On-Demand Recharging Strategies for Sensors in WRSNs: A Review

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Abstract
An innovative technology called a wireless rechargeable sensor network (WRSN) has emerged with the goal of extending the network lifetime of traditional wireless sensor networks (WSNs). The longevity of data gathering, increased charging effectiveness, increased network lifetime, and greater network utilization are all made possible by WRSNs. Wireless rechargeable sensor networks (WRSNs) have been strengthened by the most recent advancement in wireless power transfer (WPT) technology by enabling reliable and continuous energy supply to sensors using mobile chargers (MCs). Over the past ten years, a huge number of studies have been conducted in this area. In this research, we have provided a thorough description of emerging wireless rechargeable networks where sensor nodes utilize wireless power transfer strategies to extend the network's lifespan. Additionally, this document offers a summary and brevity of other WRSN-related papers from the previous nine years. Following a quick introduction, we established a few key concepts and categorized the charging schemes according to the aims, system architecture, charging plans, charging categories, and restrictions. We concluded by discussing the survey's future trajectory and making some closing remarks after summarizing the entire survey.

Keywords: wireless rechargeable sensor networks; wireless power transfer; charging scheduling schemes, mobile charging problems. mobile charging techniques, on-demand charging.

1. Introduction:

Over the past few years, wireless sensor networks (WSNs) have substantially developed and become crucial technologies. WSNs are important in a variety of applications, including industrial applications, environmental monitoring, agriculture and animal tracking, health monitoring and medical diagnostics, security and surveillance, transportation, and logistics [55]. Fig.1.

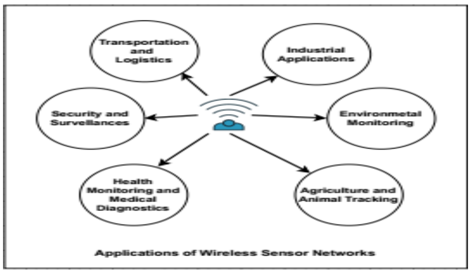

Fig.1 Applications of Wireless Sensors Networks

Despite the widespread use of WSNs, there is still room for improvement in terms of successful creation and deployment. In the past, data transmission on the network was slowed down by a WSN that has a static sink and is used for data collection. The hotspot issue, where sensor nodes next to sinks tend to drain their batteries more quickly than other sensor nodes, was the main issue [56-58]. Researchers suggested utilizing a mobile sink to help lessen the hotspot problem by moving traffic concentration with sink mobility, hence improving network life, to alleviate this load balancing difficulty created by the static sink [59]. However, the sink's mobility brought up several problems, including inconsistent packet delivery and frequent location updates. A methodology called empirical data propagation for mobile sink networks to address these problems, and they also present a mobile sink dispersed data dissemination protocol that addresses the hotspot issue. Additionally, before transmitting data that has caused a new outflow to the network from a mobile sink, the nodes must ascertain the sink's present location. An inventive hierarchical tree structure that can avoid the lengthy processing time and overhead cost of delivering fresh sink positions was proposed in order to reduce overhead. Moreover, WRSNs are gaining attention over

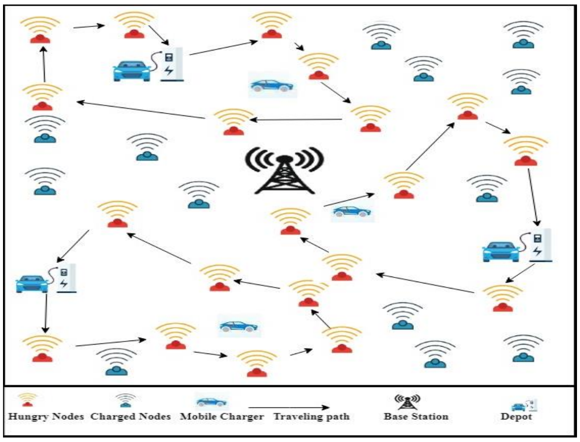

Fig.2. Wireless Rechargeable Sensor Network Architecture

Time as a way to further enhance the network. Their contribution to lengthening network lifetimes accounts for their appeal. In particular, WRSNs have made significant contributions to the most important aspects of the network's effectiveness, such as its lifetime and eternal functioning. The most important elements, such as the network's longevity and everlasting operation, have been greatly impacted by WRSNs. Recent The development of wireless power transfer (WPT), a targeted charging method in WRSNs, has proven to be the best way to support the ongoing performance of a network. In WRSNs, the sensor nodes can be wirelessly charged by wireless charging vehicles (WCVs) or mobile chargers (MCs). Wireless power transfer (WPT) is the process where electrical energy is transmitted from a power source to an electrical load across an air gap using induction coils. By using fewer energy services, energy conservation aims to cut down on unnecessary energy use. This can be accomplished by modifying one's behavior to use less energy and use it more efficiently.

Although energy conservation considerably lengthens the lifetime of the network, it does not guarantee continuous network operation [60-61]. Also security remains as major concern in WSNs [62-65]. This is due to the sensors' low battery life eventually running out, rendering them useless. Additionally, the most important component of WRSN is charging scheduling, which organizes the tasks of mobile chargers. Depending on the time that decisions are made to charge hungry nodes, charging scheduling operates both offline and online. When the sensor node is close to reaching the charging threshold under an online scheduling scheme, it makes a charging request, and the mobile charger arrives right away to top it off (Fig. 2). In contrast, the mobile charger completes the specified charging tasks according to established timetables when charging offline. If MCV runs out of battery while on the recharge tour, the charging schedule might not be completed. One of the crucial things to note is that the majority of recent research has given less attention to energy consumption as a result of the MCV movement. We mainly addressed the brief disadvantages and advantages of each strategy and categorized them into various groups. To make it easier to comprehend and compare the benefits and drawbacks of each strategy, we extracted key information from each publication and presented it in tables. The rest of this paper is structured as follows: An overview of the relevant survey articles is provided in Section II. Sections III presented a detailed discussion of wirelessly powered sensor networks and wireless power transfer systems, and Section IV provided an overview of fundamental system design issues in mobile charging problems and Section V presented a thorough examination of the existing on-demand mobile charging approaches. Future research is provided in Section VI. This survey paper concludes with Section VII. Table I provide a list of commonly used abbreviations in the survey. Tables II and III compare on-demand charging schemes using single mobile charger-based techniques and multiple mobile charger-based schemes, respectively.

II. RELATED WORK

We start by introducing works on energy harvesting and its uses in the paradigms indicated above. With an emphasis on receiver-side designs, the numerous writers offered a thorough survey of radio frequency energy harvesting networks (RF-EHNs). The same authors have also examined other WPT technologies from the standpoint of transmitter-side designs, including magnetic inductive coupling, magnetic resonance coupling, and radio frequency (RF) radiation. They also provided a summary of notable publications on charger deployment and scheduling. Recent years have seen a substantial increase in the development of WRSNs due to WPT technology. According to the behaviors and functionalities of chargers, past works may generally be divided into two categories: stationary charging and mobile charging. Wireless chargers are deployed at various locations to recharge sensor nodes during stationary charging. The majority of studies on stationary charging focus on the positioning of chargers.

Table 1: Notations and Abbreviation

S. N	Notations	Abbreviation	S. N	Notations	Abbreviations
1	WPT	Wireless Power Transfer	15	MCUCS	Maximum Coverage Utility Charging Scheduling
2	SMT	Single Mobile Charging Techniques	16	CC	Centralized Coordination
3	MMT	Multiple Mobile Charging Techniques	17	DC	Distributed Coordination
4	WPSNs	Wirelessly powered sensor networks	18	DCLK	Distributed Coordination Local Knowledge
5	MCP	Mobile Charging Problems	19	CCRK	Centralized coordination reactive knowledge
6	PoI	Points of Interest	20	CCGK	Centralized Coordination Global Knowledge
7	MNoP	Minimum Number of Mobile Charger	21	CCDDP	Called Charger Dispatch Decision Problem
8	UAV	Unmanned Aerial Vehicle	22	MCV	Mobile charging vehicle
9	AC	Alternative Current	23	MC	Mobile charger
10	EM	Electromagnetic	24	WCV	Wireless charging vehicle
11	IPT	inductive power transfer	25	BS	Base station
12	CPT	Capacitive power transfer	26	WSN	Wireless sensor network
13	CS	Collaborative Strategies	27	WRSN	Wireless rechargeable sensor network
14	MCTs	Mobile Charging Techniques	28	RF-EHNs	Radio Frequency Energy Harvesting Networks

In order to maximize charging quality while adhering to a tight power budget, H. Dai et al. [3] found a solution to the charger positioning and power allocation challenge. A cooperative deployment strategy with a minimal number of sink and charger stations was proposed by X. Lu et al. [2]. In contrast to the aforementioned factors, we focused on charger placement to maximize charging usefulness by figuring out charging sites as well as charger orientations. In this article, the potential security issue brought on by RF exposure was examined. Overall, the problem of increasing costs and constrained coverage affects stationary charging methods negatively. Mobile charging, in contrast to stationary charging, focuses on preparing a small number of chargers to recharge energy for sensor nodes while moving around the network, turning the charging problem into a travel planning challenge. In the publications [6], various wireless charging technologies and renewable energy sources were categorized and compared, along with their foundations and applications in WRSNs. The studies [8], and [9] in particular provided different energy management and harvesting strategies. Sudevalayam et al. [4] pursued various academic fields. energy harvesting sensors, energy storage techniques, and energy source features. Brief remarks on various energy storage techniques were offered by Akhtar et.al. [12]. Based on the application at hand, Bhatti et al. [11] presented a discussion for choosing the best REH/WPT technology. Short summaries of periodic mobile charging scheduling, together with some design information, were supplied in the surveys [13].

III. Wireless Power Transfer (WPT):

Without the use of wires that transmit current, wireless power transfer (WPT) enables the delivery of power across an air gap. Without physical connectors or cables, WPT may supply power from an AC source to suitable batteries or devices. WPT can refuel cellular phones, tablets, drones, automobiles, and transportation-related equipment. Even wireless transmission of power generated by solar panel arrays in space may be viable. WPT, which has replaced wired charges, is an innovative advancement in consumer electronics. With WPT, energy is transferred between transmitters and receivers over an air gap using fields produced by charged particles. The energy is transformed into a form that can pass through the air, bridging the air gap. The energy is transformed into an oscillating field, sent through the air, and then transformed by a receiver into a usable electrical current. Energy can be effectively transported through electromagnetic (EM) waves like radio waves, microwaves, or even light, depending on the strength and distance. One of the innovative methods for wirelessly transferring electrical energy from a transmitter to a receiver is called wireless power transfer (WPT). Due to its many advantages over wired connections, WPT is a desirable choice for many industrial applications. The benefits include ease of charging, lack of fuss while carrying wires, and smooth power transmission even in harsh climatic conditions. Nicola Tesla first proposed the concept of wireless power transmission (WPT) at the turn of the 20th century. He created a wireless lighting bulb for receiving electrical charges wirelessly [16]. Tesla's device consisted of two closely spaced metal plates. The bulb turned on when high-frequency alternative current (AC) potentials were transferred between these two plates. However, some of the problems surfaced when WPT technology was used. The fact that the minimum power density and low transfer efficiencies have an impact as distances rise is one of the key problems. The performance of WPT technology consequently degrades drastically. When the distance goes above 2 m while wirelessly charging, the WPT technology is thereby enhanced and uses "strongly linked" coils. Inductive power transfer (IPT) and capacitive power transfer (CPT) are the two key WPT technologies. IPT can be utilized for huge air gaps of about several meters and has a much higher output power than CPT, but CPT is only relevant to low-power applications with extremely small air gaps between 10-4 and 10-3 m. The main types of WPT systems include electromagnetic induction, microwave, evanescent wave, magnetic resonance, and electrical resonance. A brand-new electromagnetic induction technique without transformer coupling has been put forth by scientists. It was discovered that using this technique enables the transfer of electric power over a distance that includes a magnetic field resonance approach. The main types of WPT systems include electromagnetic induction, microwave, evanescent wave, magnetic resonance, and electrical resonance. A brand-new electromagnetic induction technique without transformer coupling has been put forth by scientists. It was discovered that using this technology makes it possible to transmit electric power over a distance using a magnetic field resonance technique. WPT systems can be electromagnetic induction, microwave, evanescent wave, magnetic resonance, or electrical resonance systems.

WPT Techniques and Empirical Models

The WPT approaches can be divided into two main categories: radiative [2] and non-radiative. Far-field, electric-field-based radiative technologies transmit energy. RF waves, or radio frequency waves Typically, the transmitter uses a magnetron to convert the alternating current first into direct current and then the direct current into RF waves. The receiver then receives the RF wave, which is rectified into direct current by the receiver via an aerial. The near-field, non-radiative techniques transmit energy based on the coupling of magnetic fields between two coils [2]. As an alternating current is given to the transmitter coil, a changing magnetic field is created across the receiver coil, which in turn induces electrical energy between the two coils. This process is known as magnetic inductive coupling. Inductive coupling requires the transmitter and receiver coils to be precisely aligned and spaced at a distance of a few centimeters. In contrast, these coils are firmly coupled using compensating capacitors in magnetic resonant coupling at the same resonance frequency. As a result, resonant coupling allows for more wireless energy transmission over longer distances than inductive coupling while also having a higher energy transfer efficiency. Moreover, it permits simultaneous wireless power transmission from one transmitter to numerous receivers.

Recent mid-range wireless charging solutions based on inductive coupling and resonant coupling, respectively, include MagMIMO and Witricity. In, there is a thorough description of the hardware designs, architectures, and implementations of these techniques. We currently specify different empirical models that are utilized in WRSNs to mimic wireless charging. Let l represent the distance between a sensor and an MC, and let c represent the charging range (radius) of an MC. Similarly, let Erx and Etx stand for a sensor's energy reception rate and an MC's energy transmission rate, respectively.

1) RF-Based un directional WPT Model: According to the un directional WPT model is based on the Friis's free space equation.

$$E_{rx} = \frac{A_{tx}A_{rx}\eta}{P_l}\left(\frac{\lambda}{4\pi(d+\beta)}\right)^2 E_{tx} \qquad (1)$$

In this formula, Atx denotes the MC antenna gain, Arx the sensor antenna gain, η

denotes the rectifier efficiency, P_l the polarization loss, denotes the RF signal wavelength, and denotes a variable that can be changed in the Friis free space equation. It should be noted that the sensor's power reception rate would be too low to be corrected when the MC was too far from the sensor. As a result, the aforementioned model is reduced to:

$$E_{rx} = \{\frac{\square}{(l+\beta)^2}, \quad if\ l \le c\ 0, \quad if\ l > c$$

$$where\ \alpha = \frac{A_{tx}A_{rx}\eta}{P_l}\left(\frac{\lambda}{4\pi}\right)^2 E_{tx}.$$

2) RF Based Directional WPT Model: The Friis's free space equation-based directional WPT will be used if represents the charging orientation angle between a sensor and an MC.Model can be written as:

$$E_{rx}(l,\theta) = \frac{\eta G_{rx}G_{tx}^{max}(coscos\ \square + e)}{P_l\lambda^2(l+\beta)^2}E_{tx} \tag{2}$$

When e and are constants, $G_{rx}\ and\ G_{tx}^{max}$, respectively, are the effective power receiving area and the maximum power transferring area of the sensor and MC respectively e and β are constants.

$$E_{rx}(l,\theta) = \{\square\frac{\square\square\square\ cos\ \square\ + e}{(l+\beta)^2}, \quad if\ l \le c\ and\ -\frac{\pi}{2} \le \theta \le \frac{\pi}{2}\ 0, \quad if\ l > c$$

$$where\ \gamma = \frac{\eta G_{rx}G_{tx}^{max}}{P_l\lambda^2}E_{tx}.$$

3) Resonant Coupling Based Single Hope WPT Model: The single-hop WPT model with resonant coupling is presented in:

$$E_{rx} = \mu(l)E_{tx} \tag{3}$$

Where $\mu(l)$ is the efficiency of WPT between a sensor and an MC at distance l, which is express as:

$$\mu(l) = \{-0.0959l^2 - 0.0378l + 1, \quad if\ l \le c\ 0, \quad if\ l > c$$

4) Resonant Coupling-Based Multi-Hop WPT Model: In this model, the sensors serve as repeaters, transmitting excess energy to the sensors next to them. As stated in [42], the resonant coupling-based multihop WPT model is:

$$E_{rx} = \mu_k(l)E_{tx} \tag{4}$$

Where $\mu_k(l)\ is\ the$ charging efficiency of the k^{th} repeater sensor, which is given by:

$$\mu_k(l) = \{\frac{j_k^2}{\sum_{j=1}^{k}\ \ I_j^2}, \quad if\ l \le c\ 0, \quad if\ l > c$$

Where j_k is the current on k^{th} repeater sensor.

IV. Fundamental system design issues in MCP (mobile charging problems):

The fundamental system design difficulties that the researchers addressed in tackling the MCP are presented in this section. These issues specifically entail using sensor deployment redundancy for long-term network operation to provide continuous sensor coverage of points of interest (PoI) and communication between sensors.

Similar to this, figuring out the bare minimum of MCs (MNoM) required to maintain network operation perpetually and their methods of cooperating are essential. The completion of the sensor's flow routing and the scheduling of MC's journey path, charging period, and velocity are the other urgent issues. We now go into great depth about each of these concerns.

Coverage and Connectivity: The PoI in WRSNs must be fully covered by sensors, just as it is in traditional WSNs, and communication between the sensors must be guaranteed. the least number of sensors necessary to guarantee PoI coverage by placing them on the vertices of equilateral triangles. However, deploying sensors to ensure coverage and connectivity is insufficient to provide ongoing monitoring of PoI because sensors eventually run out of battery life and stop functioning. In these situations, it is crucial to plan the sensors' charging schedule while taking connectivity and coverage concerns into account. Another crucial concern is charging as many panic sensors as possible before they run out of juice. This is in addition to making sure the POI is covered and connected.

Sleep Scheduling: As a result of redundancy in the deployment pattern, the sensors can duty cycle and switch between the active and sleeping states. The sensors use very little energy while in sleep mode and turn off their communication and sensing hardware. As a result, the network demands those at all times; one or more sensors from the overlapped areas remain in inactive mode, while other sensors continue to operate in sleep mode to save energy. When the batteries in the first batch of sensors run out. Before taking over detecting duties from another batch, the sensors of that batch must first be recharged. As a result, the space-time scheduling of the MCs is typically created according to the sleep scheduling of the sensors, and vice versa.

Minimum Number of MCs (MNoM): A single MC has been demonstrated to perform well in small-scale networks because there are fewer sensors and a smaller deployment area. Due to its low battery capacity and the lengthy charging times of the energy-critical sensors, a single MC cannot fully recharge the entire large-scale network of sensors. Numerous panic sensors will fail, making it impossible to maintain a perpetual network operation. Deploying numerous MCs with limited energy capacity is therefore necessary to ensure that each panic sensor's energy is replenished before it runs out of life. However, employing numerous Since MCs are generally more expensive than sensors, they are typically not cost-effective for energy replenishment.

Travelling path: For both periodic and on-demand timelines, the journey route is chosen. In the first scenario, the controller first chooses each MC's charging path, and each MC thereafter repeats that path on occasion throughout the network operation period. In the second scenario, the controller often modifies MC's route in response to the energy requirements of the sensors. Typically, the controller chooses a group of sensors that need to be recharged and acquires certain APs close to those sensors. The route taken by MC to maximize a particular objective function under the highlighted restrictions Then, with full energy, each MC departs from its depot and sojourns with its APs to replenish sensors along its route. The MC returns to the depot for upkeep after its charging tour is finished or when its energy level is too low.

Charging Time: The naive idea is to assign the same charging time to all sensors based on a full [17] or partial charging plan. However, in real-time applications, the charging time of sensors varies due to their different characteristics. Rates of non-deterministic energy consumption [18]. Furthermore, the distance between sensors and MCs influences the energy received by sensors from MCs [19]. The charging time increases with increasing distance between the sensors and the MCs, as the efficiency of WPT decreases with increasing distance. As a result, it is preferable that an MC recharge a sensor from the closest possible location and for as long as possible.

Collaboration Strategy (CS): When multiple MCs work independently in a large-scale network, their energy consumption rates may not be identical [18]. This is due to the fact that non-deterministic data generation and transmission rates of the sensors frequently result in an unbalanced charging load distribution among the MCs. In other words, some MCs may be more burdened than others. Furthermore, because individual MCs with limited energy can barely travel to and recharge the farthest sensors, a collaborative charging paradigm is required to eliminate the influence of the uncertainties described above. In collaborative charging [42], the MCs work together to ensure that sensors remain operational. There are two kinds of collaboration. To begin, energy can be transferred from one MC to another in order to improve network coverage [43]. Second, the charging load of low residual energy MCs can be transferred to high residual energy MCs.

V. ON DEMAND CHARGING SCHEMES

In this section, we provide a thorough examination of various on-demand SMT (single *MC-based techniques*) and MMT (multiple MC-based techniques). In contrast to periodic charging, on-demand charging recharges only those sensors that have sent a charging request to the controller. When compared to the use of static chargers, using mobile chargers for wireless charging in sensor networks is more cost-effective. The majority of studies on mobile chargers make the assumption that the charging path has been previously computed. Obviously The pre calculation requires knowledge from the outset (e.g., the energy status of all nodes). The concept of on-demand scheduling of mobile chargers based on no prior knowledge is put forth by Dai et.al. [19]. The mobile charger makes its decisions about where to go after receiving energy requests from the sensor nodes. The authors take into account an event monitoring application in which field sensors are scattered around to cover a few POIs (points of interest). Based on the energy requests it receives, the mobile charger will move throughout the network and charge the sensors.

The ratio of the number of PoIs that are currently covered to the total number of PoIs that can be covered at any time is known as the coverage utility. Be aware that some sensors may be disabled in order to avoid covering a POI. By reducing the geometric TSP (Travelling Salesman Problem) problem, the authors show that the maximum coverage utility charging scheduling (MCUCS) problem is NP-complete. The MCUCS problem at hand is to determine if there is a workable schedule for the mobile charger to visit the sensors in order to record all occurrences. There are three heuristics suggested. The first is to fulfil the energy request with the greatest marginal coverage utility; the second is to fulfil the energy request with the greatest gain in coverage utility throughout the course of its service. Here, the service time also includes charging and travel time. This is based on the idea that, even if they might result in greater utility gains, some energy demands are less preferable if the nodes are far away.

Planning for a Single Mobile Charger:

The concept of adopting distributed and reactive methods for the planning of mobile chargers is put forth by Angelopoulos et.al. Fig. 3 shows the reference models of single MCs based on techniques. The red-colored sensors are hungry sensors, and the blue-colored sensors are charged sensors; the hungry sensors have sent the charging request to the controller, while the blue sensors have sufficient energy. Here in, the request queue of the mobile charger in both single-node charger and multimode charger approaches is empathy, as the controller intends to serve all the pending charging requests in the current round. After completing each charging task in a single mobile charging technique, the controller updates the charging plans for the mobile chargers. in fig. 5. As the mobile charger only supports one sensor at a time, the reference model of a single MC based on demand charging techniques in this figure still has the sensors EGH and I in its request queue. They observe that the majority of centralized methods are computationally complex. They suggest thinking about two connected issues: (1) the amount of charge each sensor needs and (2) the paths the mobile charger should take. In order to gauge each node's significance, they suggest using a new metric called node criticality, which is based on how much traffic passes through the node and how much energy it uses. Typically, a node with high traffic and low remaining energy has a higher priority for recharging. Simulated tests are used to assess three protocols. The first protocol is one that depends on an extensive understanding of the network. According to the node's criticality and the distance between the mobile charger and the node, this protocol takes precedence. The more critical the situation and the closer the node, the greater the priority. The sink gathers data about a few representative nodes across the network and notifies the mobile charger in the protocol with restricted global knowledge. The mobile charger travels around a series of concentric circles according to protocol and local knowledge.

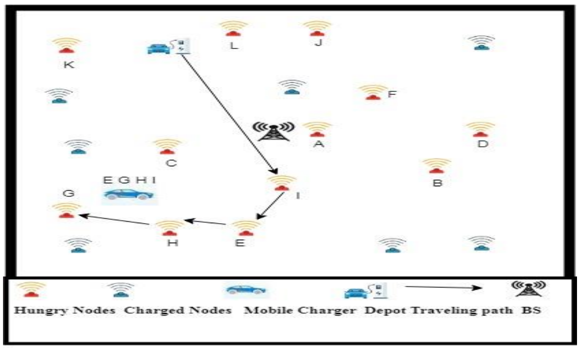

Fig.3.Single mobile chargers-based architecture in on demand charging schemes

In [16], they develop their concept further. Energy/flow criticality, which is the multiplicity of flow passing the node and energy consumption at the node, is an improvement above node criticality. There is a detailed and in-depth evaluation of the protocols with global network knowledge, limited network information, and local knowledge.

In order to determine whether there is a feasible schedule for the mobile charger to charge the sensors and no data is lost due to an energy shortage. [21] Propose the so-called charger dispatch decision problem (CCDDP). Given the network information, including the energy capacity of each node, the distance between nodes, and the charging information of the mobile charger, they need to decide. This issue has been shown to be NP-complete. The authors discover that partial charging is more effective than always charging the nodes to their full capacity. There are five potential directions for the mobile charger:

- The mobile charger moves to the node minimization first in the global knowledge traversal strategy.
- The mobile charger moves to the sink first in the spiral knowledge traversal strategy. Despite covering the entire network, this approach is not adaptive.
- The mobile charger first moves to the network's perimeter, moves along the perimeter for a certain amount of time once it gets there, and then moves along a diameter to the other side of the network.
- In the random walk traversal strategy, the mobile charger staying at a node turns to one of its neighbors with an equal probability.
- In the proposed adaptive circular traversal protocol, the mobile charger departs from the sink and moves in concentric circles of increasing radii. If it is moving towards areas that are energy-hungry, it keeps going in that direction; if it is moving towards areas that are energy-rich, it changes its direction.

A comparison of the current energy profile with the historical energy profile determines whether the area is energy-rich or energy-hungry.

Table 2: Comparison table of on-demand charging scheme using single mobile charger-based techniques

R. N	Aims	System architecture	Charging Plan	Restriction
38	Escalation of Charging Throughput and Deprecation of Charging Delay	Centralized and Greedy	Fully charged	perpetual network lifetime is not guaranteed
26	Depreciation of number dead sensors and Escalation of energy usage efficiency	Centralized heuristics approximation	Fully charged	Same energy consumption rate of sensors and perpetual network lifetime is not guaranteed
35	Escalation of accumulated monitoring quality	Centralized and Heuristics	Fully charged	perpetual network lifetime is not guaranteed
27	Escalation of Number of alive sensors and Depreciation of traveling energy	Centralized and Heuristics	Fully charged	perpetual network lifetime is not guaranteed

32	Escalation of Energy Usage Efficiency and Depreciation of number of dead nodes	Centralized and Heuristics	partial	No constraint of mobile chargers' energy capacity and perpetual network lifetime is not guaranteed
28	Depreciation of penalty and Depreciation of Service Cost	Centralized and Greedy	Fully charged	perpetual network lifetime is not guaranteed
29	Depreciation of Total Energy Consumption	Semi Distributed, Approximation	Fully charged	No constraint on Mobile Chargers energy capacity
31	Escalation of Charging Time and Depreciation of Service Cost	Semi Distributed, Approximation	Hybrid	Same energy consumption rate of sensors and perpetual network lifetime is not guaranteed
36	Escalation of payload energy and Escalation of Service Cost	Centralized and Approximation	Fully charged	Same energy consumption rate of sensors and perpetual network lifetime is not guaranteed
33	Escalation of Charging Utility/ Charging Reward	Centralized and Heuristics	partial	Fixed energy consumption rate of sensors capacity and perpetual network lifetime is not guaranteed
34	Escalation of Charging Utility/ Charging Reward	Centralized and Approximation	Hybrid	perpetual network lifetime is not guaranteed
30	Escalation of difference of payload and traveling energy	Centralized and Greedy	Fully charged	perpetual network lifetime is not guaranteed
37	Escalation of Energy Usage Efficiency	Centralized and Heuristics	Fully charged	perpetual network lifetime is not guaranteed

39	Escalation of Energy Usage Efficiency	Semi Distributed Heuristics	Hybrid	perpetual network lifetime is not guaranteed
40	Escalation of payload energy and Depreciation of Service Cost	Centralized and Greedy	Partial	perpetual network lifetime is not guaranteed

Coordinating Multiple Mobile Chargers:

The idea of distributed coordination among numerous mobile chargers is put forth in [28], contains an expanded version of [27]. Fig. 4 demonstrates the reference model of multiple MC-based techniques. For the purpose of charging every static sensor node in the network, it is anticipated that numerous mobile chargers will be installed. Figure 6 illustrates how the current MCTs choose the upcoming recharging entity for the MCs using either a partition-based strategy or a non-partition-based approach. In the first method, an MC can recharge any sensor (or MC) in the network, whereas in the second method, an MC can recharge only those sensors that are part of a particular region or group. The partition-based tactics use clustering or area partitioning techniques. This technique combined the temporal and spatial importance of the energy-deficit sensors by using two charging request thresholds. To choose the next recharging sensor for a single MC, they first provided a double warning threshold with a double preemption algorithm. They then expanded it for multiple MCs. The authors take into account two important issues:

- ❖ How can these mobile chargers cooperate with one another to maximize network performance?
- ❖ What types of trajectories should the mobile chargers take?

The network is expected to be set up in a circular region and separated into various sectoral areas. Only one sensor may be charged by the mobile charger, and each sensor's data rate varies (drawn from a uniform distribution). The charging process in the suggested design is divided into two phases: coordination and charging. Since the data rates of sensor nodes vary, the mobile chargers may have various energy reserves after providing network service for a while. Smaller locations can be given access to mobile chargers with less energy during the coordination phase. A distributed or centralized approach can be used to complete the synchronization amongst chargers. Depending on how much knowledge they have about the network throughout the charging period, the mobile chargers may have a wide range of possible paths. The authors provide five coordinating and charging mechanisms in particular. The distributed coordination (DC) protocol is the first. During the coordination phase, nearby mobile chargers work together to either increase or decrease the charging area based on the energy data. The mobile charger roams the whole network during the charging phase to reach all sensor nodes. The centralized coordination (CC) protocol is the second one. Each mobile charger is given a sector during the coordination phase based on its energy reserve. A mobile charger's trajectory could be a scanning pattern that visits each node in its charging area.

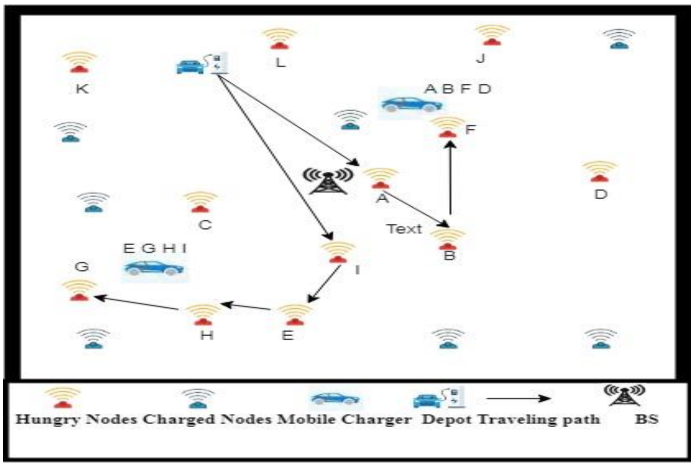

Fig.4.Multiple mobile chargers-based architecture in on demand charging schemes

The distributed coordination local knowledge (DCLK) protocol is the third one. The coordination stage is comparable to the DC protocols. The information on the remaining energy of the nodes in its charging area comes from the local knowledge the mobile charger gains during the charging period. The mobile charger can therefore charge specific sub-areas first. Centralized coordination reactive knowledge (CCRK) is the fourth procedure. Through the sink node, coordination information is transmitted.

Table 3: Comparison Table of on-demand charging schemes using multiple mobile charger-based techniques

R. N	Aims	System architecture	Charging Plan	Restriction
51	Depreciation of number of dead sensors	Semi Distributed, Clustering	Fully charged	perpetual network lifetime is not guaranteed
45	Depreciation of Service Cost	Centralized and Approximation	Fully charged	No constraint on Mobile Chargers energy capacity
52	Escalation of Network Lifetime	Centralized and Metaheuristics	Fully charged	No constraint on Mobile Chargers energy capacity
48	Escalation of Energy Usage Efficiency and Depreciatio	Centralized And Iterative	partial	Some energy consumption rate of sensors and perpetual network lifetime

	n of number of dead sensors			is not guaranteed
53	Depreciation of numbers of dead sensors	Centralized and Reinforcement Learning	Partial	perpetual network lifetime is not guaranteed
50	Depreciation of Charging Utility/ Charging Reward	Centralized, Approximation	Fully charged	No constraint of mobile chargers' energy capacity and perpetual network lifetime is not guaranteed
49	Escalation of Network Lifetime	Semi Distributed, Heuristics	Fully charged	perpetual network lifetime is not guaranteed
54	Escalation of Energy Usage Efficiency	Centralized and Approximation	Fully charged	Same energy consumption rate of sensors and perpetual network lifetime is not guaranteed
43	Escalation of Network Lifetime and Escalation of EUE	Centralized and Reinforcement Learning	Fully charged	No constraint on Mobile Chargers energy capacity
47	Depreciation of number of dead sensors	Centralized and Heuristics	Fully charged	perpetual network lifetime is not guaranteed
41	Escalation of Energy Usage Efficiency	Semi Distributed	Fully charged	perpetual network lifetime is not guaranteed
44	Depreciation of Total Energy Consumption	Semi Distributed, Metaheuristics	Partial	No constraint on Mobile Chargers energy capacity

46	Escalation of Charging Utility/ Charging Reward	Centralized, heuristics, approximation	Fully charged	perpetual network lifetime is not guaranteed
42	Depreciation of Total energy consumption	Centralized, clustering	Fully charged	perpetual network lifetime is not guaranteed

The mobile charger assigns precedence to nodes based on the required travel distance and the node's remaining energy. The centralized coordination of global knowledge (CCGK) protocol is the sixth one.

VI. Future Direction:

The network's lifespan has effectively been extended with WRSN; however, there are a lot of disadvantages as well. In terms of power management, data collection, reliability, security, etc., WRSNs provide a number of research issues. There is a lot to investigate in this field, but there are more research hurdles. Fig. 5 shows the year-wise distribution of research papers covered in this survey.

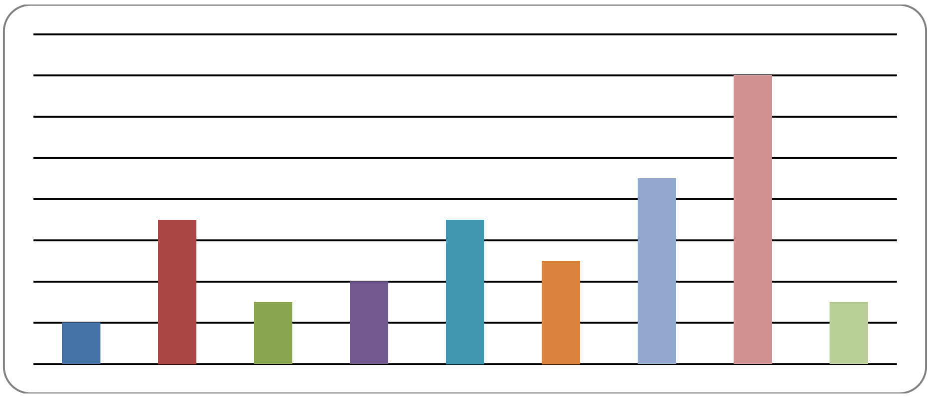

Fig.5.-Year wise distribution of number of papers surveyed

The main challenge in WRSNs is minimizing charging costs to ensure the sensor nodes' promised lifetime, which necessitates a thorough investigation of charging variables such as quantity, rate of travel, range, power, path, and duration of the wireless charging vehicle (WCV). The major challenge is how to have MCVs move more cheaply so that nodes can recharge as much as possible while using the least amount of energy possible. How to formulate a unique charge scheduling issue to balance charging across wireless charging channels, increase charging rates, and reduce charging expenses. How to maximize charging utility and reduce charging latency is another important concern. That is the best way to improve the mobile charger's efficiency and maximize its utility for charging. In the interim, we should keep the charging delay in mind and try to minimize it. After the WCV reaches the requesting node, it also needs to be focused on determining the shortest recharging path, or Hamiltonian cycle, as well as the best stopping time there. To understand how the power utilization rate is computed depending on location and traffic load, it is also necessary to study the calculation of the power utilization rate at the connecting junction. How to respond to asking sensor nodes, particularly in an urgent situation. The problem is that as renewal time and journey time increase, recharge power decreases with time.

VII. Conclusion:

Since the last ten years, sensors have become a prominent issue among researchers due to the sharply rising demand for them. Both daily life and mission-critical activities rely heavily on sensors. They carry out everything from the simplest tasks, like measuring temperature and humidity, to the most challenging ones, like monitoring volcanoes or forest fires. Currently, energy harvesting, energy conservation, and wireless energy transfer, also known as wireless power transfer, are three strategies that can lengthen the lifespan of a network. WPT shows itself to be the best at extending the network's lifetime in contrast to the other two strategies. To improve network performance, numerous academics have developed various network models with unique network elements and methodologies. The majority of the researchers' charging strategies just included one mobile charger. Using merely a mobile charger has the advantage of being inexpensive and effective in small-scale networks. Large networks cannot use it since it will not be able to react to all asking nodes in a timely manner. While using several chargers can extend the life of the network, it is generally recommended to utilize multiple charges for a huge network. The drawback is that using numerous chargers in a network would be expensive. Although using several chargers can extend the network's lifetime, it is recommended that large-scale networks employ multiple chargers. The drawback is that using numerous chargers in a network would be expensive. Also, because the charger doesn't need to return as early, a full charging scheme is more practical for travelling than a partial one. Although partial charging has a higher charging efficiency because the maximum number of nodes may be recharged and there is a fair distribution of energy, each charger's available resources The major disadvantage is that partial charging is not battery-friendly because recharging a mobile charger's battery often reduces its capacity. Also, because there are more recharging excursions, the service cost is higher as well. While one-to-many charging is more responsive in a dense network environment, one-to-one charging is better when the network is not congested. Final thoughts: Every method has benefits and drawbacks, and we need new solutions to get rid of the disadvantages. As a last point, we would like to note the reason we chose to go further into WRSN: because it is evolving quickly, understanding and using it successfully requires familiarity with earlier research. The research work that has been previously presented in WRSN during the past ten years is summarized in this document. Also, for better and more efficient outcomes, we have specified nearly every phrase that may be employed while building enhanced charge scheduling systems.

References

[1] Kaswan, A., Jana, P. K., & Das, S. K. (2022). A Survey on Mobile Charging Techniques in Wireless Rechargeable Sensor Networks. *IEEE Communications Surveys & Tutorials*, *24*(3), 1750–1779. https://doi.org/10.1109/comst.2022.3189387
[2] Lu, X., Wang, P., Niyato, D., Kim, D. I., & Han, Z. (2015). Wireless Networks With RF Energy Harvesting: A Contemporary Survey. *IEEE Communications Surveys & Tutorials*, *17*(2), 757–789. https://doi.org/10.1109/comst.2014.2368999
[3] Dai, H., Liu, Y., Chen, G., Wu, X., He, T., Liu, A. X., & Ma, H. (2017, December). Safe Charging for Wireless Power Transfer. *IEEE/ACM Transactions on Networking*, *25*(6), 3531–3544. https://doi.org/10.1109/tnet.2017.2750323
[4] Kamalinejad, P., Mahapatra, C., Sheng, Z., Mirabbasi, S., M. Leung, V. C., & Guan, Y. L. (2015, June). Wireless energy harvesting for the Internet of Things. *IEEE Communications Magazine*, *53*(6), 102–108. https://doi.org/10.1109/mcom.2015.7120024
[5] D. Ma, G. Lan, M. Hassan, W. Hu, and S. K. Das, "Sensing, computing, and communications for energy harvesting IoTs: a survey," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 2, pp. 1222–1250, 2020.
[6] Sah D.K., Amgoth T. Renewable energy harvesting schemes in wireless sensor networks: A Survey. *Inf. Fusion.* 2020;63:223–247. doi: 10.1016/j.inffus.2020.07.005.
[7] Shaikh, Faisal Karim & Zeadally, Sherali, 2016. "Energy harvesting in wireless sensor networks: A comprehensive review," Renewable and Sustainable Energy Reviews, Elsevier, vol. 55(C), pages 1041-1054. DOI: 10.1016/j.rser.2015.11.010.
[8] A. A. Babayo, M. H. Anisi, and I. Ali, "A review on energy management schemes in energy harvesting wireless senso rnetworks,"Renew. Sustain. Energy Rev., vol. 76, pp. 1176–1184, Sep, 2017.
[9] S. Upadhyay, M. Kumar, A. Upadhyay, "Digital Image Identification and Verification using Maximum and Preliminary Score Approach with Watermarking for Security Enhancement and Validation", Journal of Electronics, Vol. 12, Issue 7, pp. 1-15, 2023.
[10] N. A. Bhatti, M. H. Alizai, A. A. Syed, and L. Mottola, "Energy harvesting and wireless transfer in sensor network applications: Concepts and experiences," *ACM Trans. Sensor Netw.*, vol. 12, no. 3, pp. 1–40, 2016.
[11] F. Akhtar and M. H. Rehmani, "Energy replenishment using renewable and traditional energy resources for sustainable wireless sensor networks: A review," *Renew. Sustain. Energy Rev.*, vol. 45,pp. 769–784, May 2015.
[12] S. Upadhyay, M. Kumar, A. Kumar & K Z Gafoor, "Smart Healthcare Solution for Future Development using Speech Feature Extraction Integration Approach with IoT and Blockchain**"**, Journal of Sensors, Vol. 2022, pp. 1-13, May 2022.
[13] Z. Fan, Z. Jie, and Q. Yujie, "A survey on wireless power transfer based charging scheduling schemes in wireless rechargeable sensor networks," in *Proc. IEEE 4th Int. Conf. Control Sci. Syst. Eng. (ICCSSE)*, 2018, pp. 194–198.
[14] S. Upadhyay, M. Kumar, A. Kumar, R. Kranti, "Feature Extraction Approach for Speaker Verification to Support Healthcare System using Blockchain for Data Privacy", Computational and Mathematical Methods in Medicine, Vol. 2022, pp. 1-12, July 2022.
[15] Cheng, R. H., Yu, C. W., Xu, C., & Wu, T. K.. "A distancebased scheduling algorithm with a proactive bottleneck removal mechanism for wireless rechargeable sensor networks". IEEE Access, 8, 148906–148925,2020
[16] Chen, F., Zhao, Z., Min, G., & Wu, Y, "A novel approach for path plan of mobile chargers in wireless rechargeable sensor networks". In 12th International conference on mobile ad-hoc and sensor networks (MSN) (pp. 63–68). IEEE,2016

[17] Chan, L., Chavez, K. G., Rudolph, H., & Hourani, A,"Hierarchical routing protocols for wireless sensor network: A compressive survey". Wireless Networks, 26(5), 3291–3314,2020.
[18] A. Londhe, P VRD Rao, S. Upadhyay & R. Jain, "Extracting behavior identification features for monitoring and managing speech dependent smart mental illness healthcare systems**"**, Computational Intelligence and Neuroscience, Vol. 2022, pp. 1-14, May 2022.
[19] Angurala, M., Bala, M., & Bamber, S. S. "Wireless battery recharging through UAV in wireless sensor networks". Egyptian Informatics Journal, 23(1), 21–31,2022
[20] Madhja, A., Nikoletseas, S., Raptis, T.P, "Distributed wireless power transfer in sensor networks with multiple Mobile Chargers". *Comput. Netw.* 2015, *80,* 89–108.
[21] S. Upadhyay, SK Sharma & A. Upadhyay, "Speaker Identification and Verification Using Different Model for Text-Dependent", International Journal of Applied Engineering Research, Vol. 12, No. 08, pp. 1633-1638, 2017.
[22] Wang, C.; Li, J.; Ye, F.; Yang, Y, "NETWRAP: An NDN Based Real-Time Wireless Recharging Framework for Wireless Sensor Networks". *IEEE Trans. Mob. Comput.* 2014, *13*, 1283–1297.
[23] Aslam, M. M., Zhang, J., Qureshi, B, & Ahmed, Z,"Beyond6G-consensus traffic management in CRN, applications,architecture and key challenges". In IEEE 11th international conference on electronics information and emergency communication (ICEIEC) (pp. 182–185). IEEE,2019

[24] A. Kumari, N. Gandadotra et. al. "Impact of Mobility on the Performance of Wireless Ad hoc Networks Scenario using Distance Vector Routing Protocol", International Journal of Computer Application (IJCA), Volume-57, No. - 12, pp. 14-21, November 2012.

[25] Aslam, M. M., Du, L., Ahmed, Z., Irshad, M. N., & Azeem, H," A deep learning-based power control and consensus performance of spectrum sharing in the CR network", Wireless Communications and Mobile Computing. 2021,https://doi.org/10.1155/2021/7125482.
[26] C. Lin, J. Zhou, C. Guo, H. Song, G. Wu, and M. S. Obaidat, "TSCA: A temporal-spatial real-time charging scheduling algorithm for ondemand architecture in wireless rechargeable sensor networks," *IEEE Trans. Mobile Comput.*, vol. 17, no. 1, pp. 211–224, Jan. 2018.

[27] S. Upadhyay, A. Upadhyay et. al "A Study and Analysis of Suitable Channel Access Protocol for Mobile Ad-hoc Network Considering Different Application" International Journal of Computer Engineering and Application (IJCEA), Vol.-5, Issue-3, pp. 93-106, March 2014.

[28] G. Tsoumanis, K. Oikonomou, S. Aïssa, and I. Stavrakakis, "Energy and distance optimization in rechargeable wireless sensor networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 1, pp. 378–391,Mar. 2021.
[29] A. Upadhyay, SK Sharma, S. Upadhyay, "Robust Feature Extraction using Embedded HMM for Face Identification & Verification" International Journal of Applied Engineering Research, Vol. 12, No. 24, pp. 15729-15777, 2017.
[30] C. Wang, J. Li, F. Ye, and Y. Yang, "A mobile data gathering framework for wireless rechargeable sensor networks with vehicle movement costs and capacity constraints," *IEEE Trans. Comput.*, vol. 65, no. 8, pp. 2411–2427, Aug. 2016.
[31] C. Wang, J. Li, Y. Yang, and F. Ye, "Combining solar energy harvesting with wireless charging for hybrid wireless sensor networks," *IEEE Trans. Mobile Comput.*, vol. 17, no. 3, pp. 560–576, Mar. 2018.

[32] A. Upadhyay, SK Sharma, S. Upadhyay “Face Identification & Verification Using Hidden Markov Model with Maximum Score Approach”, Indian Journal of Science & Technology, Vol. (10) 47, pp.1-6, December 2016.

[33] T. Liu, B. Wu, W. Xu, X. Cao, J. Peng, and H. Wu, “RLC: A reinforcement learning-based charging algorithm for mobile devices,” *ACM Trans. Sensor Netw.*, vol. 17, no. 4, pp. 1–23, 2021.

[34] S. Upadhyay, SK Sharma e. al. “Analysis of Different Classifier Using Feature Extraction in Speaker Identification and Verification Under Adverse Acoustic Condition for Different Scenario”, International Journal of Innovations in Engineering and Technology, Volume 6, Issue 4, ISSN: 2319-1058, pp. 425-434, April 2016.

[35] Z. Lu, B. Fan, J. Cai, and L. Tang, “J-RCA: A joint routing and charging algorithm with WCE assisted data gathering in wireless rechargeable sensor networks,” *IEEE Sensors J.*, vol. 21, no. 3, pp. 3888–3899, Feb. 2021.

[36] W. Ouyang, M. S. Obaidat, X. Liu, X. Long, W. Xu, and T. Liu, “Importance-different charging scheduling based on matroid theory for wireless rechargeable sensor networks,” *IEEE Trans. Wireless Commun.*, vol. 20, no. 5, pp. 3284–3294, May 2021.

[37] A. Kumari, N. Gandotra. P. Joshi, S. Upadhyay, “Impact of Node Movement on MANET Using Different Routing Protocol for QoS Improvement under Different Scenario”, International Journal of Smart Sensors and Ad Hoc Networks (IJSSAN) ISSN No. 2248- 9738 Volume- 1, Issue- 3, pp. 95-101, 2012.

[38] L. He, L. Kong, Y. Gu, J. Pan, and T. Zhu, “Evaluating the on-demand mobile charging in wireless sensor networks,” *IEEE Trans. Mobile Comput.*, vol. 14, no. 9, pp. 1861–1875, Sep. 2015.

[39] P. Joshi, A. Kumar, S. Upadhyay, S. Vijay et. al., “Impact of Various Mobility Model and Judgment for Selecting Mode of Network in Different Mobility Situation for Mobile Ad-Hoc Network (MANET)”, IEEE International Conference on "Emerging Technology Trends in Electronics, Communication and Networking (ET2ECN- 2012)At: Gujarat, Volume: 978-1-4673-1628-6, 2012.

[40] Dai, H., Ma, Q., Wu, X., Chen, G., Yau, D. K. Y., Tang, S., Li, X. Y., & Tian, C. (2020, January 1). CHASE: Charging and Scheduling Scheme for Stochastic Event Capture in Wireless Rechargeable Sensor Networks. *IEEE Transactions on Mobile Computing*, *19*(1), 44–59. //doi.org/10.1109/tmc.2018.2887381.

[41] Lin, C., Wei, S., Deng, J., Obaidat, M. S., Song, H., Wang, L., & Wu, G. (2018, December). GTCCS: A Game Theoretical Collaborative Charging Scheduling for On-Demand Charging Architecture. *IEEE Transactions on Vehicular Technology*, *67*(12), 12124–12136. https://doi.org/10.1109/tvt.2018.2872890

[42] S. Upadhay, SK. Sharma, A. Upadhyay, “Analysis of Different Classifier Using Feature Extraction in Speaker Identification and Verification under Adverse Acoustic Condition for Different Scenario”, International Journal of Innovations in Engineering and Technology (IJIET), Volume 6 Issue 4ISSN: 2319 – 1058, pp. 425-434, April 2016.

[43] Y. Chen, H. Wu, Y. Liang, and G. Lai, “VarLenMARL: A framework of variable length time-step multi-agent reinforcement learning for cooperative charging in sensor networks,” in *Proc. 18th Annu. IEEE Int. Conf. Sens. Commun. Netw. (SECON)*, 2021.

[44] P. Zhong, A. Xu, S. Zhang, Y. Zhang, and Y. Chen, “EMPC: Energy-Depreciation path construction for data collection and wireless charging in WRSN,” *Pervasive Mobile Comput.*, vol. 73, Jun. 2021, Art. no. 101401.

[45] Tifenn. Rault, “Avoiding radiation of on-demand multi-node energy charging with multiple mobile chargers,” *Comput. Commun.*, vol. 134, pp. 42–51, Jan. 2019.

[46] S. Upadhay, SK. Sharma, A. Upadhyay, " Analysis of Feature Extraction Behavior for Speaker Identification and Verification in Adverse Acoustic Condition", International Journal of Control Theory and Applications, IJCTA 10 (9) ISSN: 0974-5572, , pp. 25-31, 2017.
[47] MC Saxena, F Banu, A Shrivastava, M Thyagaraj & S. Upadhyay, "Comprehensive Analysis of Energy Efficient Secure Routing Protocol for Sensor Network", Volume 62, Part 7, pp. 5003-5007, 2022, Material Today
[48] A. Tomar, L. Muduli, and P. K. Jana, "A fuzzy logic-based ondemand charging algorithm for wireless rechargeable sensor networks with multiple chargers," *IEEE Trans. Mobile Comput.*, vol. 20, no. 9, pp. 2715–2727, Sep. 2021.
[49] P . Yang, T. Wu,H. Dai, X. Rao, "MORE: Multi-node mobile charging scheduling for deadline constraints," *ACM Trans. Sensor Netw.*, vol. 17, no. 1, pp. 1–21, 2020.
[50] Y. Zhu, K. Chi, P. Hu, K. Mao, and Q. Shao, "Velocity control of multiple mobile chargers over moving trajectories in RF energy harvesting wireless sensor networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 11, pp. 11314–11318, Nov. 2018.
[51] Y. Feng, W. Zhang, G. Han, Y. Kang, and J. Wang, "A newborn particle swarm optimization algorithm for charging-scheduling algorithm in industrial rechargeable sensor networks," *IEEE Sensors J.*, vol. 20,no. 18, pp. 11014–11027, Sep. 2020.
[52] H. Yu, C.-Y. Chang, Y. Wang, D. S. Roy, and X. Bai, "CAERM: Coverage aware energy replenishment mechanism using mobile charger in wireless sensor networks," *IEEE Sensors J.*, vol. 21, no. 20, pp. 23682–23697, Oct. 2021
[53] W. Xu, W. Liang, X. Jia, H. Kan, Y. Xu, and X. Zhang, "Minimizing the maximum charging delay of multiple mobile chargers under the multi-node energy charging scheme," *IEEE Trans. Mobile Comput.*, vol. 20, no. 5, pp. 1846–1861, May 2021.
[54] N. Gharaei, Y. D. Al-Otaibi, S. Rahim, H. J. Alyamani, N. A. K. K. Khani, and S. J. Malebary, "Broker-based nodes recharging scheme for surveillance wireless rechargeable sensor networks," IEEE Sensors Journal, vol. 21, no. 7, pp. 9242–9249, 2021.
[55] Kumar, M., Kumar, A., Verma, S., Bhattacharya, P., Ghimire, D., Kim, S. H., & Hosen, A. S. (2023). Healthcare Internet of Things (H-IoT): Current Trends, Future Prospects, Applications, Challenges, and Security Issues. Electronics, 12(9), 2050
[56] Kumar, M., Mittal, S., & AKHTAR, A. K. (2020). A NSGA-II Based Energy Efficient Routing Algorithm for Wireless Sensor Networks. Journal of Information Science & Engineering, 36(4).
[57] Kumar, M., Kumar, D., & Akhtar, M. A. K. (2021). A modified GA-based load balanced clustering algorithm for WSN: MGALBC. International Journal of Embedded and Real-Time Communication Systems (IJERTCS), 12(1), 44-63.
[58] Kumar, M., Mittal, S., & Akhtar, A. K. (2021). Energy efficient clustering and routing algorithm for WSN. Recent Advances in Computer Science and Communications (Formerly: Recent Patents on Computer Science), 14(1), 282-290
[59] Kumar, M., Kumar, D., & Akhtar, M. A. K. (2018, October). Mathematical model for sink mobility (MMSM) in wireless sensor networks to improve network lifetime. In Communication, Networks and Computing: First International Conference, CNC 2018, Gwalior, India, March 22-24, 2018, Revised Selected Papers (pp. 133-141). Singapore: Springer Singapore
[60] Upadhyay, S., Kumar, M., Kumar, A., Karnati, R., Mahommad, G. B., Althubiti, S. A., ... & Polat, K. (2022). Feature Extraction Approach for Speaker Verification to Support Healthcare System Using Blockchain Security for Data Privacy. Computational and Mathematical Methods in Medicine, 2022.
[61] Upadhyay, S., Kumar, M., Kumar, A., Ghafoor, K. Z., & Manoharan, S. (2022). SmHeSol (IoT-BC): smart healthcare solution for future development using speech

feature extraction integration approach with IoT and blockchain. Journal of Sensors, 2022

[62] Kumar, M., Verma, S., Kumar, A., Ijaz, M. F., & Rawat, D. B. (2022). ANAF-IoMT: A Novel Architectural Framework for IoMT-Enabled Smart Healthcare System by Enhancing Security Based on RECC-VC. *IEEE Transactions on Industrial Informatics*, *18*(12), 8936-8943.

[63] Kumar, M., Mukherjee, P., Verma, K., Verma, S., & Rawat, D. B. (2021). Improved deep convolutional neural network based malicious node detection and energy-efficient data transmission in wireless sensor networks. *IEEE Transactions on Network Science and Engineering*, *9*(5), 3272-3281.

[64] Kumar, M., Mukherjee, P., Verma, S., Shafi, J., Wozniak, M., & Ijaz, M. F. (2023). A smart privacy preserving framework for industrial IoT using hybrid meta-heuristic algorithm. *Scientific Reports*, *13*(1), 1-17

[65] Pratap, A., Kumar, A., & Kumar, M. (2021, May). Analyzing the Need of Edge Computing for Internet of Things (IoT). In *Proceedings of Second International Conference on Computing, Communications, and Cyber-Security: IC4S 2020* (pp. 203-212). Singapore: Springer Singapore