DEVELOPING IMPROVED ENERGY-BASED NODE CHARGE REPLENISHMENT MODEL IN LARGE-SCALE WIRELESS RECHARGEABLE SENSOR NETWORKS

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Abstract

In Wireless Rechargeable Sensor Network (WRSN), the distributed energy-constrained sensor nodes are to be recharged after consuming for sensing operations. In recent days, researches proposed recharging model with single mobile charger that moves along the network to refill each sensor. But, it is not efficient in Large-Scale WRSNs because of that the mobile charger is also having limited energy. It can be solved by using multiple mobile chargers, but, the implementation and maintenance are costlier process. With that note, this paper develops a novel model called Improved Energy-based Node Charge Replenishment Model (IENCR) that contains Single Portable Device (SPD) with Multiple Charger Nodes (MCNs), which are detachable in design. When energy starvation is found in LS-WRSN, the sensors are to be refilled by the SPD that carries Multiple Charger Nodes through which the nodes are provided with energy services concurrently, by fixing the SPD in the locality of one sensor. Moreover, using the proposed model, lifetime of sensors is effectively enhanced and total route path travelled by the SPD can be considerable reduced. In this work, the least active time of each node is evaluated based on its consumed and residual energy levels. Based on that, Analytical Charging Route (ACR) is framed for energy replenishment of the sensor nodes that are running to be in-active or dead. Further, the IENCR model is examined using simulations and the obtained results outperforms the existing works.

Index terms: Large-Scale Wireless Rechargeable Sensor Networks (LS-WRSNs), Improved Energy based Node Charge Replenishment Model (IENCR), Single Portable Device (SPD), Multiple Charger Nodes (MCNs), Analytical Charging Route (ACR).

INTRODUCTION

Wireless Sensor Networks (WSNs) are effectively used in various applications like medical, health care data tracking, and military services and so on [1] [2]. But, the sensor nodes in the network are resource constrained with limited lifetime. For mitigating the issues of energy and power constrains in WSN, Wireless Rechargeable Sensor Networks (WRSNs) are developed in which the sensor nodes can be recharged with some external sources [3]. The recharging methods are generally classified into two categories. One is based on energy replenishment from the environmental resources such as wind energy, solar energy, etc, [4] [5]. However, the surroundings in which the sensors

deployed are time-variant, the replenishment process is unstable. Another category of energy replenishment in WRSN is using mobile vehicles for node recharge [6] [7] [8]. Through this type, stable energy supply can be provided for the energy starving sensor nodes on time.

The charging vehicles are moving towards the locality of nodes and perform refilling based on their levels of energy starving. The typical framework of WRSN that recharges based on the energy levels of nodes is presented in Figure 1.
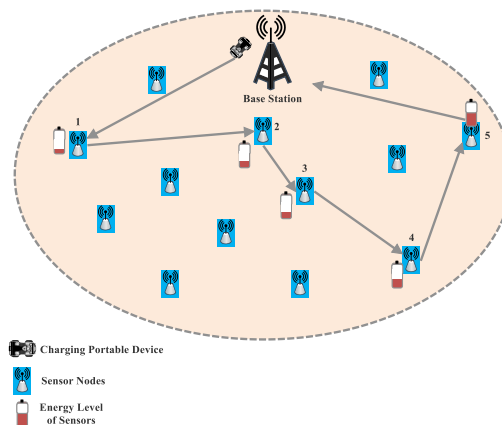

Fig. 1. Typical WRSN Framework for Energy Level based Node Recharge

There are several research works done for recharging sensor nodes using single mobile charging vehicle [9] [10] or multiple charging vehicles [11] [12]. In the case of energy recharging with single charging vehicle, some sensors will drain all its energy before the vehicles reaches its locality [13]. Hence, the model can use multiple charging devices, which may increase the service or implementation cost. On that note, this paper proposes a novel model called Improved Energy-based Node Charge Replenishment Model (IENCR) that contains Single Portable Device (SPD) with Multiple Charger Nodes (MCNs) to recharge nodes in large-scale WRSN. Moreover, Analytical Charging Trajectory is derived for rising the active time of sensor nodes and to reduce the travel distance of SPD. The Multiple charger nodes are effectively engaged by the SPD based on the energy starvation of deployed nodes.

The Analytical Charging Route framing includes the methodology how to displace charging nodes on the locality of sensors and revisiting to the same locations for collecting back those MCNs. This becomes very complicated and significant process to be included in the charging trajectory. For that, the scheduling issues are separated into two and solved in the proposed model. Firstly, shortest charging path is determined for SPD to recharge the vehicles having minimal residual energy and about to dead, without considering the remaining lifetime of sensors. Secondly, the ACR is determined based on the remaining lifetime of nodes, thereby increasing the network active time and reducing the travel distance of charging device. Through the proposed IENCR model, multiple sensors can be recharged simultaneously and the lifetime of sensor nodes can be increased effectively.

The remaining part of the paper is framed as follows: Section 2 contains the descriptions about the related researches on none replenishment in WRSN. Section 3 describes the problem definition of the proposed work in WRSN. The complete work process of the proposed model is presented in Section 4. Further, the experimental results and comparative charts are given in Section 5. Finally, Section 6 narrates the conclusion including some ways for enhancing the model in future.

Related works
In [14], on-demand recharge request based model has been proposed. The model mainly focussed on sensor nodes locality and time of request arrival. The authors have provided solution for On-demand Mobile Charging (DMC) issue. Moreover, the throughput increase in charging process has been defined using efficient charging route in [15]. An analytical model for random energy recharge with the description of the effective recharge patterns were discussed in [16]. The replenishment model functioned on finding the nodes at lower energy levels. In [17], there was a consideration that the charging vehicle has sufficient energy and with that assumption, the authors have evaluated about the optimization issue for enhancing the charging efficiencies in each cycle of vehicle movements. For making the recharge process without missing any sensors, an appropriate charging route has been defined in [18]. Nevertheless, there are some models discussed about the process of exact localities for charging nodes that are in lower energy and about to dead [19] and Qi-Ferry model has been developed.

The authors of [19] [20] discussed about the energy limitations of charging vehicles. Based in single to many charging pattern, the determination of selecting charging locations for energy refilling has been optimized. On account to that work, the transmission overhead and energy consumptions were clearly reduced by acquiring some knowledge regarding that in energy replenishment. In order to maximize the charging coverage, proper scheduling model for charging vehicles was defined in [21]. Thereby, the effect of event monitoring has been enhanced using three heuristic problems. Since single charger is not sufficient for energy replenishment in large scale WRSN, there

are some models presented in [22], [23] and [24]. There were single base station has been considered in the models, from which the charging vehicles are started from the base station and come back to that after servicing energy starved sensor nodes. But, utilizing multiple charging nodes may cause some implementation and maintenance complexities. A Collaborative Mobile Charging (CMC) model has been developed in [25], in which the charging vehicles can get charge from each other and also involves in charging sensor nodes. The charging pattern was worked on two cases called uniform and non-uniform using heuristic algorithm.

Wireless Charger Deployment Optimization model has been derived by the authors of [26] to describe how to distribute the available charger to the maximum coverage of the sensing area. Moreover, two algorithms for sensor nodes selection to charge, namely, Pair based Greedy Cone Selection and Node based Greedy Cone Selection. Further, in [27], the WCDO problem has been solved using the incorporation of Particle Swarm Optimization, which is named as, Particle Swarm-based Charger Deployment (PSCD).

The papers [28] [29] [30] [31] [32] presented the variant approaches for energy replenishment of WRSN with single mobile charger. An efficient routing and charging scheme for energy refilling is presented in [28], in which the scheme was framed with data about the periodic data sharing between sensor devices and mobile chargers. Further, the paper [29] discussed about the data accumulation and joint based energy refilling model for utilizing the maximum capability of charging vehicle. A routing protocol based on circular path of mobile chargers based on the energy consumption rate of each node in the network [30]. The authors of [31] presented a robust protocol that utilized minimal network knowledge for recharging nodes. Each sensor node that is low in energy generates an energy request to its corresponding charger for acquiring the recharge service [32]. Schedule-based Optimized Node Recharging Model (SONRM) has been developed in [33], for enhancing the network longevity using single charging vehicle for all sensors in WRSN. In that process, simultaneous charging is the major issue, for which multiple charging devices are required.

PROBLEM DEFINITION
In typical Node charge replenishment in WRSN, there are three possible recharging scenarios that can be considered here. The first case is presented in Figure 1, using single charging device to recharge the deployed sensors in a specific area. As it is portrayed in the figure, there are five sensor nodes that are starving for energy, which is serviced by a single charging vehicle based on the residual energy levels of nodes, prioritizing from low to high. It can be observed from the case that the sensors at longer distance from the charging vehicle may drain its complete energy and become dead, before the vehicle reaches the node to charge.

Another two scenarios are presented in Figure 2(a) and 2(b). In, the Figure 2 (a), there are 6 sensor nodes (SR), which are recharged parallel with the multiple Charging Portable Devices (CPDs), namely, CPD1, CPD2 and CPD3. The CPDs are moving to the sensor localities, which are in need of replenishment. Each CPD moves from base station to the sensors and comes back to the base station after recharging. In this scenario of sensor node replenishment, the utilization of multiple CPDs reduces the waiting time of nodes for recharge and also the travel distance of each charging device. But, the implementation process is not cost-effective and requires higher maintenance. Hence, in the proposed model, an Improved Energy-based Node Charge Replenishment Model (IENCR), in which it carries single portable device with multiple charging nodes. In this, the SPD deploys MCNs to the localities of sensor nodes that are energy starved in the designed WRSN, which is diagrammatically presented in

Figure 2 (b). Based on that, the SPD carries three MCNs for energy replenishment of sensors.

The SPD deploys those chargers in the localities of three sensors SR_1, SR_2 and SR_3 and following, the SPD visits each location for collecting the MCNs after the recharge is done respectively. After

servicing those sensors, the SPD is moving to the next set of sensors to recharge and repeats the aforementioned process. In this case, the sensor nodes can be effectively charged with respect to several factors of WRSN than the previous two scenarios of node recharge.
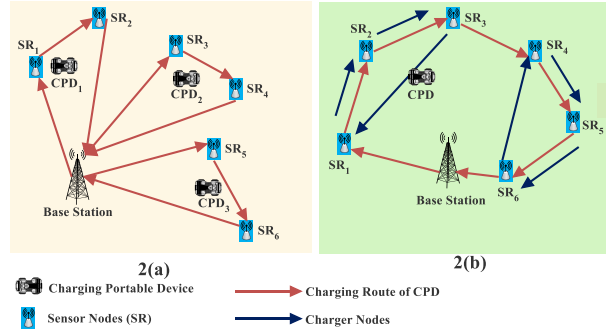

Fig. 2. Recharging Scenarios of using Multiple CPDs and Single CPD with multiple Chargers

FUNCTIONS INVOLVED IN IMPROVED ENERGY BASED NODE CHARGE REPLENISHMENT NODE MODEL

As given in Section 3, energy replenishment of sensor nodes in Large-scale Wireless Rechargeable Sensor Network can be done with three scenarios, such as, using single charging vehicle, multiple vehicles and single vehicles with multiple chargers. Among those, the third strategy of node recharge is more effective and it is taken in this work, in which the energy refilling is done with efficient manner utilizing the effectiveness of the proposed IENCR model.

Moreover, the model performs the following operations, for enhancing the network lifetime of WRSN.

1. Network Model Description
2. Derivation of Residual Energy of Nodes
3. Evaluation of Least Active Time of Nodes
4. Formation of Analytical Charging Route
5. Parallel Charging Pattern

NETWORK MODEL DESCRIPTION

In the design of network model, it is considered that the sensor nodes are distributed in a two dimensional region for environmental tracking, in which N_i number of sensors are there. The sensors are given as, $\{S_1, S_2, \dots, S_{N_i}\}$ in the defined large-scale wireless rechargeable sensor network. For optimal network administration and data accumulation, a base station BS_i is located at the middle of the WRSN. Here, each node $S_n \in R_S$, which is energized by a rechargeable source with energy volume 'E'. The sensor S_n utilizes the energy for observing the area, sensing and data transmission.

RESIDUAL ENERGY DERIVATION

It is considered that each S_n transmits the sensed information to the BS_i through the defined transmission route, which uses minimal energy for data transmission. The residual Energy of each node is given as $RES_n^t \forall S_n \in Sens_n$ and $\omega_n(t)$ is the rate of energy utilization at an instant 't'. The remaining lifespan of node S_n at instant 't' is given as,

$$RL_n^t = \frac{RES_n^t}{\omega_n(t)} \qquad (1)$$

It can be stated from the above equation that the node S_n is said to be critical, when the 'RL_n^t' drops below the threshold rate called RL_{thres}. Based on that, the request for energy replenishment is transmitted to the base station. When the base station acquires the charging_request from a node S_n, then, the SPD is scheduled for recharging the nodes at energy starvation

$\forall S_n \in Sens_n$, which is not being more than $\beta. RL_{thresh}$, can be given as,

$$Sens = \{S_n | S_n \in Sens_n, RL_n^t \le \beta. RL_{thresh}\} \qquad (2)$$

Where, 'β' is the constant factor which will be greater than or equal to 1. Based on the process explained in this section, the nodes that are having minimal residual energy is considered to be having minimal lifespan among the set of sensors, which are considered to be serviced or recharged first.

EVALUATION OF LEAST ACTIVE TIME OF NODES

For evaluating the least active time of sensor nodes, this section presents a mathematical model. Based on that, Analytical Charging Route for optimal node charging is also derived, through which, the dead rate of nodes can be minimized considerably. In some cases, the length of route may be longer. For reducing that effectively, an algorithm is to be derived for ensuring the least active time of sensor nodes in the network.

For estimating the Least Active Time of sensors, it is assumed that $G = (Sens \cup \{BS_i, ED; WT : ED \to R_S\})$, in which, 'ED' denotes the Euclidean Distance of two sensor nodes at X and Y positions, 'W' denotes the weight of each node. Based on the remaining lifespan of each node 'RL_n^t', a SPD carrying 'M' MCNs and the recharge rate of each S_n is given as 'λ'. It is also to be noted that the mean travel time of SPD 'ρ' for 'j' number of consecutive nodes to be recharged is must be shorter than the replenishment time of sensors 'ΔC_t'.

Consider, $T = \Delta C_t + \rho$, in which the time can be divided into equal slots with enduring 'τ' units and ordered as 1,2,... Further, the fundamental concept of deriving the least active time of sensors is to analyze that 'j' nodes are fully replenished in each slot by the 'M' number of MCNs, which is optimal and $P(= \frac{N}{j})$

slots are required for recharging the nodes in the sensor set 'Sens'. Here, $N = |Sens|$ and 'P' is the positive number (time required for node replenishment). For maximizing the optimality of the derivation, maximum weight is to be considered.

Here, it is assumed that SN be the set of sensor nodes with 'P' slots for node replenishment. The sensor nodes with respect to slots are represented as SN={S_1, S_2,..., S_P}, For each sensor 'S_i', 'r' number of virtual node are created, which is given as $SN = \{S_1, S_2, \dots, S_r, S_{r+1}, \dots . S_{Pr}\}$. A random complete bipartite graph is constructed and stated as G=(SN, S, ED;WT: $ED \to R_S \ge 0$). In between any sensor $S_i \in SN$, an edge $(S_i, SN_j) \in ED$, for any virtual slot $S_r \in S$ and Weight WT (SN_i, S_r) of each (S_i, SN_j) is

considered to be the least active time of sensor S_i, it is recharged with a charging node at the starting point of 'p'th time slot.

It is taken that Opt_Mat as the optimal matching in the graph G based on the lower and higher values of edge weight. Here, WT_{opt} is given as the higher value of edge weight in Opt_Mat. For finding the perfect matching of Opt_Mat, a sub-graph for graph G is framed as $G' = (SN', ED', WT')$. Here, for optimal matching, the threshold weight is denoted as, WT_T and it should satisfy $WT_T \geq$

WT_{opt}. Moreover, the edges are ordered in increasing rates of their weights.

Based on that, optimal matching is derived for finding the time duration of nodes to be active in the designed network. Hence, the least active time of each node is computed and the algorithm is presented in Table 1.

Table 1Algorithm for Evaluation of Least Active Time of Sensor Nodes

Input: Graph G=(SN, ED, WT), Remaining Lifespan of node RL_n^t
Output: Charge_plan of sensors in SN based on Least Active Time of Nodes

1. **Begin**
2. Let $SN = \{S_1, S_2, .., S_n\}$
3. Frame Bipartite Graph G=(SN, S, ED;WT: $ED \rightarrow R_S \geq 0$),
4. Sort edges of Graph G, in increasing order of weights as, $v_1, v_2, ... v_m$
5. Let min-hop=1 and max-hop=m; minimal and maximum values of edge labels
6. While min-hop<max-hop do
7. Let mid-rate =[(min-hop+max-hop)/2]
8. Let $WT_T = WT(v_{mid-rate})$
9. Frame sub-graph $G' = (SN', ED', WT')$
10. **If** not-matched with G'
11. Let min-hop=mid-rate+1
12. **Else**
13. Let $WT(v_{mid-rate}) \geq WT_{opt}$
14. Let max-hop=mid-rate
15. **End if**
16. **End while**
17. Determine Opt_Mat
18. Frame Optimal Charing_plan for nodes
19. Sequence(charge_plan)=Sequence (Least Active time(nodes))=L(S_n)
20. **Return** L
21. **End**

FORMATION OF ANALYTICAL CHARGING ROUTE

In this section, the Analytical Charging Route for recharging the nodes in optimal way is framed by using the opy-mat found from the previous section. Here, the sensor node set is divided as $SN(= S_{non-active} \cup S_{active})$ in 'p' separate subsets $\{S_1, S_2, .., S_p\}$, there the time slot required for completing the recharge process of nodes in SN is given as P(=Nj). Moreover, a node with $RES_n^t = 0$ is considered to be $S_{non-active}$, which is presented in the disjoint subset SN_i, when it finds an optimal matching to virtual slot. Simultaneously, the active nodes are listed increasing order of their remaining lifespan, given as $RL_1, RL_2, ..., RL_N$, in which 'N' denotes $|S_{active}|$. For each $S_N \in S_{active}$, it can be observed that there are some active nodes, if it is recharged by a charger node at the 'p'th time slot, where S_N is matched to S_j', p($=\frac{j}{N}$). Further, the sensor sets are divided and in order to minimize the travel distance of charging vehicle, Si is presented in the subset SNHmin, where $= arg_{min_{p \leq r \leq p}}\{ED(S_i, S_r)\} = min\, S_j \in S_r\{ED_{i,j}\}$.

Here, $ED_{i,j}$ denotes the Euclidean distance between two consecutive sensors.

Based on those considerations with the divided subsets of sensors, the model determines Minimum Span Tree 'TR' that covers all nodes in the P+2 subsets of $S_0, S_1, ..., S_{P+1}$. The minimum span tree is framed for each sensor subsets, which is not having empty set. The algorithm creates tree by joining the links $TR_1, TR_2, ... TR_{P+1}$ in consecutive steps. The mathematical derivations finally convert the TR to the Analytical Charging Route called CR that begins at node S_u and ends at S_v. The route from S_u to S_v is initially determined based on the tree 'TR' formation. By reproducing the edges of TR with respect to the route, the graph 'L' id framed. From that, Eulerian route from the two nodes are determined, by which the 'CR' is effectively obtained by replicating the nodes involved in Eulerian distance. The algorithm for Analytical Charging Route formation is presented in the Table 2.

Table 2Algorithm for Analytical Charging Route Formation

Input: Graph G=(SN $\cup \{BS_i\}, ED; WT$), remaining lifespan of nodes 'RL_n^t'
Output: Analytical Charging Route based on Least Active Time of Nodes

1. **Begin**
2. **Call** LeastActiveTime()
3. Let $S_{non-active} = \{S_i | S_i \in SN, (P-1)\tau > RL_n^t\}$
4. Let $S_0 = \{S_u\}$ and $S_{P+1} = \{S_v\}$
5. Let $S_r = \emptyset, 1 \leq r \leq p$
6. $\forall S_i \in S_{non-active}$, add S_r to subset S_p
7. Sort nodes in S_{active} in increasing order of RL_n^t
8. **for** $\forall S_i \in S_{non-active}$ **do**
9. Let p($=\frac{j}{N}$) and $p' = min\{\frac{RL_n^t}{\tau} + 1, p\}$;
10. **If** subset S_p is empty **then**
11. **Add** node S_i to S_p

12. **End if**
13. **End for**
14. Let MST 'TR'=$\{S_u\}$;
15. **For** $\forall$ subset $S_r (1 \leq r \leq p + 1)$ do
16. **If** S_r contains sensors **then**
17. Determine TR of sensors in S_r
18. Consider, 'v=maximum node index'
19. Add TR$_r$ to TR with the min_WT between sensors S$_i$ to S$_r$
20. **End if**
21. **End for**
22. Convert TR to Path CR
23. **Return** CR
24. **End**

PARALLEL CHARGING PATTERN USING SPD WITH MCNS

In order to increase the active time of sensor nodes, an enhanced parallel charging pattern is framed with improved replenishment capability. In the proposed IENCR model, it is assumed that there 'M' number of MCNs, which are given as $\{CN_1, CN_2, \ldots, CN_m\}$, for recharging the nodes with minimal RES_n^t and RL_n^t. Moreover, each CN_i is embedded with a battery with high-capacity. Initially, the charging device is located at the BS. In each recharge cycle, the SPD starts moving from the base station and comes back to it for recharging for themselves, when the 'M' MCNs finishes the recharge service to nodes. It is also assumed in proposed work that the SPD and MCNs are having enough amount of battery power for completing the charging cycle.

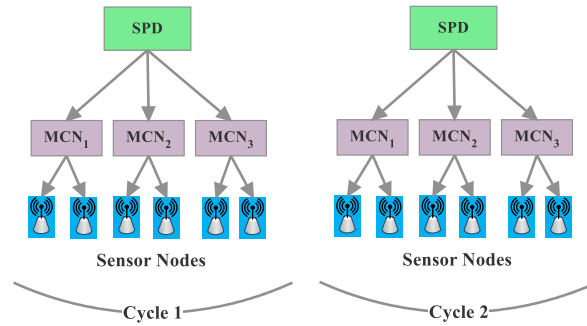The pictorial representation of energy replenishment process of proposed model is given in Figure 3.

Fig. 3. Energy Replenishment Process of Proposed Model

The number of MCNs is divided for the nodes having least active time and to be recharged for being in active state. That is, 'N' number of sensors in each sensor set is divided with 'M' number of MCNs. Here, it is considered that N=k.M, where 'k' is the positive integer. It is also to be assumed in the proposed model that the SPD travels at constant speed v, the MCN replenishes sensors at the recharge rate of μ and the recharge times are similar for all nodes in the network. That is, '$\Delta C_t \approx BP. \mu$, where BP is the battery power of each node. From the derivations in the aforementioned sections, for a set of sensors SN, the charge_plan is stated as, $S_1 \rightarrow S_2 \rightarrow .. \rightarrow S_n$. In the parallel charging pattern, the MCNs perform energy replenishment for the SN in the following process. Here, the SPD begins from bs_i and reaches the first set of sensors $S_k = \{S_1, S_2, \ldots, S_k\}$ one by one, by fixing the charging nodes in the location of each node in the set. After performing charge replenishment, the SPD moves to all the sensors at Sk for colleting the MCNs from the sensor locations from S_1 to S_k. Following, the portable device that carries the MCNs are moving to the next set of sensors, given as, $= \{S_{k+1}, S_{k+2}, \ldots, S_{2k}\}$. The process repeats till all nodes in the Sequence(charge_plan) to be charged and then, the SPD comes back to the BS.

Based on the Analytical Charging Route, the charging cycle can be shown as, BS$\rightarrow (S_1 \rightarrow S_2 \rightarrow .. \rightarrow S_k) \rightarrow \rightarrow (S_1 \rightarrow S_2 \rightarrow .. \rightarrow S_k) \rightarrow (S_{k+1} \rightarrow S_{k+2} \rightarrow .. \rightarrow S_{2k}) \rightarrow (S_{k+1} \rightarrow S_{k+2} \rightarrow .. \rightarrow S_{2k}) \rightarrow \cdots \rightarrow S_n \rightarrow$BS. As mentioned above, the charging route is framed by considering the remaining energy and remaining lifespan of each node.

The scenario explains the work process of the proposed IENCR model using SPD with MCNs is shown in Figure 4. The SPD follows the path derived from Analytical Charging Route, based on the residual energy and lifespan of each sensor node. The nodes are prioritized based on the least active time provided in the section 4.3. The SPD travels to the locations of those nodes and deploys the charging node. After recharging, the SPD travels along the same path for collecting those nodes.
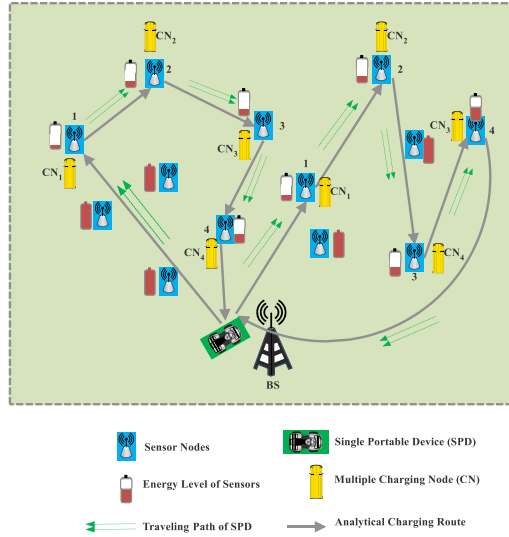
Fig. 4. Work Process of Proposed Model with SPD and MCNs

RESULTS AND DISCUSSION

This section presents the performance evaluations of the proposed model by experimenting it using the simulation platform called Network Simulator (NS-3). The obtained results from the evaluations are compared with the existing models such as, Collaborative Mobile Charging (CMC), Particle Swarm-based Charger Deployment (PSCD) and Schedule-based Optimized Node Recharging Model (SONRM) for evidencing the efficacy of the proposed IENCR model. Moreover, the models are evaluated on the basis of factors such as charging efficiency, number of active nodes in the designed WRSN, Mean time for recharge, average throughput, and Active time of sensors and average lifespan of nodes.

For simulation, it is considered that the sensor nodes are distributed in 1000×1000 m² area and the BS is located at the central position. There are 10 to 100 nodes are assumed to be present inside the sensing area for observation, which are deployed in random manner. The Single Portable Device (SPD) that carries multiple charging nodes is located nearer to the base station, from which the SPD is started to move along nodes. The mobile speed of SPD is taken as 5 m/s. The SPD will carry K number of mobile charger nodes and value of K ranges from 1 to 4. Moreover, the replenishment rate of each charger is taken as 5 w/s. Here, the battery power (BP) of each node is 10.8KJ. The data sensing rate of each node is lies between 1kbps to 10 kbps. The sensors transmits charging request to the BS, when the remaining lifespan becomes lesser than the threshold lifespan value, RL_n^t. The initial energy level of each sensor is given as 500 joules. The Initial values for the significant simulation parameters are presented in Table 3.

TABLE 3 Simulation Parameters and Values

Simulation Parameters	Initial Values
Simulation Tool	NS-3
Sensing area (Simulation area)	1000m x 1000m
Simulation Time	1000s
No. of sensors	Varies from 10 to 100
Energy Level of each sensor	500 Joules
Energy Level of each Charging Node	50000 J
Mobility Model	Random Waypoint
Mobility speed of MC	3 m/s
Traffic type	CBR
Payload Size	512 bytes
Energy Replenishment Rate	5 w/s
MAC type	IEEE 802.11

Mobility speed of Charging Node	3 m/s
Transmission Range	250 m
Frequency	9 Mhz

Among the factors for evaluating the proposed model, charging efficiency analysis is a significant and the comparison chart is portrayed in Figure 5. Here, the charging efficiency is analysed on the basis of increasing number of nodes. It can be observed from the figure that the charging efficiency obtained by the proposed model is approximately 91%, which is greater than other models. Because of the utilization of multiple charging nodes, parallel charging is possible in the proposed mode, which enhances the efficiency of charging.
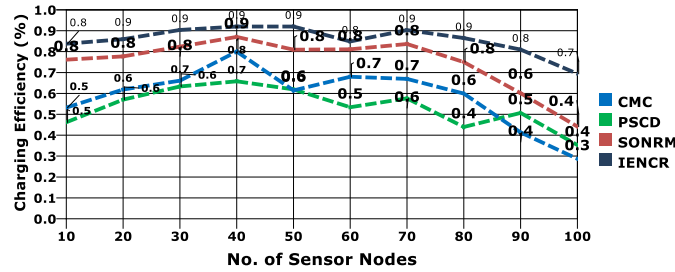

Fig. 5. Analysis of Charging Efficiency

In the designed WRSN, the network longevity can be evaluated based on the number of active sensors present in the network. Hence, number of active nodes with respect to the simulation time is found and the results are presented in Figure 6. Among other models, the number of active sensors presented at the end of the simulation time 1000 seconds is more in the proposed IENCR model. This is achieved by the optimal replenishment model derived by considering the lifetime and energy of nodes, along with the formation of Analytical Charging Route, through which the number of sensors to-be-dead are effectively reduced. The figure 7 presents the results obtained for average active time of sensors with respect to the simulation time. Here, the lifetime of each sensor can be maintained high, when compared to other models, using the efficient energy replenishment model that serving the nodes at right time.
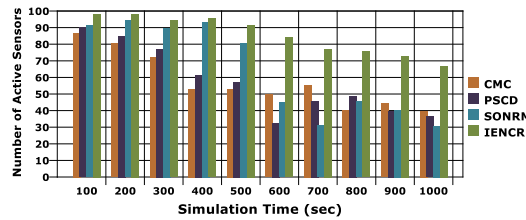

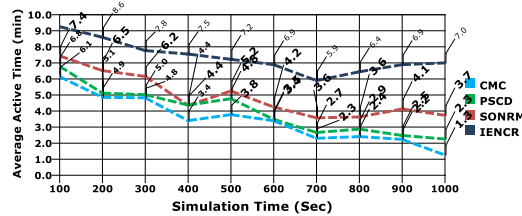**Fig. 6. Number of Active Nodes on Simulation Time=1000seconds**

Fig. 7 Average Active Time of Sensors with respect to Simulation Time

The analysing mean recharging time of each node is another important factor for evaluating the work process of a recharge model in WRSN. The values of Mean Recharging time for models are given in Table 4 and chart is displayed in Figure 8.
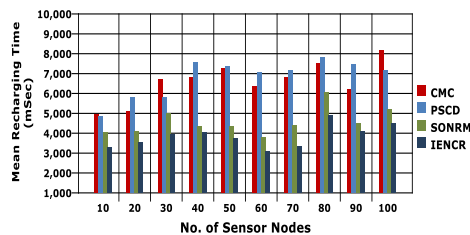

**Fig. 8 Mean Recharging Time of Sensor Nodes**

Comparing the results of other methodologies of recharging nodes in WRSN, the proposed IENCR achieves lesser time, which make the model more efficient than others. Here, the speed recharge is obtained using the multiple charging nodes in optimal charging pattern. On considering the charging throughput, defined as the number of sensors getting recharged among the sensors at energy requirements.

Table 4 Values obtained for Mean Recharging Time Analysis for Models

No. of Sensors	10	20	30	40	50	60	70	80	90	100
CMC	4,935	5,075	6,704	6,802	7,243	6,328	6,797	7,499	6,214	8,142
PSCD	4,844	5,816	5,816	7,554	7,369	7,047	7,129	7,810	7,450	7,151
SONRM	4,023	4,073	4,988	4,350	4,312	3,757	4,394	6,028	4,481	5,173
IENCR	3,294	3,544	3,936	4,035	3,740	3,092	3,343	4,879	4,089	4,481

The results are displayed in Figure 9 and it is obvious from the figure that greater charging throughput than other models than others.
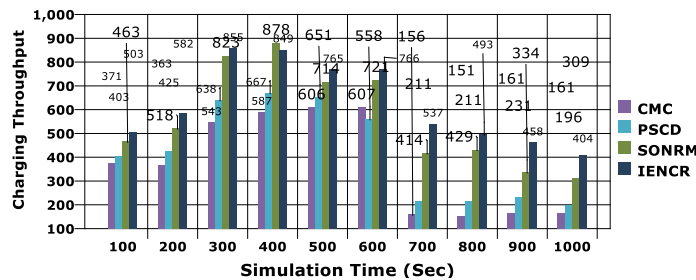
Fig. 9. Charging Throughput Vs Simulation Time

CONCLUSIONS AND FUTURE SCOPES

In this paper, a novel model for recharging sensor nodes in WRSN called Improved Energy-based Node Charge Replenishment Model (IENCR) is proposed. The model uses Single Portable Device (SPD) that carries Multiple Charging Nodes (MCNs) for recharging nodes simultaneously, when there is a demand for energy among nodes for sensing the environment and transmitting that to the base station. Moreover, two algorithms are derived in the proposed model for deriving the least active time of nodes and analytical charging route based on remaining energy and the remaining lifespan of sensor nodes. These algorithms make the model more efficient by increasing the lifetime of each node and thereby increasing the overall network longevity. The simulation results showed the efficiency of the proposed model based on factors such as charging rate, efficiency and network lifetime, and that outperform the existing models.

In future, the scheduling model can be focussed for using multiple charger nodes in large-scale WRSN. Moreover, methods can be derived for minimizing the number of charging nodes to be used for recharging sensors.

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