LBCSM: Load Balanced Constant Scheduling Model for Node Recharging in Wireless Rechargeable Sensor Networks using Multiple Mobile Charging Devices

G. R. Sakthidharan, P.Saravanan, P. Chandra Sekhar Reddy, V. Saravanan

Abstract*: In large-scale Wireless Rechargeable Sensor Networks (WRSNs), limited battery capacity of nodes may reduce the network longevity. For enhancing the network lifetime, the nodes in the network can recharged periodically based on their operational executions. The rechargeable sensor nodes in the network are replenished using external sources. Using single charging device can be feasible only for small scale WSNs, whereas in managing large scale wireless sensor networks, multiple charging devices are to be modelled for efficiently recharging the sensor nodes, since single devices are having energy constraints to recharge more number of nodes. On focussing those issues, this paper contributes on developing a new model called Load Balanced Constant Scheduling (LBCS) for the replenishment of the sensor nodes. Moreover, multiple Mobile Charging Devices (MCDs) are used here for recharging the sensor nodes effectively, without facing resource limitations. In this model, constant and time based charge scheduling approach and charging route for MCD has been frame optimally. The scheduling mode focuses on a concrete classification procedure for avoiding needless visits of nodes having adequate energy. Providing further improvement in schedule based node replenishment, algorithm for Charging Route Definition (CRD) is also developed in this work. For evidencing the efficiency of the proposed model, the work is simulated and evaluated. The simulation results are compared with some existing models based on the network lifetime, time taken for recharge and efficiency.

***Keywords* : Wireless Rechargeable Sensor Network (WRSN), Load Balanced Constant Scheduling (LBCS), Mobile Charging Devices (MCD), Charging Route Definition (CRD).**

I. INTRODUCTION

In the present decade, the applications of Wireless Sensor Networks (WSNs) are widely used in various fields like security and military services, IoT, health monitoring, video surveillance, etc [1,2].

But, the sensor nodes in WSNs are highly resource constrained, which may reduce the longevity and performance of the network [3, 4]. Hence, it has become a great issue in WSN to enhance the network lifetime with better performance. Specifically, energy is a very significant metric that creates greater impact on the performance of large-scale WSNs. As is auspicious, the sensor nodes acquire energy from batter resources, which are having limited resources. Therefore, the researchers of previous works on increasing the network life involves in reducing the energy utilization using models like efficient routing [5] and in some other works energy harvesting techniques [6] have also been included for fixing this issue.

In recent trends, portable charges are utilized for charge replenishment of sensor nodes using some external energy sources. Different from conventional efficient energy utilization and harvesting techniques, using charges provides resource stability and consistent energy resources to the sensors [7]. Hence, Wireless Rechargeable Sensor Network has become an emerging field, in which, the sensor nodes are periodically recharged using two techniques in general, using energy harvesting method or with some charging devices. This prevents the node from being dead or inactive during the processing over network. In the first type of node recharging, the energy is observed from the environment includes water, solar, etc for recharging sensors [8, 9]. In the second type, the more stable method of node recharging is provided using a portable charger [10, 11]. Moreover, the recharging of nodes can effectively done with some scheduling models for making the network performance more effective, reducing resource wastage and enhancing efficient resource utilization [12].

For prolonging the network lifetime, effective recharge scheduling model is required, which focuses on both the coverage of sensing area and the part of connectivity of the nodes. Based on that, this paper presents a new model called Load Balanced Constant Scheduling (LBCS). The model schedules the charging operations based on the functions to be accomplished by the sensors using multiple Mobile Charging Devices (MCDs) with optimal route formation for refilling the sensors with sufficient power, periodically. The model also focuses on,

- Reducing the energy starvation of nodes due to late recharge

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- Enhancing charging efficiency by preventing the MCDs visiting sensor_nodes with sufficient energy
- Using multiple MCDs to prevent the nodes from waiting for recharge (reduces the waiting time of node for replenishment)

Instead of using single mobile charger for serving the whole network, here, multiple MCDs are used. It reduces the waiting time of nodes for getting recharged. In some cases, when single charger is used, the node may dead before the charger comes to that. And, with single charger, only small WSN can be maintained effectively. For large-scale WSN, multiple mobile chargers are to be used [13]. The scenario of recharging sensor nodes based on its remaining energy is illustrated in the Figure 1.

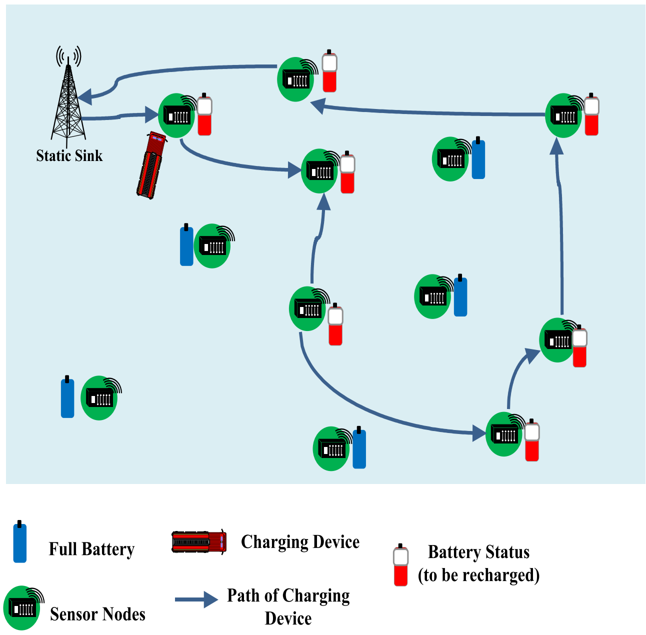

Fig. 1.Illustration of Recharging Sensor Nodes using Charging Device

1.1. Contributions of this Work:

1. Load Balanced Constant Scheduling (LBCS) is developed for enhancing the network lifetime
2. Concrete Node classification procedure has been defined for avoiding unnecessary visit of chargers to the nodes that are having higher source of power
3. Multiple MCDs are used for avoiding the waiting time of nodes for power replenishment and boosting the recharge efficiency
4. Parallel to Multiple MCDs, Charging Route Definition (CRD) is also developed for proving optimal routes for chargers to move in the sensing area towards nodes with lower power
5. Using this, the sensor nodes are refilled with power, parallel with multiple chargers

The remainder of the paper is organized as follows: Section 2 presents the literature survey based on the proposed model. Section 3 provides the background model. The working procedure and the computations involved in the proposed LBCS model are described in Section 4. Section 5 contains the experimental analysis and simulation results. Finally, Section 6 concludes the paper with some ideas for future enhancement.

II. RELATED WORKS

In [14], wireless recharging mechanism for small-scale wireless sensor networks has been developed based on proof-of-type protocol. The routing issues of WRSN were clearly defined in [15]. Optimal Scheduling model has been designed for efficient energy distribution using mobile chargers in [7]. The sensor nodes has scheduled for efficiently observing the operational quality in the network. Approximation model based on constant approximation rates for charging efficiency using mobile chargers could be enhanced [16].

Another work in [17], discussed about the localization approach in WRSN based on TOC called Time of Charge. The authors of [18] have used the semi- Markov Energy Prediction model, for performing the functions called joint energy refilling and data gathering from sensors. In the model, the sensing area was divided into number of clusters and each cluster had been provided with two charging devices for recharge. On demand based recharging mechanism has been developed in [19], thereby, efficient energy consumption was accomplished. Moreover, optimal path has been framed for refilling the sensor nodes that are low in energy. But, this algorithm could not provide any assurance for improving the overall network performance.

Several researches have been done based on efficient energy consumption and recharging. In [20], the mobile charger has been designed to recharge the sensor nodes in periodical manner for maintaining prolonged network functions. Moreover, the authors have discussed about the technique for increasing the rate of idle time of the mobile charger and the periodic time. The methodology utilized Travelling Salesman Problem (TSP) based solution for various recharging issues. The same TSP based pre-optimized charging models have also been utilized in the works [21] and [22]. In such cases, the charging vehicles are designed to move in a pre-optimized path for replenishing a sensor group in the large scale WSN. Nevertheless, it is very hard for the TSP based solution model, when there is a variation in the utilization rate of energy amount among the sensors. This scenario may cause redundant or needless trip to the sensors that are having adequate energy for data processing. This may also increase the path length of the charging vehicle to be travelled and also increases the waiting time of the nodes that are already in need of energy (called energy starvation nodes).

Energy Synchronized charging protocol called ESync was developed by the authors of [23]. Considering the energy utilization rate of the sensor nodes, nester TSP tour has been designed, in such a way that, the nodes with minimal energy are given more priority on framing the tour. Thereby, needless visits of charging vehicles to the nodes having higher energy levels were prevented effectively. But, in ESync model, the loads of recharging mechanism among sensor are not balanced on all visits. Hence, the work of this paper concentrates on load balancing recharge framework based on constant energy management.

In a different way, combined model of energy recharging and data accumulation based on anchor based model was given in [24].

The model addressed the issues on energy consumption variation on nodes and time variations during the node recharge.

For providing reliable power supply to the overall network, parallel charging mechanism has been designed in [25], which is termed as multi-node charging model. But, for that, the model depended on a single charger with may provide various complications. Moreover, the technique is feasible only for small scale networks, which ranges from 50 to 100 meters of sensing area. Further, the works that are given in [26] and [27], discussed about using multiple charging vehicles from charge replenishment of nodes. The energy distribution issues have been well addressed using he heuristic model and the approximation technique. On-demand based Real-Time Charging Schedule Scheme (RCSS) was given in [28] for providing charging facilities for the sensor nodes based on their energy consumption rates.

III. BACKGROUND MODEL

In the proposed model, it is considered that the large-scale WSN is framed with number of energy rechargeable sensor devices. The devices can be replenished using number of Mobile Charging Devices (MCDs). The MCD is an energy transmitting device containing sufficient energy storage for recharging nodes. The MCDs are travel along the network path for providing parallel recharge to multiple sensors that are in need of energy sources. When the MCDs are in the sensing area, which is having nodes with energy starvation, 'n' number of MCDs are used for recharging 'n' number of sensor nodes, considerably. When Sb is the status of the battery, the MCD will take TDc Time Duration to complete full recharge on the specific sensor node from zero battery level. Then, the MCD will move to next region for proving energy services to the starved node. This complete recharging mechanism is termed as single Charging_Round (CR).

It is well-known that the working process of sensor nodes is to accumulate data from the environment and transmitting that the Base Station (BS). The transmission of data is carried out in multi-hop mode, and all the sensor nodes in each hop distance are with full battery initially. The charge dissipation is initiated, while the process of data accumulation starts. It is also to be assumed that the network topology routing paths of the nodes in WSN are stable. But, based on the data gathering and transmission process, the energy consumption rate of the sensor nodes are non-stable. The nodes that are closer to the BS have to do more functions and dissipate more energy than the other nodes. Accordingly, those nodes are needed to be recharged frequently than the nodes in other parts of the network. For providing perfect balance on the rates of energy consumption and energy supply, an efficient scheduling algorithm is derived. This also involves in increasing the network lifetime and performance.

IV. WORKING PROCEDURE OF LBCSM

This paper described a mechanism for recharging sensor node, in periodic manner using the Load Balanced Constant Scheduling Model (LBCSM) with the consideration that all nodes acquire stable rate of energy utilization. Moreover, periodic Charging_Rounds are used for supplying energy to the nodes in constant rates. For that, the sensor nodes are classified and scheduling is accomplished based on the time-window basis. Further, load balanced scheduling methodology is described.

4.1. Concrete Classification Procedure

Based on the energy utilization rates of sensor nodes, the nodes are classified and the classification results in efficient construction of CRs for energy replenishment. In the classification model, the power is denoted as 'ρ' and it creates a greater impact on defining performance efficiency of charging. When the sensors are at energy starvation, the nodes may have the residual energy of '$\frac{\rho-1}{\rho}$' in total. In concrete classification procedure, the nodes are grouped on the basis of energy dissipation with certain limits. Moreover, two design factors 'ρ' and 'φ', which define the energy levels of the sensor nodes. And, the procedure performs two steps for nodes classification.

Step 1: In this procedure, 'n' time intervals are built based on the amount of time slot needed for node recharge.

Let $TD_{(min)} = \frac{S_b}{ECR_{max}}$ be the minimal time slot needed for charge replenishment of all nodes in the network. Further, the time slots are divided into 'n' intervals, as,

{[$TD_{(min)}, \rho TD_{(min)}), [\rho TD_{(min)}, \rho^2 TD_{(min)}), \ldots, \rho^{N-2} TD_{(min)}, \rho^{N-1} TD_{(min)}), [\rho^{N-1} TD_{(min)}, \frac{S_b}{ECR_{max}}]$ },

Where '$TD_{(min)}$' is the minimal time durarion taken for completing the recharge process and 'ECR_{max}' is the maximum Energy Consumption Rate.

Step 2: Each interval is equally separated into 'φ' number of sub- classes. The k-th interval (k=1,2,3,..., n) interval $\left[\rho^{k-1} TD_{(min)}, \rho^{k} TD_{(min)}\right)$ is divided into number of sub intervals. The recharging time required for all sensor nodes are in the divided sub intervals. Hence, in the k-th sub class, the recharging time with respect to the 'φ' sub class is given as,

$$\rho^{k-1} TD_{(min)}, \frac{\rho^{k-1} TD_{(min)}(\varphi+\rho-1)}{\varphi}, \ldots, \frac{\rho^{k-1} TD_{(min)}(\varphi+(\varphi-1)+(\rho-1)}{\varphi}.$$

In total, there are approximately 'φn' sub-classes. Using this classification procedure, the recharging efficiency can be increased effectively. The residual energy of the sensor node that are to be charged is given as $\frac{(\rho-1)}{(\varphi+\rho-1)}$. It can be clearly stated that minimal value of 'ρ' and maximal value of 'φ' may lead to the lesser residual energy of sensors. The sample scenario of classification is given in Figure 2. The nodes that are nearer to the base station dissipate more energy than the other nodes in the field.

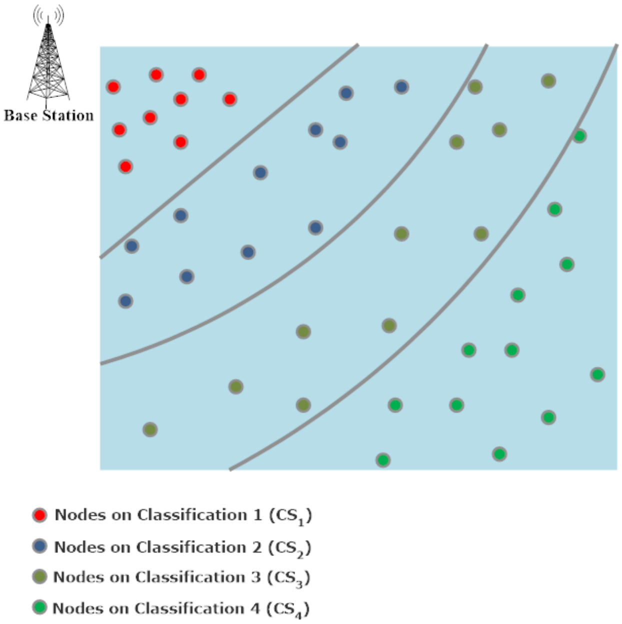

Fig. 2. Sample Scenario of Sensor_node Classification

4.2. Time-Window based Constant Scheduling

In the proposed LBCSM, Constant Scheduling algorithm is developed for recharging the node in periodic manner using Charging_Rounds (CR). The operations in each CR are similar and will be repeated in each process. Based on the demands of nodes for energy, the charging time is varying node-by-node. For assisting that, in the proposed model, the overall recharging time is dived in to rigid time intervals called 'time-windows' (TW). A particular CR comprises several TWs, and for serving each, the MCDs move for charging the sensor nodes that are having minimum or lower energy levels. A Time-Window can also be clearly defined that it is the least time segment in which a CR can be accomplished. Since the sensors utilize energy in different rates, in each TW, the nodes under different classifications are replenished. It is also to be maintained that each round should be completed before ending the current TW process; thereby assuring the next round can be initiated on time in the next TW. Moreover, time-window based constant scheduling is combined with the process of load balancing incorporation for the efficient development of the proposed Load Balancing Constant Scheduling Model.

The total length of the window is given as follows,

$$T_L = \frac{(\rho-1)TD_{min}}{\varphi} \quad (1)$$

It can also be termed as the time duration taken for the first sub-class. Therefore, the total recharging time needed for all nodes under all classifications are the multiples of the window length. In this scenario, both the Charging_Round duration and the needed recharging time for all classifications can be calculated based on the amount of time-windows. When the sensor_nodes are classified into 'z' number of classes, in which 'z' denotes z(z= φn) and classes as {CS_1, CS_2,..., CS_z}. The required recharging time for classes CS_z (z=1,2,3,..,Z) is given as RT_z. Based on the concrete classification and the time-window based constant scheduling process, the energy replenishment for the starved nodes can be effectively done. It is also possible to schedule several classifications of sensor nodes in a single TW. Based on the scheduling process, the MCD involves in recharging the nodes in such a way that the gap between every two successive recharges is not larger than its required least recharging time.

4.3. Incorporation of Load balancing Operations

In the previous section, the scheduling process is discussed for energy recharging. But, the numbers of sensor_nodes that are to be refilled in each CRs are not balanced in all rounds. For balancing that, load balancing operations are included in this work, for balancing the replenishment functions through all time windows. The nodes are evenly serviced in each time window that is indistinguishable.

A particular class CS_z is divided into number of sub-classes as, $m_z^{sub} = \frac{RT_z}{T_L}$.

Then, each sub-class is offered with energy service according to their time window based scheduling. The process contains two steps,

1. Each class CS_z is divided into number of sub-classes
2. Each sub-class is further allotted into time-windows

By processing the two steps, the recharging operations are optimized for each Charging_Round (CR).

4.3.1. Process of Dividing the Sub-Classes of Sensor_nodes:

The process of making sub-classes is accomplished using the clustering mechanism. This categorization is done based on the energy utilization rates of the sensor nodes. Here, K-means clustering algorithm is applied for dividing the classes, in which the centroid values are appended based on R number of iterations. In each R_{iter}, each class is divided into two classes based on their similarities. In the algorithm, the class with larger sizes are selected first for the process of sub classification for balancing the amount of sensors to be refilled in each round.

4.3.2. Balanced Management of Sub-Classes:

After the process of sub-class division, the scheduling is framed for each time-window. There are states are to be assured with this,

i. Each sub-class of CS_z is to be replenished in every $\frac{RT_z}{T_L}$ periods

ii. Single Sub-class of each classification is to be recharged in every round

The Table 1 contains the algorithm for Sub-Class Determination and their Balanced Management effectively. The process initiates with the empty schedules and on process, completes 'Z' iteration for framing schedules. In each round, biased schedule is updated by proper allotment of sub-classes to process. Moreover, the biased schedule is termed as B_n, in which the distance between that and the corresponding sub-class, CS_{zk} is given as, $B_n\left(n = 1,2,3,\ldots,\frac{T_L}{T_D}\right)$, denotes the distance between two closer sensors and the schedule. Further, the distance is given as, $\omega(CS_{zk}, B_n)$.

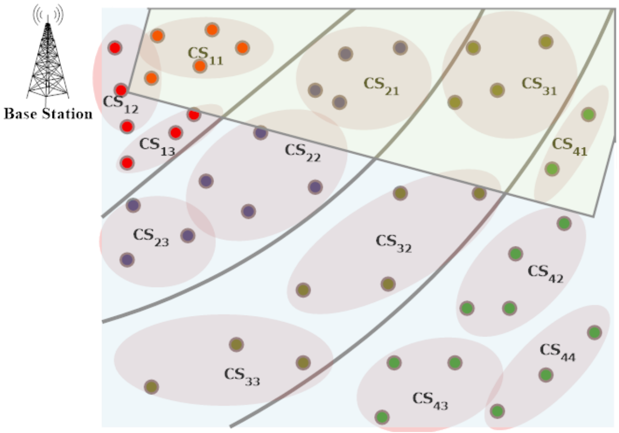

Fig. 3. Sample Scenario with 13 Sub-Class and Balanced Scheduling for Replenishment

The Figure 3 portrays a sample scenario of balancing 13 sub-classes in the defined sensing area from 4 main classification of sensor nodes based on their energy rates. In that, the four sub-classes {CS_{11}, CS_{21}, CS_{31}, CS_{41}} are scheduled based on the proposed algorithm in the single time-window.

Table 1: Algorithm for Sub-Class Determination and Balanced Sub-Class Management

//Sub-Class Determination of CS_z

Input: Class CS_z

Output: Sub- Classes m_z^{sub}

For 1 to m_z^{sub}

Do

Select Class for Sub division

For 1 to R_{iter} **do**

Divide the selected class using k-means approach

End for

Select the clusters with higher similarities

End for

//Balanced Sub-Class Management

For each Class z

Get m_z^{sub}

For all biased schedule $B_n \leftarrow \theta$

For all z=1 to Z **do**

For all n=1 to m_z^{sub} do

Select B_n and CS_{zk} that reduces $\omega(CS_{zk}, B_n)$

End for

End for

4.4. Charging Route Definition (CRD) for multiple Mobile Charging Devices (MCDs):

This section describes about the processing Charging Route Definition in each CR for managing with the multiple mobile charging devices for simultaneous recharging operations.

It is considered that are 'k' number of MCDs in every CRs. In each charging round, single charger is allotted for each sensor node. The Mobile Charger Device is to be deployed for recharging the node at starving of energy. After accomplishing the recharging process in single round, the MCDs are moving to the successive target area for initiating the next round of energy replenishment process. Based on this, the charging devices are designed to perform multiple rounds of node recharging.

In contrast to the traditional single charger mechanism, the proposed model utilizes multiple charger model for charging the sensors with multiple chargers simultaneously, thereby, reducing the waiting time of the starved nodes for long time. Additionally, it also reduces processing time of each charger and hence, in each round, more number of nodes is replenished. The Figure 4 depicts the route definition for charging nodes that comprises four CRs. It is clearly noted in the figure that a complete CR contains the route within CRs and routes between CRs. Moreover, it is to be stated that the path is determined by the solution of Travelling Salesman Problem (TSP).

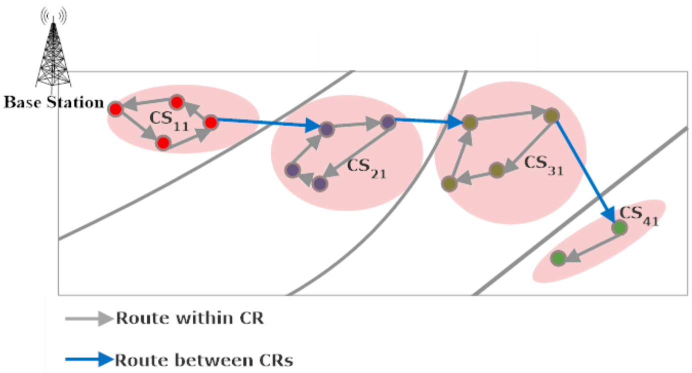

Fig. 4. Route Definition for Recharging Nodes

Clustering of sensor nodes for efficient routing is incorporated here for solving the critical issues in CR management and framing. The algorithm provides the solution for how to derive route for efficient node recharging. The clustering models are framed with 'x' sensor_nodes involved in the round that is classified under several clusters. It is also to be stated that every cluster contains 'M' nodes approximately. In this scenario, all SN (sensor_nodes) in single cluster can be replenished in single CR in parallel manner. When SNs in one round are optimally clustered in such a way that every CR only performs in sensors nearer. This makes the time acquired in executing each round can be effectively reduced and the time taken by the charging round is also reduced. In Table 2, the algorithm for clustering model of SNs in efficient CR execution is presented.

Table 2: Algorithm for Clustering Model of SNs in Efficient CR Execution

While Size(Cluster)>M **do**
Select the cluster for division
For 1 to R_{iter} **do**
Divide the selected class using k-means approach
End for
Select the part with maximum similarity
End while
Put all CS_z in S
While $S \neq \theta$
Select a CS_i with larger size
If dividing CS_i reduces processing time **then**
Divide CS_i
End if
$S \leftarrow S/CS_i$
End while
Put all CS_z in S
While $S \neq \theta$
Select a CS_i with smaller size
If releasing CS_i reduces processing time **then**
Release CS_i
Transfer nodes(CS_i) in neighbour clusters
End if
$S \leftarrow S/CS_i$
End while

The algorithm analyzes all clusters based on the ascending order of the cluster size (S). Compared with the cluster size, the nodes in the particular cluster are divided into further classes or released from the clusters accordingly. Hence, the routing can be effectively done and the optimal node recharging can be effectively done.

V. EXPERIMENTAL RESULTS AND EVALUATION

The proposed model is implemented and tested using the NS-3 Simulator with the initial settings as in Table 3. The obtained results are compared with the existing models such as On-demand based Real-Time Charging Schedule Scheme (RCSS) [28] and Energy Synchronized Charging Protocol (ESync) [23]. The proposed LBCSM are analyzed based on the performance metrics such as charging efficiency, number of surviving nodes in the network, average recharging time, processing time and charging throughput. The simulation region considered here is about 1000×1000 m2 and each node is assigned with 500J as initial energy.

TABLE 3: Initial Settings

PARAMETERS	INITIAL VALUES
Simulator	NS-3
Sensing area (Simulation area)	500m x 500m
Simulation Time	1000s
No. of nodes	Varies from 10-100
Energy Capacity of each node	500J
Energy Capacity of each MCD	50000J
Mobility Model	Random Waypoint
MAC type	IEEE 802.11
Traffic type	CBR
Payload Size	512 bytes
Moving Consumption	5 J/m
Recharging Rate	5 w/s
Energy capacity of PCD	50,000 J
Mobility speed of MCD	3 m/s
Energy Request Threshold	225 J
Transmission Range	250 m
Frequency	9 Mhz

The Figure 5 presents the comparison chart for evaluating the charging efficiency of the compared and the proposed LBCSM. It is clearly shown from the figure that the proposed model produces higher percentage of charging efficiency than others, since the model utilizes multiple MCDs for simultaneously recharging the sensor nodes. This reduces the waiting time of nodes for MCD and increases the charging efficiency. Moreover, the overall processing time evaluation is portrayed in the Figure 6. It also involves in evaluating the efficiency of the proposed model. On evaluation, it is shown that LBCSM obtains minimal amount of time to complete the overall recharging mechanism. Hence, it is evidencing the proficiency of the model.
The network lifetime of the considered large-scale WSN is determined based on analyzing the number of surviving nodes in the network. The result of the analysis is presented in the Figure 7. The analysis has been made based on the simulation time. From the results, it is obvious that the numbers of surviving nodes are more in the proposed model than others. It is achieved by providing periodic recharging mechanism before the nodes dissipate complete energy. The results produced 92% of nodes (in average) to be active in the overall simulation period.

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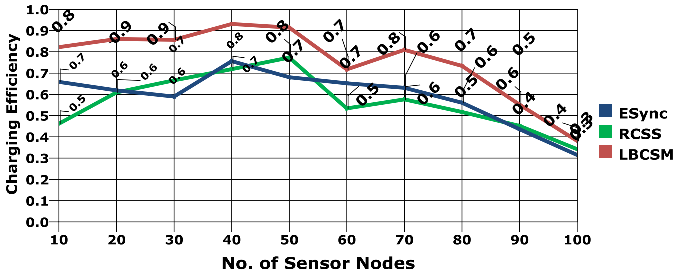

Fig. 5. Efficiency based Evaluations

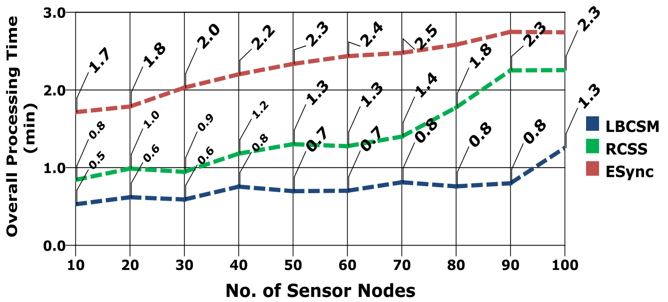

Fig. 6. Comparison between Models in Overall Processing Time

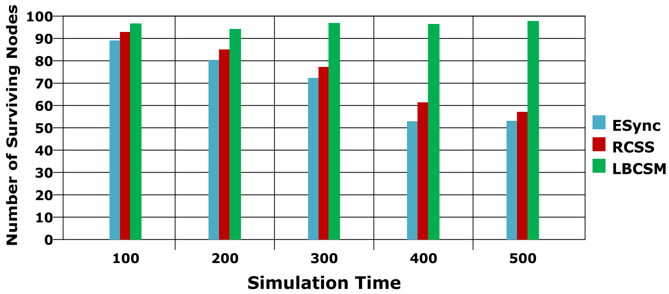

Fig. 7. No. of Surviving Nodes Vs Simulation Time

The average recharging time taken by the models for energy replenishment is analysed and the results are given in the Figure 8.

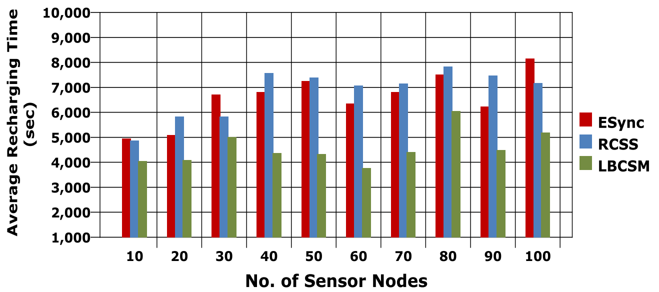

Fig.8. Average Recharging Time (RT) Analysis

It is explicitly shown from the figure that the recharging time (RT) taken by the Load Balanced Constant Scheduling Model is lesser than others. Because of the proper charging route definition based on the concrete node classification mechanism and load balancing technique, the nodes that are to be recharged are effectively scheduled. Hence, better results are achieved for the proposed model.

Further, charging throughput is another significant parameter to evaluate the efficiency of a proposed mechanism in WSN. In this result analysis provided in Figure 9, the model attain higher throughput in providing charging services to the energy starved nodes.

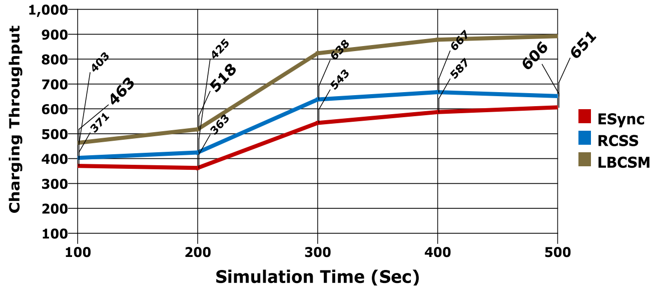

Fig. 9. Charging Throughput Vs Simulation Time

VI. CONCLUSION AND FUTURE ENHANCEMENT

In this paper, a novel method called Load-Balanced Constant Scheduling Model is developed for solving the energy recharging issues in large-scale WSN. The large number of nodes in the network is recharged using multiple Mobile Charging Devices (MCDs). Moreover, Concrete Node Classification procedure and time-window based scheduling model makes the process to provide efficient recharging for nodes based on their rates of energy consumptions periodically. For MCD, charging route definition is described using a clustering model, for providing efficient energy services to the nodes that are on energy starvation on time. The model has experimented using the NS-3 simulation tool and the results are analyzed on the basis of parameters such as charging throughput, Recharging time, network lifetime and efficiency. In the proposed model, the recharging time is very minimal for all nodes, since the waiting time of nodes is effectively reduced using the optimal scheduling. Further, network lifetime, efficiency and charging throughput is increased, when compared with other models, by providing better load balanced recharging mechanism.

In future work, the work can be extended on focusing the number of charging devices to be used for effective recharge model and also the co-ordination between the devices.

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