of SNs. They proposed a predictive model for the energy consumption of SNs to the making charging path algorithm by determining the feasibility of the charging path in order to guarantee a long network performance and charging efficiency.

In [35], the charge scheduling model was proposed that used incorporating various network parameters such as the residual critical SN energy, used distance between the critical node and MC, and critical SN density to charge SNs. The results obtained demonstrated its good performance in reducing the charge delay and increasing the survival rate of SNs and energy efficiency. In

[20], their aim was to address the issue of mobile directional charging and maximize energy charging efficiency by identifying the minimum number of SP and their accompanying charging angles and then determine the optimal travel path for the MC (Figure 10).

3.2.2. Strategies of Several MCs

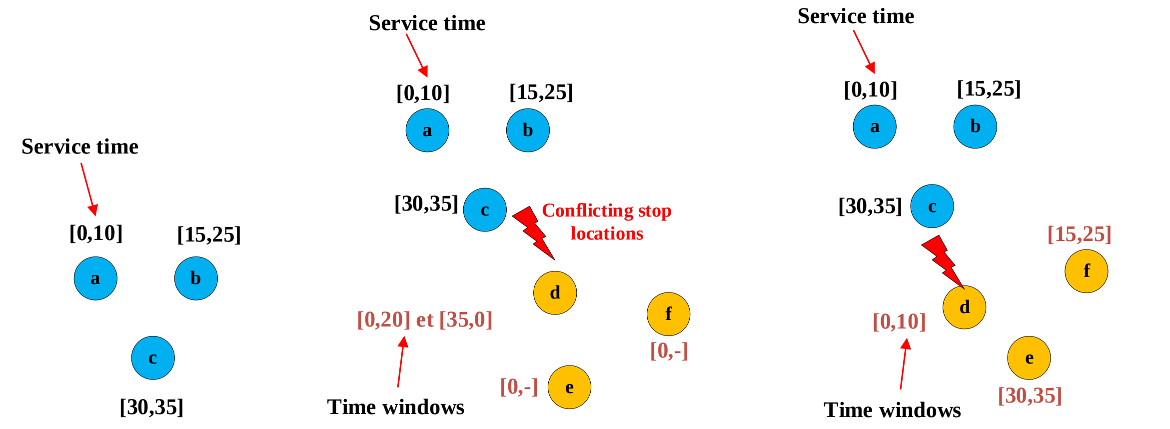
In [27], their aim was to minimize the travel path of MCs considered as TSP with a multiple time windows problem. This method clusters the requests in teams of the minimum set of stop times in each cluster in order to balance between the requests. After that, each MC selects the shortest travel path. Further, they tried to prevent the radio interference between MCs (Figure 12 shows an example of the time windows). The authors in [72] devised an optimization problem that aimed to minimize the travel cost of MCs. This problem is close to the vehicle routing problem (VRP). Their protocol for energy management of nodes selects the SN that has the least total weight, travel time, and remaining lifespan for charging. In [73] , they employed a fine-grained clustering method in order to classify SNs and then applying TSP with neighborhoods to gain the best travel path. In addition, to enhance the charging efficiency, they proposed a route-charging planning algorithm that allowed recharging with several portable batteries. The authors in [74] focus to minimize the network maintenance cost, which includes in the decrease the distance traveled by MCs over a period for large-scale networks. In [58], they provided an optimization problem with the goal of maximizing the charge coverage and scheduling of MCs; if required, it can be reduced to the geometric TSP problem [75]. Thus, they have proposed two greedy heuristic algorithms to find SPs and a right place for MCs by considering the maximum charging coverage. In [68], it has been stated the issue of cooperation between several MCs for maximum energy efficiency and the survival rate of SNs simultaneously (Figure 11). The main point of this approach was on sub-category clustering and charge planning based on the temporal and spatial features, respectively. This method works better than [50, 71].

4. Future Perspectives

In this section, we deal with the future prospects for the use of MCs for charging SNs in rechargeable WSNs, including the use of MCs in 3D as well as directional mobile and stationary chargers instead of their omni-directional. Finally, we present a comprehensive overview of the number of recent articles by classification of the MC dispatching methods in Figure 13.

4.1. 3D WSNs

Recently, the application of MCs in 3D space such as the unmanned aerial vehicle (UAVs) is employed in the data collection system and the recharging of underground or underwater SNs scenario; the SNs in 3D environments are deployed, and are interesting for the researcher. However, most of the available methods have discussed SNs located in 2D space that is not enough for these research works.



(a) The 1nd MC computing its charging tour using TSP. The resulting service is displayed.

(b) The 2nd MC identifies the conflicting nodes between its nodes and those of the 1nd MC. The 2nd MC then computes the available time windows of its nodes. We can see that node d cannot be visited when c is visited by the 1nd charger since c and d are the conflicting nodes.

(c) The 2nd MC solves the TSPMTW in order to obtain a charging tour that respects the constrains on the time windows. Then, we can see that node d is not visited during the service time of c.

Figure 12. Time windows in [27].

Table 5. Summary of the MC dispatch strategies.

References	Objective	Methods and Considerations
(2019) [69]	Reducing the charging time of SNs, increasing the charging efficiency, survival rate of SNs	Applying network characteristics and their ranks by weighted entropy method [81] and determine the travel path of MC by method [26], superior to methods [73] and [75]
(2019) [73]	Charging schedule and determining the travel path of mc, increase charging efficiency, reduce charging time	Fine-grained-TSP with neighborhoods using some workers Article modification [17] and [33] by preventing famine, high efficiency only when the charge time of SNs is significant
(2018) [65]	Minimize charging delay taking into account the charging time plus the travel time between the nodes, and the waiting time for SNs to be charged	A linear model finding the charging scheduling by GSA Just in small scale
(2018) [67]	Maximize the performance of MC, prevent premature death of SNs, time window	Closed tours created by directional angel movement and then determining travel path based on distance and the remining energy of MC, not considering the charging time
(2018) [27]	Minimum distance traveled and reduced charging delay with SN clustering, considering the time window in the dynamic network and determining the optimal path	Solving by TSP with multiple time-windows Reduce failure SNs in a dynamic network, prevent radio interference
(2014) [72]	Minimize travel costs, SN charging management based on the lowest total weight of travel time and remaining lifetime of SN	VRP, not scalable, MCs do not communicate with each other, do not transfer energy
(2018) [28]	Maximum vacation time	Non-linear model with minimum energy consumption of MC, solving by the meta-heuristic method Just in small scale
(2017) [15]	Maximum vacation time.	Non-linear model, simplex solution, just in small scale
(2017) [39]	Maximum vacation time	Maximum energy efficiency per cluster and optimal path, Providing two heuristic algorithms, just in a small scale
(2017) [29]	Charging schedule, reducing the number of MCs and energy consumption	Similar to work [21], except that MCs can charge each other, considering energy loss in energy transfer to nodes in calculating energy MC, development in 2D space by preventing energy loss, developed article [21], energy loss with exchange energy between MCs is not considered
(2017) [62]	Reducing charging time	Heuristic algorithm periodically and on-demand, considering charging time and charging time window Close to optimal answer in small scale
(2016) [18]	Increase charging efficiency	Processing routing according to the energy level of the SNs, the determining the travel path of the MC and charging time in the central point to establish the overall energy balance Just in small scale
(2016) [74]	Minimum distance traveled by MC, schedule of MC for a specified period of time	Heuristic and approximate algorithms in heterogeneous and homogeneous networks, based on the idea of the q-root TSP No considering the charging time
(2015) [64]	SN survival rate, travel path reduction	STD algorithm, considering the time window, charging time is zero.
(2015) [61]	Reduce charging delay, maximum throughput charger of MC.	NJNP algorithm according to the distance to the MC and the arrival time of SN small scale-just considering the charging value and charging delay.
(2015) [51]	Balance the profit from charging SNs and SNs information	Multi-TSP with time window, heuristic algorithm, modifying article [3] by considering time window
(2015) [30]	Maximum vacation time	Nonlinear model, solving by discretization and a reformulation-linearizing-technique, just in small scale
(2014) [56]	Maximize charging throughput.	Greedy method and MST heuristic, considering travel time, SN charging time, depends on location.
(2014) [57]	Reduce the distance traveled and delay charging	Coarse-grained method, Famine

(2014) [58]	Maximum charging coverage and scheduling of MCs if required	Reduction to the Geometric TSP algorithm, greedy heuristic methods, no cooperation between MCs
(2014) [46]	MCs Scheduling, reducing the number of MCs	Distance constrained DVRP, solving by approximate methods, analysis only in theory and on homogeneous networks
(2014) [47]	MCs scheduling, travel path minimization, homogeneous and heterogeneous networks	Designing five different scheduling scenarios for article development [33] Uncertain performance difference between the proposed method and the optimal solution
(2014) [44]	Minimum number MCs, minimum energy for charging SNs and distance traveled in 1D and 2D spaces	Approximate and heuristic algorithm, TSP, development of the method [33] by running in 2D space and transferring energy between MCs, only for ring and linear topology
(2014) [45]	Minimum number of MCs in a heterogeneous and homogeneous network	Greedy method and optimal linear algorithm, linear method, only 1D ring and line topology, no charging time Small scale
(2014) [14]	Maximum vacation time	Optimal travel path, nonlinear model, development [10] with dynamic routing instead of static
(2013) [48]	An MC scheduling, minimum number of MCs	Q-root TSP, no consideration of the time window, the tree decomposition algorithm based on the energy of SNs, the energy of MC is considered
(2013) [33]	Maximum vacation time.	Minimum charging time at each SPs, non-linear model, dynamic routing solutions, just in small scale
(2015) [34]	Maximum vacation time	Minimizing the charging delay, clustering by Lloyd k-means algorithm, no considering time travel to BS
(2012) [10]	Maximum vacation time	Optimal travel route, nonlinear model, take a piecewise linear approximation technique
(2013) [49]	An MC scheduling in 2D network	Two approximate algorithms, 2D space, homogeneous network, long distance from the optimal answer
(2010) [43]	Maximum network lifetime	Maximum network life time, considering optimal flow path, use several metaheuristic methods under different routing methods
(2010) [9]	Maximum network lifetime	Modification of [45] considering charging time
(2010) [36]	Maximum energy efficiency	Providing a routing model for choosing the best route, consideration of charging time, charging prioritization

Thus, it is necessary to design suitable 3D designs for WSNs. References [76,77] have recently been presented on the usage of MCs in 3D as UAV utilizing WTP technologies for charging SNs. Reference [78] deals with the simultaneous use of MCs and UAVs in 3D.

4.2. Mobile and Static Chargers with Directional Charging Model Against the Omni-Directional Charging Model

Rechargeable WSNs are implemented by the WTP technology, the mobile or static charger acts as an energy transmitter, and SNs or rechargeable devices operate as an energy receiver. However, the relatively low energy transmission of the WTP technologies still limits their widespread use in rechargeable WSNs. Recently, one method that has received a great deal of attention is improving efficiency using the directional WPT [79]. Unlike the omni-directional WPT, the transmitter of energy in the directional WPT collects the energy propagated in limited directions through the energy beamforming [20]. Further, the directional WTP will be more accurate in charging, and will transfer more energy, although a more precise design is required. The current studies focus on the optimizing network performance based on the omni-directional WPT technology. In summary, articles [19, 20, 22] have recently been investigated in the field of mobile and static directional chargers.

5. Conclusion

The WPT is considered as a promising technology for energy compensation in SNs on WSNs, so the network can work continuously. WPT mainly uses the magnetic resonance technology or radio frequency radiation technology. Based on the studies, it can be stated that the strategies focus on the demand-based methods and use of multiple MCs as well as point-to-multi-point charging mode in 2D space in order to reduce costs and increase energy efficiency by the least number of MCs. In addition, in, viewpoint of the recent articles is the advent of the directional MC based on the WPT technology in 2D WSNs, and the problems are related to UAVs in 3D WSNs.

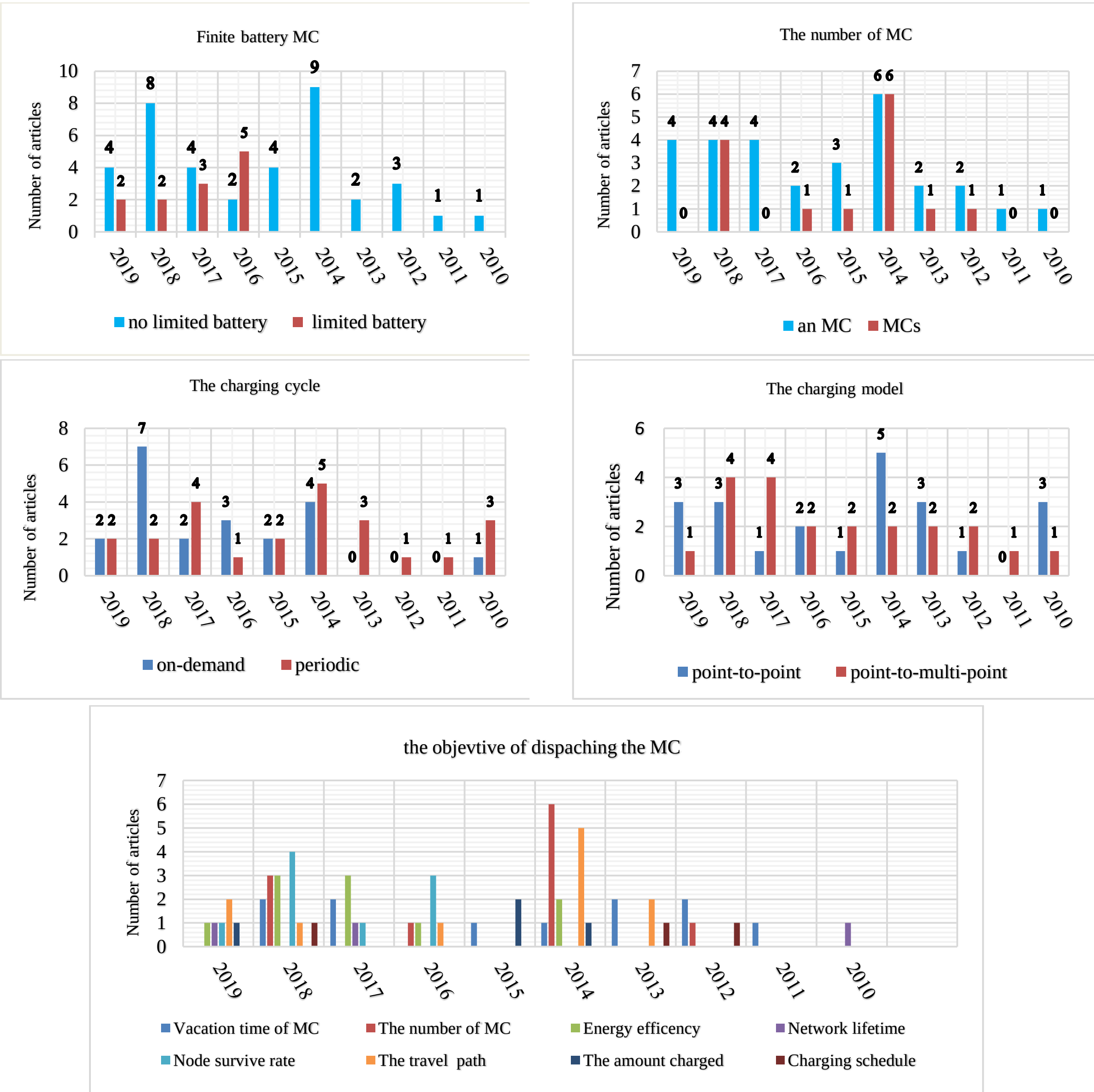


Figure 13. View the number of recent articles by classification of the MC dispatching methods.

Reference

[1] M. Rajasekaran, A. Yassine, M.S. Hossain, M. F. Alhamid, and M. Guizani, "Autonomous monitoring in healthcare environment: Reward-based energy charging mechanism for IoMT wireless sensing nodes," Future Generation Computer Systems, vol. 98, pp. 565-576, 2019.

[2] F. Sumi, L. Dutta, and F. Sarker, "Future with Wireless Power Transfer Technology," J Electr Electron Syst, vol. 7, no. 279, pp. 2332-0796.1000279, 2018.

[3] M. Gruber, A. Trüschel, and J.-O. Dalenbäck, "CO2 sensors for occupancy estimations: Potential in building automation applications," Energy and Buildings, vol. 84, pp. 548-556, 2014.

[4] Y. Shu, Y. J. Gu, and J. Chen, "Dynamic authentication with sensory information for the access control systems," IEEE Transactions on Parallel and Distributed Systems, vol. 25, no. 2, pp. 427-436, 2013.

[5] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless charging technologies: Fundamentals, standards, and network applications," IEEE Communications Surveys & Tutorials, vol. 18, no. 2, pp. 1413-1452, 2015.

[6] F. Engmann, F. A. Katsriku, J.D. Abdulai, K.S. Adu-Manu, and F. K. Banaseka, "Prolonging the lifetime of wireless sensor networks: a review of current techniques," Wireless Communications and Mobile Computing, vol. 2018, 2018.

[7] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless power transfer via strongly coupled magnetic resonances," science, vol. 317, no. 5834, pp. 83-86, 2007.

[8] L. Xie, Y. Shi, Y. T. Hou, and A. Lou, "Wireless power transfer and applications to sensor networks,"

IEEE Wireless Communications, vol. 20, no. 4, pp. 140-145, 2013.

[9] Y. Peng, Z. Li, W. Zhang, and D. Qiao, "Prolonging sensor network lifetime through wireless charging," in 31st IEEE Real-Time Systems Symposium, 2010, pp. 129-139.

[10] L. Xie, Y. Shi, Y. T. Hou, and H. D. Sherali, "Making sensor networks immortal: An energy-renewal approach with wireless power transfer," IEEE/ACM Transactions on networking, vol. 20, no. 6, pp. 1748-1761, 2012.

[11] G. Han, H. Guan, J. Wu, S. Chan, L. Shu, and W. Zhang, "An uneven cluster-based mobile charging algorithm for wireless rechargeable sensor networks," IEEE Systems Journal, 2018.

[12] J. Hu, K. Yang, G. Wen, and L. Hanzo, "Integrated data and energy communication network: A comprehensive survey," IEEE Communications Surveys & Tutorials, vol. 20, no. 4, pp. 3169-3219, 2018.

[13] S. He, J. Chen, F. Jiang, D. K. Yau, G. Xing, and Y. Sun, "Energy provisioning in wireless rechargeable sensor networks," IEEE transactions on mobile computing, Vol. 12, no. 10, pp. 1931-1942, 2012.

[14] L. Shi, J. Han, D. Han, X. Ding, and Z. Wei, "The dynamic routing algorithm for renewable wireless sensor networks with wireless power transfer," Computer Networks, vol. 74, pp. 34-52, 2014.

[15] X. Rao, P. Yang, Y. Yan, H. Zhou, and X. Wu, "Optimal recharging with practical considerations in wireless rechargeable sensor network," IEEE Access, vol. 5, pp. 4401-4409, 2017.

[16] L.Xie, Y.Shi, Y.T. Hou, W. Lou, H.D. Sherali, and S. F. Midkiff, "On renewable sensor networks with wireless energy transfer: The multi-node case," in 9th annual IEEE communications society conference on sensor, mesh and ad hoc communications and networks (SECON), 2012, pp. 10-18.

[17] Y. Shi, L. Xie, Y. T. Hou, and H. D. Sherali, "On renewable sensor networks with wireless energy transfer," in Proceedings IEEE INFOCOM, 2011, pp. 1350-1358.

[18] G. Han, A. Qian, J. Jiang, N. Sun, and L. Liu, "A grid-based joint routing and charging algorithm for industrial wireless rechargeable sensor networks," Computer Networks, vol. 101, pp. 19-28, 2016.

[19] C. Lin, Y. Zhou, F. Ma, J. Deng, L. Wang, and G. Wu, "Minimizing Charging Delay for Directional Charging in Wireless Rechargeable Sensor Networks," in IEEE INFOCOM Conference on Computer Communications, 2019, pp. 1819-1827.

[20] X. Xu, L. Chen, and Z. Cheng, "Optimizing Charging Efficiency and Maintaining Sensor Network Perpetually in Mobile Directional Charging," Sensors, vol. 19, no. 12, p. 2657, 2019.

[21] J.-H. Liao, C.M. Hong, and J.R. Jiang, "An Adaptive Algorithm for Charger Deployment Optimization in Wireless Rechargeable Sensor Networks," in ICS, pp. 2080-2089, 2014.

[22] X. Wang, H. Dai, H. Huang, Y. Liu, G. Chen, and W. Dou, "Robust scheduling for wireless charger networks," in IEEE INFOCOM 2019-IEEE Conference on Computer Communications, pp. 2323-2331, 2019.

[23] H. Dai, H. Ma, A. X. Liu, and G. Chen, "Radiation constrained scheduling of wireless charging tasks," IEEE/ACM Transactions on Networking, vol. 26, no. 1, pp. 314-327, 2018.

[24] N. Yu, H. Dai, A. X. Liu, and B. Tian, "Placement of connected wireless chargers," in IEEE INFOCOM 2018-IEEE Conference on Computer Communications, pp. 387-395, 2018.

[25] T. Wu, P. Yang, H. Dai, W. Xu, and M. Xu, "Charging Oriented Sensor Placement and Flexible Scheduling in Rechargeable WSNs," in IEEE INFOCOM 2019-IEEE Conference on Computer Communications, pp. 73-81, 2019.

[26] C.-L. Hwang and K. Yoon, "Methods for multiple attribute decision making," in Multiple attribute decision making: Springer, pp. 58-191, 1981.

[27] T. Rault, "Avoiding radiation of on-demand multi-node energy charging with multiple MCs," Computer Communications, vol. 134, pp. 42-51, 2019.

[28] Z. Fan, Z. Jie, and Q. Yujie, "A Multi-Node Rechargeable Algorithm via Wireless Charging Vehicle with Optimal Traveling Path in Wireless Rechargeable Sensor Networks," in 2018 Tenth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 531-536, 2018.

[29] T. Liu, B. Wu, H. Wu, and J. Peng, "Low-cost collaborative mobile charging for large-scale wireless sensor networks," IEEE Transactions on Mobile Computing, vol. 16, no. 8, pp. 2213-2227, 2016.

[30] L. Xie, Y. Shi, Y.T. Hou, W. Lou, H.D. Sherali, and S.F. Midkiff, "Multi-node wireless energy charging in sensor networks," IEEE/ACM Transactions on Networking, vol. 23, no. 2, pp. 437-450, 2014.

[31] L. Xie, Y. Shi, Y. T. Hou, W. Lou, H. D. Sherali, and S. F. Midkiff, "Bundling mobile base station and wireless energy transfer: Modeling and optimization," in 2013 Proceedings IEEE INFOCOM, pp. 1636-1644, 2013.

[32] H.D. Sherali, W.P. Adams, and P.J. Driscoll, "Exploiting special structures in constructing a hierarchy of relaxations for 0-1 mixed integer problems," Operations Research, vol. 46, no. 3, pp. 396-405, 1998.

[33] Z. Qin, C. Zhou, Y. Yu, L. Wang, L. Sun, and Y. Zhang, "A practical solution to wireless energy transfer in WSNs," in 2013 International Conference on ICT Convergence (ICTC), pp. 660-665, 2013.

[34] L. Fu, P. Cheng, Y. Gu, J. Chen, and T. He, "Optimal charging in wireless rechargeable sensor networks," IEEE Transactions on Vehicular Technology, vol. 65, no. 1, pp. 278-291, 2015.

[35] A. Tomar, L. Muduli, and P. K. Jana, "An efficient scheduling scheme for on-demand mobile charging in wireless rechargeable sensor networks," Pervasive and Mobile Computing, Vol. 59, p. 101074, 2019.

[36] B. Tong, Z. Li, G. Wang, and W. Zhang, "How wireless power charging technology affects sensor network deployment and routing," in 2010 IEEE 30th International Conference on Distributed Computing Systems, 2010, pp. 438-447.

[37] E. Welzl, "Smallest enclosing disks (balls and ellipsoids)," in New results and new trends in computer science: Springer. pp. 359-370, 1991,.

[38] S. Martello, D. Pisinger, and P. Toth, "New trends in exact algorithms for the 0–1 knapsack problem," European Journal of Operational Research, vol. 123, no. 2, pp. 325-332, 2000.

[39] W. Na, J. Park, C. Lee, K. Park, J. Kim, and S. Cho, "Energy-efficient mobile charging for wireless power transfer in Internet of Things networks," IEEE Internet of Things Journal, vol. 5, no. 1, pp. 79-92, 2017.

[40] Z. Li, Y. Peng, W. Zhang, and D. Qiao, "Study of joint routing and wireless charging strategies in sensor networks," in International Conference on Wireless Algorithms, Systems, and Applications, Springer, pp. 125-135, 2010.

[41] L. Tang, Z. Chen, J. Cai, H. Guo, R. Wu, and J. Guo, "Adaptive Energy Balanced Routing Strategy for Wireless Rechargeable Sensor Networks," Applied Sciences, vol. 9, no. 10, p. 2133, 2019.

[42] C. Lin, Y. Zhou, H. Dai, J. Deng, and G. Wu, "MPF: Prolonging network lifetime of wireless rechargeable sensor networks by mixing partial charge and full charge," in 2018 15th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), pp. 1-9, 2018.

[43] W. Xu, W. Liang, X. Jia, and Z. Xu, "Maximizing sensor lifetime in a rechargeable sensor network via partial energy charging on sensors," in 2016 13th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), pp. 1-9, 2016.

[44] J. Wu, "Collaborative mobile charging and coverage," Journal of computer science and technology, vol. 29, no. 4, pp. 550-561, 2014.

[45] R. Beigel, J. Wu, and H. Zheng, "On optimal scheduling of multiple MCs in wireless sensor networks," in Proceedings of the first international workshop on Mobile sensing, computing and communication, pp. 1-6, 2014.

[46] H. Dai, X. Wu, G. Chen, L. Xu, and S. Lin, "Minimizing the number of MCs for large-scale wireless rechargeable sensor networks," Computer Communications, vol. 46, pp. 54-65, 2014.

[47] W. Xu, W. Liang, X. Lin, G. Mao, and X. Ren, "Towards perpetual sensor networks via deploying multiple mobile wireless chargers," in 2014 IEEE 43rd International Conference on Parallel Processing, pp. 80-89, 2014.

[48] C. Wang, J. Li, F. Ye, and Y. Yang, "Multi-vehicle coordination for wireless energy replenishment in sensor networks," in 2013 IEEE 27th International Symposium on Parallel and Distributed Processing, pp. 1101-1111, 2013.

[49] S. Zhang, J. Wu, and S. Lu, "Collaborative mobile charging for sensor networks," in 2012 IEEE 9th international conference on mobile ad-hoc and sensor systems (MASS 2012), pp. 84-92, 2012.

[50] W. Liang, W. Xu, X. Ren, X. Jia, and X. Lin, "Maintaining sensor networks perpetually via wireless recharging mobile vehicles," in 39th Annual IEEE Conference on Local Computer Networks, pp. 270-278, 2014.

[51] A. Madhja, S. Nikoletseas, and T. P. Raptis, "Distributed wireless power transfer in sensor networks with multiple MCs," Computer Networks, vol. 80, pp. 89-108, 2015.

[52] Z. Ma, J. Wu, S. Zhang, and S. Lu, "Prolonging WSN lifetime with an actual charging model," in 2018 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1-6, 2018.

[53] P. Guo, X. Liu, S. Tang, and J. Cao, "Concurrently wireless charging sensor networks with efficient scheduling," IEEE Transactions on Mobile Computing, Vol. 16, No. 9, pp. 2450-2463, 2016.

[54] C. Lin et al., "GTCCS: A Game Theoretical Collaborative Charging Scheduling for On-Demand Charging Architecture," IEEE Transactions on Vehicular Technology, vol. 67, no. 12, pp. 12124-12136, 2018.

[55] Y. Shu et al., "Near-optimal velocity control for mobile charging in wireless rechargeable sensor networks," IEEE Transactions on Mobile Computing, vol. 15, no. 7, pp. 1699-1713, 2015.

[56] X. Ren, W. Liang, and W. Xu, "Maximizing charging throughput in rechargeable sensor networks," in 2014 23rd International Conference on Computer Communication and Networks (ICCCN), pp. 1-8, 2014.

[57] L. He et al., "Esync: An energy synchronized charging protocol for rechargeable wireless sensor networks," in Proceedings of the 15th ACM international symposium on Mobile ad hoc networking and computing, pp. 247-256, 2014.

[58] L. Jiang, X. Wu, G. Chen, and Y. Li, "Effective on-demand MC scheduling for maximizing coverage in wireless rechargeable sensor networks," Mobile Networks and Applications, vol. 19, no. 4, pp. 543-551, 2014.

[59] C. M. Angelopoulos, S. Nikoletseas, and T. P. Raptis, "Wireless energy transfer in sensor networks with adaptive, limited knowledge protocols," Computer Networks, vol. 70, pp. 113-141, 2014.

[60] L. He, L. Kong, Y. Gu, J. Pan, and T. Zhu, "Evaluating the on-demand mobile charging in wireless sensor networks," IEEE Transactions on Mobile Computing, vol. 14, no. 9, pp. 1861-1875, 2014.

[61] L. He, Y. Zhuang, J. Pan, and J. Xu, "Evaluating on-demand data collection with mobile elements in wireless sensor networks," in 2010 IEEE 72nd Vehicular Technology Conference-Fall, pp. 1-5, 2010.

[62] X. Ye and W. Liang, "Charging utility maximization in wireless rechargeable sensor networks," Wireless Networks, vol. 23, no. 7, pp. 2069-2081, 2017.

[63] Y. Ma, W. Liang, and W. Xu, "Charging utility maximization in wireless rechargeable sensor networks by charging multiple sensors simultaneously," IEEE/ACM Transactions on Networking, vol. 26, no. 4, pp. 1591-1604, 2018.

[64] H. Huang, S. Lin, L. Chen, J. Gao, A. Mamat, and J. Wu, "Dynamic MC scheduling in heterogeneous wireless sensor networks," in 2015 IEEE 12th International Conference on Mobile Ad Hoc and Sensor Systems, pp. 379-387, 2015.

[65] A. Kaswan, A. Tomar, and P. K. Jana, "An efficient scheduling scheme for MC in on-demand wireless rechargeable sensor networks," Journal of Network and Computer Applications, vol. 114, pp. 123-134, 2018.

[66] Z. Lyu et al., "Periodic charging planning for a mobile WCE in wireless rechargeable sensor networks based on hybrid PSO and GA algorithm," Applied Soft Computing, vol. 75, pp. 388-403, 2019.

[67] Z. Chen, H. Shen, and X. Zhao, "Delay-Tolerant On-Demand Mobile Charging Scheduling Scheme for Wireless Rechargeable Sensor Networks," in 2018 9th International Symposium on Parallel Architectures, Algorithms and Programming (PAAP), pp. 29-35, 2018.

[68] C. Lin, Z. Wang, J. Deng, L. Wang, J. Ren, and G. Wu, "mTS: Temporal-and spatial-collaborative charging for wireless rechargeable sensor networks with multiple vehicles," in IEEE INFOCOM 2018-IEEE Conference on Computer Communications, pp. 99-107, 2018.

[69] A. Tomar and P. K. Jana, "Mobile Charging of Wireless Sensor Networks for Internet of Things: A Multi-Attribute Decision Making Approach," in International Conference on Distributed Computing and Internet Technology,
Z Springer, pp. 309-324, 2019.

[70] P. Zhong, Y. Zhang, S. Ma, X. Kui, and J. Gao, "RCSS: A real-time on-demand charging scheduling scheme for wireless rechargeable sensor networks," Sensors, vol. 18, no. 5, p. 1601, 2018.

[71] C. Lin, D. Han, J. Deng, and G. Wu, "P $^ 2$ S: A Primary and Passer-By Scheduling Algorithm for On-Demand Charging Architecture in Wireless Rechargeable Sensor Networks," IEEE Transactions on Vehicular Technology, vol. 66, no. 9, pp. 8047-8058, 2017.

[72] C. Wang, J. Li, F. Ye, and Y. Yang, "NETWRAP: An NDN based real-timewireless recharging framework for wireless sensor networks," IEEE Transactions on Mobile Computing, vol. 13, no. 6, pp. 1283-1297, 2014.

[73] M. Hu, Z. Chen, K. Peng, X. Ma, P. Zhou, and J. Liu, "Periodic charging for wireless sensor networks with multiple portable chargers," IEEE Access, Vol. 7, pp. 2612-2623, 2018.

[74] W. Xu, W. Liang, X. Lin, and G. Mao, "Efficient scheduling of multiple MCs for wireless sensor networks," IEEE Transactions on Vehicular Technology, vol. 65, no. 9, pp. 7670-7683, 2015.

[75] C. M. Angelopoulos, S. Nikoletseas, T. P. Raptis, C. Raptopoulos, and F. Vasilakis, "Efficient energy management in wireless rechargeable sensor networks," in Proceedings of the 15th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems, pp. 309-316, 2012.

[76] X. Ding et al., "Optimal charger placement for wireless power transfer," Computer Networks, vol. 170, p. 107123, 2020.

[77] C. Caillouet, T. Razafindralambo, and D. Zorbas, "Recharging wireless sensor networks using drones and wireless power transfer," in 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) pp. 1136-1137, 2018.

[78] C. Lin, C. Guo, J. Deng, and G. Wu, "3DCS: A 3-D Dynamic Collaborative Scheduling Scheme for Wireless Rechargeable Sensor Networks with Heterogeneous Chargers," in 2018 IEEE 38th International Conference on Distributed Computing Systems (ICDCS), pp. 311-320, 2018.

[79] Z. Ding et al., "Application of smart antenna technologies in simultaneous wireless information and power transfer," IEEE Communications Magazine, vol. 53, no. 4, pp. 86-93, 2015.

شارژر متحرک مبتنی بر فن آوری‌های انتقال انرژی بی سیم : بررسی مفاهیم، تکنولوژی‌ها، چالش‌ها و کاربردها در شبکه‌های حسگر بی سیم قابل شارژ مجدد

نیوشا نوروزیان و فرزاد تشتریان*

گروه مهندسی کامپیوتر، واحد مشهد، دانشگاه آزاد اسلامی، مشهد، ایران.

ارسال ۳۱ /۲۰۲۰/۰۷؛ بازنگری ۲۰۲۱/۰۴/۲۱؛ پذیرش ۲۰۲۱/۰۵/۲۱

چکیده:

محدودیت انرژی باتری گره‌های حسگر، چالش اصلی شبکه‌های حسگر بی‌سیم می‌باشد که بقای شبکه را تحت تاثیر خود قرار می‌دهد. از این رو بهینه کردن مصرف انرژی گره‌های حسگر و همچنین افزایش طول عمر گره‌ها و به تبع آن، افزایش طول عمر شبکه‌های حسگر بی سیم، از موضوعات بسیار مهم و حیاتی در این نوع شبکه‌ها می‌باشد. شارژرهای متحرک و تکنولوژی‌های انتقال انرژی بی‌سیم، مدتهاست که نقش مهمی در شبکه‌های حسگر بی‌سیم ایفا می‌کنند و تلاش‌های تحقیقاتی زیادی در مورد چگونگی استفاده از شارژر متحرک برای افزایش عملکرد شبکه‌های حسگر بی‌سیم در دهه-های اخیر صورت گرفته است. در این مقاله، ابتدا بررسی اجمالی بر روی کاربرد شارژر متحرک و تکنولوژی‌های انتقال انرژی بی‌سیم در شبکه‌های حسگر بی‌سیم، انجام داده‌ایم. سپس مسائل پیشروی ارسال شارژر متحرک در نقش تحویل دهنده انرژی در شبکه‌های حسگر بی‌سیم مورد توجه قرار گرفته و روش‌های موجود در این زمینه طبقه‌بندی شده و اهداف و محددیت‌های ارسال شارژر متحرک نیز بررسی شده است. سپس مروری بر مقالات موجود انجام شده و برای درک بهتر مطالب، جداول و اشکالی ارائه شده است که روش‌های موجود را به طور خلاصه طبقه‌بندی کرده و آنها را از ابعاد مختلف همچون مزایا و معایب و ویژگی‌ها مورد بررسی قرار داده ایم. در نهایت مسائل و چشم اندازهای آتی در زمینه شارژر متحرک بحث شده است.

کلمات کلیدی: تکنولوژی شارژ بی‌سیم، شارژر متحرک، شبکه حسگر بی‌سیم قابل شارژر مجدد، انتقال انرژی بی سیم.