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Toward Efficient Mobile Electric Vehicle Charging under Heterogeneous Battery Switching Technology

Afaq Ahmad [1], Zahid Ullah [1], Muhammad Khalid [2] and Naveed Ahmad [3,*]

[1] Institute of Management Sciences, Peshawar 25000, Pakistan; afaqahmad348@yahoo.com (A.A.); zahid.ullah@imsciences.edu.pk (Z.U.)
[2] Department of Computer Sciences and Technology, University of Hull, Kingston upon Hull HU6 7RX, UK; m.khalid@hull.ac.uk
[3] Department of Computer Science, Prince Sultan University, Riydah 12435, Saudi Arabia
* Correspondence: nahmed@psu.edu.sa

Abstract: The fast increase in adoption and development of Electric Vehicles (EVs) has invited a significant challenge to the existing charging management techniques and infrastructure. It is necessary to efficiently manage a large number of mobile EVs. As compared to fuel and gasoline type vehicles, the EV has a limited driving range and needs to recharge its battery frequently during long journeys. Hence, with plug-in charging services one major concern is the long duration of battery recharging. In this paper, we employ heterogeneous BS (Battery Switching) technology to provide an alternative charging option to minimize the charging duration of EV. Furthermore, enabling BS reservation in a centralized manner for mobile EVs, load balancing algorithm and optimal selection of Battery Switching Station (BSS) across the network are proposed. In addition, we suggest a scheduling technique for depleted batteries to recharge effectively in BSS to minimize power loss and queuing time at selected BSS. We have conducted a performance evaluation by comparing the proposed scheme with other benchmarks, in terms of average trip duration, total trip energy consumption, etc. Finally, it is proven that the battery stock is managed across the network efficiently through the proposed scheme.

Keywords: electric vehicle; battery switching; E-mobility; charging scheduling

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1. Introduction

EV refers to a vehicle that is powered by electric energy. Normally, an EV can be charged from an external energy source and also discharged to an external energy source via a wall socket. Following the advancement of technology in the automobile industry and sustainable energy development, an EV can be compared to an Internal Combustion Engine Vehicle ($ICEV$) with the benefits of less emissions and air pollution [1]. As such, a lot of countries have pledged millions and billions of dollars to fund the development of EV to replace conventional vehicles with EVs. According to studies from the Center of Solar Energy and Hydrogen Research, the total number of EVs in the global market was 740,000 in early 2015. It is predicted that in the coming 50 years, the number of operational EV will reach 2.5 billion [2].

The proliferation and development of EV has derived both challenges and opportunities for the power grid [3]. On one hand, heavy load generation caused by EV integration into the power grid raises some issues such as operating cost, frequency excursion, and voltage stability at both (transmission and generation) side [4,5]. On the other hand, bi-directional charging and discharging have an extensive application of EV into the power grid, including peak shaving, frequency fluctuation mitigation, load flattening, and improving the integration of renewable sources [6]. The charging management of EV has been investigated in parking mode and in an on-the-move mode of charging. In the parking mode, an EV is parked at home/Charging Station (CS). On the other hand, EV's position is non-stationary in on-the-move mode. Without regard to modes, a major concern is to determine the time and place to charge EV [7].

1.1. Motivation

EV plays a key role in the advanced transportation system. Furthermore, a rapid increase of EV will not only reduce CO_2 emission but also dependency on fossil fuels [8]. However, EV users are still facing some challenges in practical drawbacks, such as the long duration of recharging the battery, limited driving range on a single charge and frequent requirement for recharging battery, higher operating cost, stochastic charging pattern and selecting convenient and appropriate CS for the requested vehicle [9,10]. There has been some work conducted relating to the charging management of EV in the parking mode and on-the-move mode [11–16]. These solutions in plug-in charging services have shown their effectiveness and minimized recharging time. However, fast charging technology is still taking around 15 min on battery recharging.

Therefore, BS can be a better alternative to provide more options in a cost-effective way. The whole process of BS takes 3–5 min in which depleted battery is replaced by a full charge battery [17]. As such, works considering BS have included scheduling technique, BSS placement and deployment [18–21] issues. However, the research works has been done in a homogeneous BS in which one type of battery is assumed in BSS. Thus, it leads to a lack of compatibility problem because each type of EV battery is different. Therefore, we employ a heterogeneous BS [22] where multiple types of EV battery are available in BSS. Along with this proposing efficient charging mechanism for mobile Battery EV (BEV) and scheduling technique for depleted batteries recharging.

1.2. Introduction of Battery Switch Services

In the automated switch platform, switching between a depleted battery from an EV and a fully charged battery is performed. The depleted battery is placed and recharged so that it can be used by other requested vehicles. This indicates that each BSS can maintain several batteries for switching. The battery switch service could be described as similar to a drive-through car wash in that switching an EV s battery is accomplished in several minutes normally without requiring a driver to get out of the vehicle. In heterogeneous BS, it is expanded to include several types of groups and hold certain types of batteries for different types of EV in BSS.

1.3. Study of a Heterogeneous-BS along with Reservations-Enabling

In addition to efficient charging mechanism for mobile EV under heterogeneous BS technology, our goal is to employ a battery reservation mechanism in BSS for mobile EV. EV send a request to Global Controller (GC) for reservation with the following information, that is, ID of the vehicle, current timestamp, average speed and maximum capacity of the battery. By proceeding the request contain information the proposed BS platform allocate the battery for requested vehicle in optimal (nearest and less congested) BSS.

1.4. Contribution of This Paper

The purpose of this research to develop an efficient charging mechanism is to minimize average waiting time, average energy consumption and is to increase the number of EVs successfully reaching to a BSS. The main contributions of the paper are as follows.

- Under heterogeneous battery switching technology, introducing a novel efficient charging mechanism for mobile EV and scheduling technique for depleted battery recharging.
- Proposed a battery reservation mechanism with the coordination of a global controller.
- Proposed algorithms for efficient charging and scheduling technique for depleted batteries recharging.
- The algorithms are discussed formally and compared the results with other benchmarks for measuring efficiency.

1.5. Paper Structure

The rest of the paper is organized as follows as: Section 2 presents an overview of up-to-date related research about EV plug-in charging services, EV charging scheduling and battery switch service of EV. Section 3 discusses in detail the system model, proposed work and along with this provides a detailed discussion regarding proposed work. Section 4, presents evaluation parameters, the simulation configuration environment and the results of the work, followed by a conclusion in Section 5.

2. Related Work

Most of the exciting work has addressed not only the plug-in charging service, but also the scheduling technique for on-the-move EV. Conundrums relative to plug-in charging services such as the long duration of battery recharging are also addressed. Moreover, some researchers address homogeneous BS and scheduling techniques to minimize recharging time and avoid congestion in BSS. The scheduling technique for charging and discharging plug-in EV aims to minimize the power loss.

2.1. Plug-in Charging Service

For the plug-in charging of EV, power flows from the grid to the EV battery. In [23], authors optimize the off-peak period to minimize charging cost and maximize the use of power. The authors in [24] propose to optimize the charging behavior of plug-in charging technology by minimizing the recharging cost, achieving a satisfactory energy level as well as optimal power balancing across the CS. Yi and Don [25] propose a smart energy control technique to not only balance the overall load profile of each grid and CS in the network but also minimize the peak hour's load to avoid energy loss. However, such issues lead to the main concern for mobility uncertainty. Therefore, some research work has been conducted to address charging reservations for plug-in charging EV to avoid overcrowding in CS while recharging the battery [26–29]. Several recent scientific studies on the optimal charging of EVs consider constraints induced by the power grid distribution lines and other components such as feeders [30–32].

2.2. On-the-Move Electric Vehicle Charging Scheduling

The authors in [33] propose a new scheme for CS selection and charging reservation of EV to minimize average trip duration. A request message for reservation includes arrival time and charging duration of EV. Furthermore, a periodical reservation updating mechanism to address mobility uncertainty is suggested to adjust the charging plan for the case when mobile EV can reach CS on time. The authors in [34] present two types of scheduling schemes for charging and discharging of EV, namely globally and locally optimal scheduling schemes. The scheduling schemes aim is to optimize charging power and minimize the recharging cost of EV, which can perform the charging and discharging process during the day. A novel charging booking algorithm is introduced to determine the most suitable charging station and search for the shortest route to preferred CS [35]. Several recent scientific studies focus on distributed/decentralized algorithms for large-scale situation, if and how the proposed model is able to deal with large-scale dimensionality of a large scale fleet of EVs [36,37].

2.3. Battery Switching Service for Electric Vehicle

The work in [38] describes a scheduling scheme for depleted batteries to recharge them efficiently and present an optimization framework for the operating model of BSS. The author of [39] proposes a novel charging strategy based on BS scenario by considering optimal BSS and charging priority of requested vehicles. The design approach and proposed model aim to minimize charging cost, voltage deviation and reduce power loss. Y. Cao et al. [18] propose BS technology to enable fast charging services, minimize the average trip duration, and reduce recharging time. Furthermore, its communication framework provides reservations for charging.

The author of [40] proposes a scheduling scheme considering the dual uncertainties of swapping demand and PhotoVoltaic (PV) generation. The objective of this research is to deal with uncertainties and minimize the cost of the electricity purchasing. Furthermore, for the evaluation quality assessment method, a probabilistic sequence for day-ahead scheduling is employed. However, Table 1 shows the summarize table of the related work.

Table 1. Summaries of related literature.

Papers	Checking Parameters							
Author [Reference No]	DC Fast-Charging	Charging Scheduling	Data Driven Framework	AC Charging Technologies	Solar PV Generation	NOL-MSSCA	Charging Reservation	Locally and Globally Scheduling	Route Optimization
Elma, Onur [23]	Yes	No	No	No	No	No	No	No	Yes
Shamsdin et al. [24]	Yes	Yes	No	No	No	No	No	No	Yes
Yi, Zonggen et al. [25]	Yes	No	Yes	No	No	No	No	No	No
Das, H.S. et al. [26]	Yes	Yes	No	Yes	No	No	No	No	No
Khan et al. [27]	Yes	No	No	No	Yes	No	No	No	No
Deliami et al. [29]	Yes	Yes	No	No	No	Yes	No	No	No
Cao et al. [30]	Yes	Yes	No	No	No	No	Yes	No	No
S.S. Barhagh et al. [31]	Yes	Yes	No	No	No	No	No	Yes	No
Zhang et al. [32]	Yes	Yes	No	No	No	No	No	No	Yes
Solanke et al. [28]	Yes	Yes	No	No	No	No	Yes	No	Yes

By considering a practical BS scenario where a number of BSS and EVs charging management is employed, their is less work conducted and a majority of the proposed work is based on homogeneous BS where a single type of battery is operated in BSS. Concerning the issue of efficient charging for mobile EV under heterogeneous BS technology and scheduling technique for a depleted battery recharging need an immediate solution.

3. System Model

By considering the high demand of EV and BS technology concerning the mobility feature of the vehicle, a suitable time and place to switch the battery is the main technical issue in this paper. Following related work for EV and switching service, we take different battery types of EV into account. Therefore, the proposed efficient algorithm for heterogeneous BS service and scheduling technique for depleted battery recharging can provide efficient service to EV.

3.1. Overview of System Model

The proposed heterogeneous BS model consists of three basic network entities, in which BSS are fixed deployed by considering a city scenario which is illustrated in Figure 1. By considering the position of EV, if Status Of Charge (SOC) of EV is below the minimum threshold, the EV moves toward the BSS with the help of GC. The basic network entities involved in the system model are described below.

- EV: Each $V_i \in U_1$ has predetermined minimum threshold where $U = \{V_1, V_2, V_3, \ldots, V_n\}$. When SOC of EV is below this threshold, a EV sends the request message to GC for BS. The message contains vehicle ID, location of EV, arrival time, and battery type of EV. Then, the GC checks each BSS in the network according to its battery type and confirm the request to the R_V (requested vehicle) by sending a reply message. When a reply message is delivered to the EV, a driver confirms the recommendation and tried to move EV toward the BSS to switch the battery.
- BSS: Each BSS maintains a stock of a limited number of fully charged batteries. These batteries are grouped into different categories according to heterogeneous EV type.

Furthermore, they are defined as a symbolic set X = {type–I; type–II; type–III; . . . ; type–X}. The depleted battery is replaced by a fully charged battery in BSS within 3–5 min. With such operations, these batteries are cycled from BSS to the charging factory for battery recharging to provide efficient service to EV.

- GC: A GC monitors each BSS in the network and manages the switching reservation of R_V. Therefore, GC caches the update information (number of fully charged batteries and available type of ones) periodically to efficiently select the BSS for R_V.

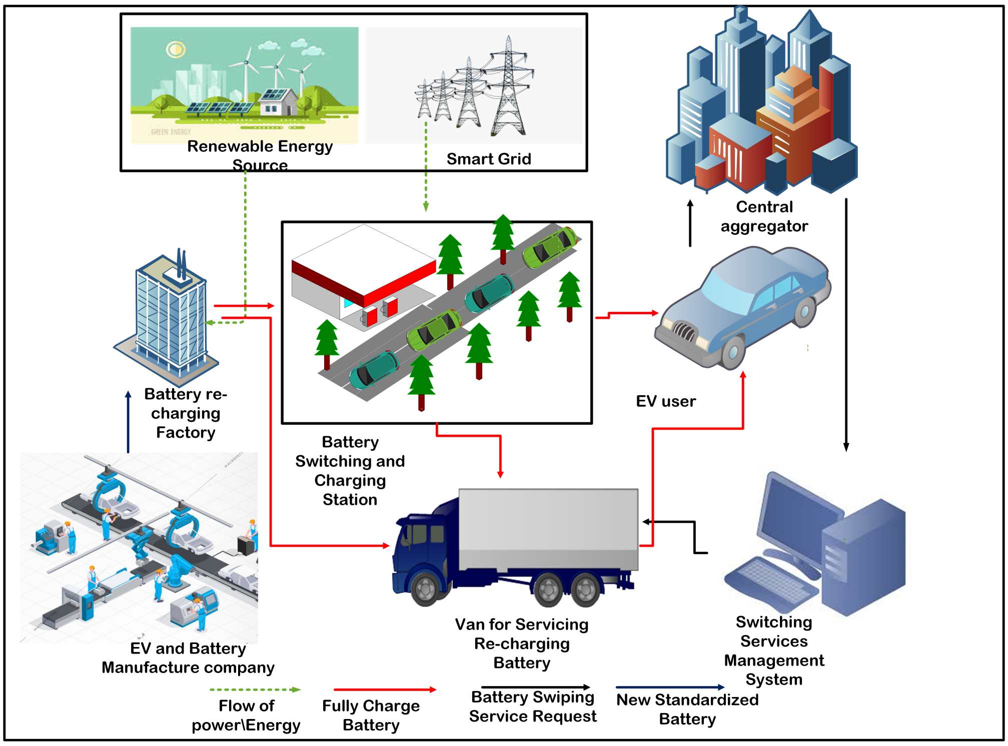

Figure 1. Generalized detailed overview of heterogeneous BSS process.

The above network entities communicate with each other via wireless communication such as ubiquitous cellular network 3G/4G allowing for real-time exchange of information. The network entities are equipped with a wireless device for communication and the exchange of information.

3.2. Heterogeneous Battery Switching Process

The process of heterogeneous BS is presented in Figure 2 step-by-step and elaborated below.

- Step 1: The GC checks each BSS in the network periodically and aggregates update information of each BSS. Aggregated information includes the ongoing charging session, number of depleted batteries in the switching station, battery stock availability in the switching station, and available battery types.
- Step 2: The mobile EV checks their SOC continuously. Once the SOC is below the minimum threshold value, the mobile EV informs the GC to require BS service along with its battery type.
- Step 3: Once a battery switch demand is requested to GC, the GC compiles the list of BSS in the network and ranks all of them according to waiting time and switching queue of vehicles. After this job is over, aggregated information regarding the required battery type of EV sends the report back to R_V and refers to the best choice in the network.
- Step 4: The EV confirms the recommendation and sends the reply to GC for reservation.

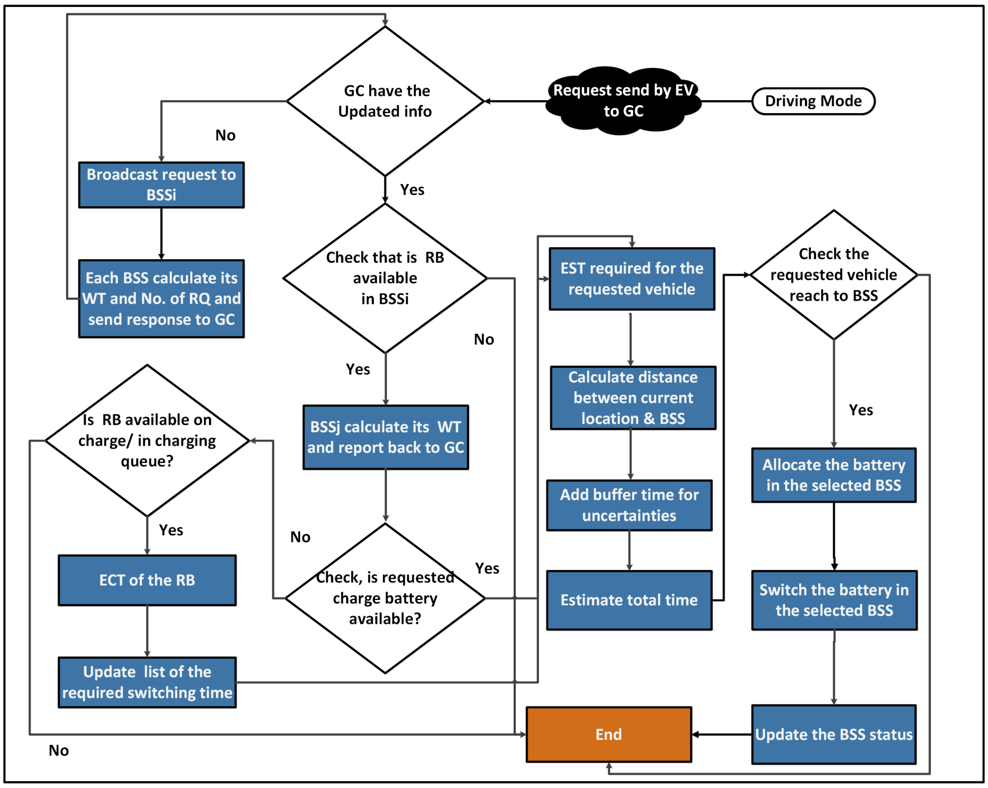

Figure 2. Flowchart of proposed work: Global Controller (GC), Set of BSS (*BSSi*), Waiting Time (WT), Requested Battery (RB), Reservation Request (RQ), Estimate Charging Time (ECT) and Estimate Switching Time (EST).

3.3. Proposed Scheme

The proposed efficient heterogeneous battery switching scheme aims to minimize the average time for each type of vehicle that has to wait for battery switching while traveling. To facilitate the issue of the proposed scheme through equation and formulation, we define some notations which are given below.

- A_t: The A_t denotes the average waiting time for battery switching at each BSS. It includes queuing time (Q_t) of vehicle for BS and the duration of the switching process.
- $\forall B_{SS}$: The $\forall B_{BSS}$ presents the set of BSS in the network.
- V_Q: The V_Q denotes the queue of requested vehicles arrived at station.
- W_t: W_t shows the overall waiting time of all vehicles in a BS. It is computed by including Q_t, battery recharging time (B_{rt}) and switching time (S_t).

With this notation, the problem is then formulated as follows:

$$W_t = \sum_{I \in \forall_{BSS}} V_Q \cdot A_t \tag{1}$$

The W_t of $V_i \in U_1$ can be minimized if the switching demand of R_V is balanced well across all BSSs in the network. However, the uniform balancing across all BSS is infeasible in complex and congested city scenarios because complete orchestration among all network entities is demanded. Hence, our approach is to achieve local optimization first and then consider global optimization.

The time to switch a battery is the main source of waiting time. However, we assume that this attribute is fixed to 3 min as a constant value across all BSS in the network. However, as compared to switching time, queuing and waiting time takes a much longer time at BSS in process of BS. Therefore, our focus is to find an optimal BSS to minimize requested vehicle (R_V) queuing time, which will be discussed in the next section.

3.4. Heterogeneous BSS Selection Concerning BS Reservation and Load Balancing across BSS

The configuration logic toward heterogeneous BSS management considering the detail of BS reservation is presented in this section. The basic operational framework namely the global planning phase for BS and reservation is discussed below.

3.4.1. Global Planing Phase

Before a vehicle at BSS arrives, the incoming flow of R_V with the demand of BS is needed to manage across the network. The aim is to minimize W_t (Q_t, B_{rt} and S_t) on the trip and select optimal BSS for the R_V. However, each BSS holds several batteries in multi types. Typically, available stock of batteries (S_b) from discharged state to charged state and the demand of BS are also required to efficiently manage the request which is discussed below. The list of notation is show in Table 2.

- When SOC of EV is below the minimum threshold, the vehicle sends request to GC for BS reservation along with its personal information including (R_VID, Current Battery Energy Level ($C^{EL}_{battery}$), Current location (C_L) and Battery type (B_{type})) (line 1 to 3 in Algorithm 1).
- If GC has updated information about BSS_j (No, of BBS in a network), then it checks the availability of R_V B_{type} across the network (line 4 and 8 in Algorithm 1). Otherwise, GC broadcasts request across the network along with information of R_V (line 5 in Algorithm 1).

Algorithm 1 Heterogeneous BS and Load balancing across BSS_j.

1: **for** each node-v_i of U **do**
2:   send request by a v_i to GC
3: **end for**
4: **while** GC do not have updated information about BSS_j **do**
5:   Broadcast request to BSS_j
6:   Each BSS_j checks that is $R_{battery}$ is available and send back response to GC
7: **end while**
8: **if** the $R_{battery}$ available in BSS_j **then**
9:   Each BSS check that the $R_{battery}$ is fully charged available
10:   **if** $R_{battery}$ is fully charged available in BSS_j **then**
11:     BSS_j calculate its waiting time
12:     Estimate $T_1 = N_v \cdot T_{ST}$
13:     Estimate $S = S_{vi \to CS} = r_{CS} - r_{vi}$
14:     Estimate $V = \frac{r_{tf} - r_{ti}}{t_f - t_i}$
15:     Estimate $T_2 = \frac{r_{BSS} - r_{vi}}{d^{hour}_{km}}$
16:     Estimate $T_3 = T_1 + T_2 + B^t_f$
17:     EST = $T_1 + T_2 + T_3$
18:     **if** v_i reach to BSS_j **then**
19:       Allocate the battery in the selected BSS
20:       Switch the battery in the selected BSS
21:       Update the BSS status
22:     **end if**
23:   **else if** $R_{battery}$ available on charging **then**
24:     BSS Calculate $T_4 = E^{time}_{cha}$
25:     EST = $T_1 + T_2 + T_3 + T_4$
26:     BSS Update ATS
27:     goto ref: [18]
28:   **end if**
29: **end if**

BSS_j checks whether the requested required battery type is available or not. After this request, it sends the updated information to GC to select the appropriate BSS for R_V to minimize the average time on the trip (lines 6 to 7 in Algorithm 1).

Table 2. List of notation.

Symbol	Description
U	Set of total vehicle
BSS	Battery Switching Station
$R_{battery}$	Requested Battery
R_V	Requested Vehicle
Q_{Dap}^{Bat}	Queue of Depleted Battery
M_B^S	Maximum number of battery stock
ATS	Available Time for switch
$NOL-MSSCA$	Nonlinear Online Maximum Sensitivity selection Based Charging Algorithm
B_f^t	Buffer Time
EST	Estimate Total Time
E_{Eng}^{Con}	Estimate Energy Consumption
t_i	Initial Time
t_f	Final Time
B_{rt}	Battery recharging Time
T_1	Estimate Switching Time
T_2	Estimate Arrival Time at BSS
T_3	Extra Time for Uncertainty
T_{ST}	Switching Time
N_V	Number of Vehicle
$C_{battery}^{EL}$	Current Battery Energy Level
E_{cha}^{time}	Expected Charging Time of drained battery
$M_{battery}^{EL}$	Maximum Battery Energy Level
V	Velocity
α	Charging Power
γ	Energy Consumption Per meter
d	Distance
r	position Vector
r_{BSS}	Position Vector of BSS
r_V	Position Vector of vehicle
M_B^S	Maximum Stock availability of Battery
W_t	Overall Waiting Time of each Vehicle in BSS
P_j	Number of charging Pole for recharging Battery
V_Q	Queue of Requested Vehicle
L_n	Line of Depleted Battery recharging Queue
BSS_j	Total number of BSS in the Network

3.4.2. Selection of BSS Phase for BS Service

Here, the selection logic of BSS for R_V is performed by GC. Typically, the current EV reservation and average waiting to switch (ATS) at each BSS across the network is computed by Equation (2). This is to identify the ones which have a minimum waiting time.

$$T_1 = N_V \cdot T_{ST} \tag{2}$$

where T_1 refers to A_t (average waiting time of vehicle at each BSS) and N_v represents number of vehicle at BSS. In addition, a T_{ST} is switching time of single vehicle which is ≈3–5 min.

- Upon sending reservation request from R_V, each BSS check that the required B_{type} is readily fully charge available (line 8 and 9 in Algorithm 1) only if requested battery ($R_{battery}$) is available across the network.

- If required B_{type} is available fully charge in BSS_j, the selected BSS calculates its waiting time and maximum number of stock availability ($M_B^S > 0$) (line 10 and 11 in Algorithm 1).

If none of the BSS_j across the network with the required battery type is available, the GC selects the one which has a minimum value of expected waiting time to switch (EWT). That is, the vehicle has to wait at BSS until the required type of battery is not fully charged in case of $M_B^S = 0$.

Key factors that contribute to the computation of switching the battery of vehicles is the estimation of waiting time to switch (W_T^S), expected arrival time of the requested vehicle (R_{vt}^{arr}) at BSS and Estimate Total Time to Switch (EST) to achieve Available Time for Switching (ATS) at BSS. However, such computation can be achieved easily at local BSS based on current status of charge (C_{SOC}) upon arrival of EV if on-going charging secession, ATS and at the station is obtained.

Thus, computation is generally done when EV is on-the-move mode because the actual situation at the selected station can be quite difficult to obtain before arrival at the station. Therefore, the estimation of ATS is defined below.

- For the purpose of estimation ATS such information is additionally needed (R_VID, B_{type}, R_{vt}^{arr}, C_{SOC}, C_L). Thus, for accounting and identifying each and every requested vehicle reach to selected BSS or not, the optimizing equation is given below (line 12 to 14 Algorithm 1).

$$T_2 = \frac{r_{BSS} - r_{vi}}{d_{km}^{hour}} \tag{3}$$

where T_2 is time that obtained the flow and distance of each vehicle, the term r_{BSS} is the position vector of selected BSS and r_{vi} is the position vector of the requested vehicle,

Similarly, the term d_{km}^{hour} is obtaining the results of time that taken by R_V from current to final location (line 15).

- After confirming the selection of BSS and reservation response back to GC, the vehicle may need extra time and cannot reach the selected BSS on required time because of road uncertainties including traffic jam signals, road congestion, and accident. By accounting uncertainty time for each R_V the Equation is given below (line 16 Algorithm 1).

$$T_3 = T_1 + T_2 + B_f^t \tag{4}$$

The arrival time of the vehicle can be accounted for according to the above Equation (4). The term B_f^t is refer to buffer time which is considering 10 min for each vehicle to address roadside uncertainties. Where T_3 is representing the approximate time (along with buffer time) which is taken by vehicle up to BSS from current location(line 17 Algorithm 1). Similarly, for accounting total time which is taken by vehicle for reaching to selected BSS and time taken while battery switching process including Q_t and S_t at the station, the Equation of problem is refined below (line 16 Algorithm 1).

$$EST = T_3 \tag{5}$$

After accounting the EST, if the R_V reach the selected BSS on current SOC and confirm the reservation. The GC allocate battery in the station when R_V reach on required ATS to selected BSS switch the battery with fully charged. BSS decrease by 1 M_B^S and update the status of the switching station (line 17 to 21 Algorithm 1).

- Upon sending request by R_V to GC some time the required battery type is not readily available ($M_B^S = 0$, $X \in B_{type}$) but available on charge. In this case, the vehicle will wait when the required battery type is fully charged according to Equation (6) when $M_{battery}^{EL} = C_{battery}^{EL}$. The switching station will change the status of the number of $M_B^S >$ 0, $X \in B_{type}$) and the update status (line 21 to 24 Algorithm 1).

$$E_{cha}^{time} = M_{battery}^{EL} - C_{battery}^{EL} \tag{6}$$

where the term E_{cha}^{time} denote the expected charging time of the drained battery, $M_{battery}^{EL}$ represent the maximum battery energy level mean that how much power will get the battery to fully recharge again and $C_{battery}^{EL}$ shows that the current battery energy level of the required battery. Along with this time again EST to find that the R_V reach to selected BBS on below Equation (7) (line 24 Algorithm 1).

$$EST = T_3 + E_{cha}^{time} \tag{7}$$

In this equation the EST refer to W_t. However, when R_V reaches selected BSS and the required battery type is readily available ($M_B^S > 0$), the vehicle will switch the battery with a fully charged battery.

After the switching process is completed, BSS decreases the number of M_B^S for the required battery type by 1. Similarly, the depleted battery of the vehicle is added to the charging queue to recharge. Updating the status of M_B^S and sharing procedure with GC are described in line 26 Algorithm 1).

As such, expected energy consumption of the entire system is refined by the following equation.

$$E_{Eng}^{Con} = \frac{(M_{battery}^{EL} - C_{battery}^{EL} + d \cdot \gamma)}{\alpha} \tag{8}$$

where the term E_{Eng}^{Con} calculate expected energy consumption, the term $M_{battery}^{EL} - C_{battery}^{EL}$ refer to energy already consume by vehicle (Kilowatt), $(d \cdot \gamma)$ corresponds to energy consumption for the EV to travel up-to selected BSS and the term α denote charging power which is using while recharging the battery.

3.5. Scheduling Technique under Heterogeneous Battery Switching Station

We present a scheduling technique concerning the issue of depleted batteries charging at BSS. Upon the arrival of the R_V at BSS. Switched the depleted battery with a fully charged battery and the reduce the maximum number of battery stock availability (M_B^S) by 1. Add the battery in the depleted battery charging queue (DB_{cha}^{que}) for recharging.

- All the depleted batteries are remove from the set of requested vehicle and identify it's current SOC and place it in the L_n (e.g., DB_{cha}^{que}) (line 1 to 2 Algorithm 2 (Battery Recharging Scheduling Technique in BSS)).

Algorithm 2 Battery Recharging Scheduling Technique in BSS.

```
1:  Initialization Phase:
2:  Initialize Parameter,
3:  for Each V_i of U do
4:      Identify the SOC and place in the L_n
5:      Based on SOC, Identify the type of batteries and place in L_{1,2,3}
            from the L_n
6:  end for
7:  while Do not Stopping the selecting type, until L_{1,2,3} each depleted battery
        is not placed to the specified P_j do
8:
9:  end while
10: for Each depleted battery of L_{1,2,3} do
11:     Start battery recharging
12:     Update the status of BSS
13: end for
14: if Each battery of L_n is schedule then
15:     Stop assigning battery from L_n to specified P_j
16: else if Select the battery from L_n to L_{1,2,3} then
17:     got ref: [8]
18: end if
```

Here, we have multi-line and slots of depleted battery recharging according to current SOC. Where the depleted batteries are charged in parallel via a number of charging slots (N_c^s).

- According to SOC identifies its belonging charging type, where if it's SOC>50% its belong to type I due to Shortest Time Charge (STC) if its SOC $\leq$ 50%, $\geq$30% its belong to type II and <30% refer to type III because of more recharging time. According to Equation (6) identify its charging time and shift the depleted batteries (D_b) from L_n to $L_{1,2,3}$ (line 4 Algorithm 2).
- Hence, the loop is operating until each battery of the L_n is not categorized and cannot assign to the specified Pole j (P_j) for recharging the battery as shown in Figure 3.

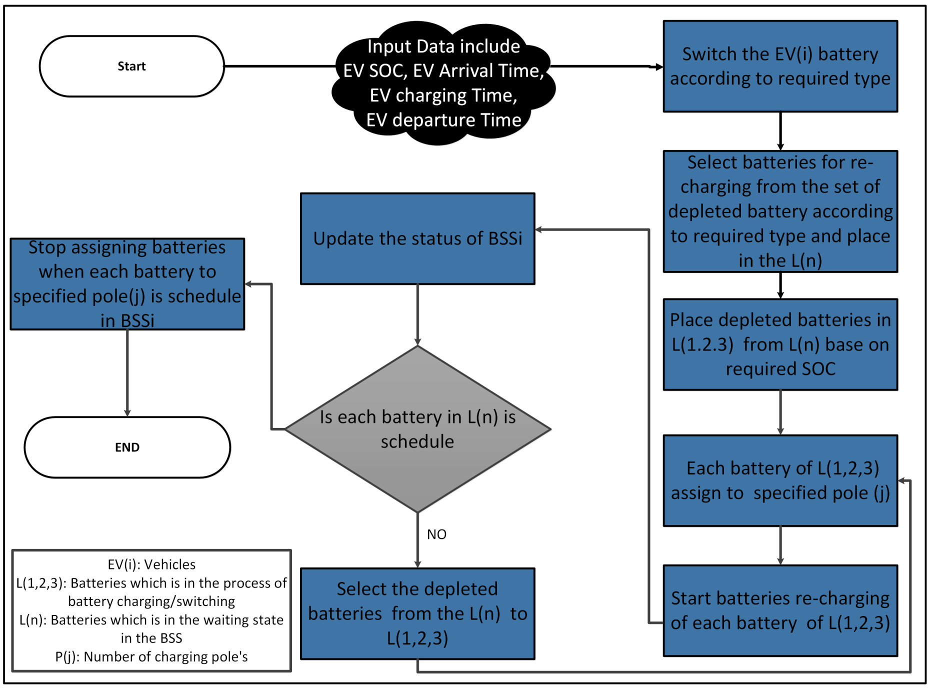

Figure 3. Flowchart of scheduling technique.

Where the term L_n is representing the line, where each battery is in waiting queue for categorization of types to shift for recharging process. Similarly, P_j is number of charging poles at BBS such as, $P_j = \{P_1, P_2, P_3\}$ and $L_{1,2,3}$ is the charging line of P_j, to start recharging of different batteries in parallel.

- After allocating each battery to its specified P_j, start recharging of the batteries. When $C_{battery}^{EL} = M_{battery}^{EL}$ the BSS update the list of M_B^S (line 8 to 11 Algorithm 2).

Once each depleted battery is charge, it will be added to its belonging battery type and the corresponding information about D_b is removed from the charging queue. After that, check is there more D_b available in L_n and its schedule according to the service facility then stop conversion from L_n to $L_{1,2,3}$ and P_j (line 12 to 13 Algorithm 2).

- If D_b are available in L_n, belong to type X and not schedule according to the required manner, schedule it and repeat operation loop from line 8 to 11 until each D_b is not fully charged.

3.6. Discussion

3.6.1. Issue Regarding Reservation Randomness

As we discussed in the global planning phase in the previous section, when EV SOC is below the minimum threshold, EV will be finding BSS regarding the swap of a depleted battery with a full charge battery. EV will send reservation request to GC, in which include

(R_VID, $C^{EL}_{battery}$, C_L, B_{type}, arrival time (A^t_r)). In request contain information the A^t_r can be quite random because of the mobility uncertainty such as traffic jams and road accident, EV may cant reach to switching station on time. Therefore, it is imperative to update the GC periodically regarding the current location of the R_V and expected arrival time. Hence, cancellation of the reservation at selected BSS can be predicted GC easily and the accuracy of expected A^t_r to switch the battery can be greatly improved.

3.6.2. Security Issue Regarding Centralize Manner

In a centralized manner, the decision is made by the GC side, EV is sending a reservation request to GC when its SOC is below the minimum threshold. The GC is selected appropriate BSS for R_V to switch the battery efficiently. However, the request contains such private information (C_L, SOC, and ID) which will raise privacy issues. Moreover, the R_V may send malicious information to GC to affect the charging management. Hence, all messages in the communication of EV and GC will be digitally signed by both parties to take hazard-free decisions and select the appropriate BSS for R_V.

3.6.3. Discussion Regarding Battery Switching and Plug-in Charging Service

In light of a practical scenario, there could interdependence among BS and plug-in-charging technology at current situation. Where EV used in a constant routine (public transportation) would prefer BS technology because of short service of time to minimize average trip duration. While EV considering for a single user (private transportation) would like to choose plug-in-charging technology, to avoid concern may that brand new battery could replace by spare battery. For efficiency concern, it require to strategically provision service among several service performance. The research work is left for future work regarding this issue.

4. Performance Evaluation

4.1. Simulation Configuration Environment

The present solution of the heterogeneous battery switching scenario was built-in Opportunistic Network Environment (ONE). The default scenario of simulation is within the area of 4500×3400 m^2, shown as the downtown area of Helsinki city in Finland. In the proposed solution simulation have considered a total number of 300 EV in on-the-move mode at speed of $30 \approx 40$ km/h and deployed six BSS as shown in Figure 4. Once EV SOC is below the minimum threshold the reservation request is send to GC, the GC select BSS for the R_V according to its $C^{EL}_{battery}$, B_{type} and considering maximum traveling distance. The route to selected BSS is randomly selected from the Goggle map. The total simulation time of the proposed work has been carried out for 12 h in ONE.

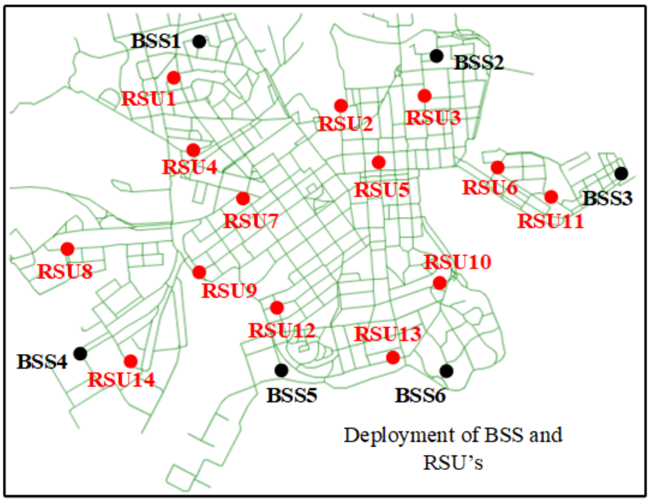

Figure 4. Deployment of BSS (Black) and RSU's (Red).

However, a number of deployed BSS have sufficient electric energy power and maintain each BSS three types of batteries to provide efficient service for R_V.

- Coda Automotive
- Wheego Whip
- Hyundai BlueOn

Each BSS 10 battery initially holds a fully charged for each type of battery and is able to switch 30 depleted batteries with a fully charged battery. However, these depleted batteries are recharging at the power of 10 kW to use for another R_V Figure 5. A battery switch time in the simulation is 3 to 5 min and the network update interval is 0.1 seconds to give a fresh update to GC. Moreover, we conducted a performance evaluation by comparing the proposed scheme with other benchmarks (measure and compare usability metrics against a baseline study). Due to consideration of several factors (batteries, BSS, vehicle) and a comparative analysis, we are using relative units with respect to the benchmark to achieve efficient results. For the sake of understanding, the simulation configuration environment is shown in Table 3.

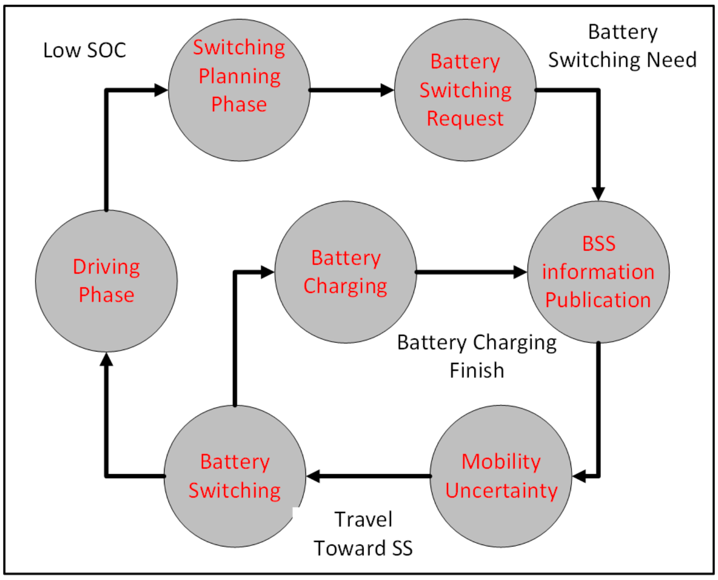

Figure 5. EV battery switching cycle.

Table 3. Simulation parameters.

Parameters	**Values**
Simulation Area	4500×3400 m^2
Total Number of EV	300
Speed of vehicle	30 to 40 Km/h
Deployed Number of BSS	6
Total Simulation Time	12 h
Type's of Batteries	(1) Coda Automotive (2) Wheego Whip (3) Hyundai BlueOn
Battery Size	(1) 33.8 KWh (2) 30 KWh (3) 16.4 KWh
Minimum SOC Threshold	(1) 30% (2) 40% (3) 50%
Maximum Traveling Distance	(1) 190 km (2) 160 km (3) 140 km
Initially Hold Number of batteries at each BSS	10
Distribution of Batteries Across the Network for 300 EV fleet	60
Charging Power of recharging the battery	10 KW
Battery Switch Time	3 min

4.2. Evaluation Parameters

The main interest is to compare the proposed scheme with benchmark on the basis of following performance metrics:

4.2.1. Total Time

The average time that an EV experiences for its trip through the battery switch services Including:

- The average waiting time which is before switching is required in BSS for achieving service.

4.2.2. Total Waiting Time for Selection of BSS

Assigning EV to the appropriate battery switching station (BSS).

- The BSS within the EV reach-ability according to CSOC of EV, that upon charging request to the GC, guarantees the lowest switching delay.
- The foreseen switching delay for EV is computed as the sum of time to complete the switching of EVs currently present at the BSS, switching time of single vehicle and battery recharging time (if required battery type is available on charge).
- If two BSS have the same switching delay, select BSS which has minimum traveled distance and nearest among to R_V.

4.2.3. Number of EV Successfully Reach to BSS

- The experiences of each EV that, how much vehicle reaches to BSS with sufficient energy for switching the battery with inbound communication to GC.

4.2.4. Total Energy Consumption on The Trip

The total energy consumption of each EV for its trip through battery switch services.

4.3. Influence of Reservation Base EV Density at BSS

We observe that the energy consumption is reduced via enabling reservation slot at BSS with the help of coordination with GC. Figure 6 depict that the influence of energy consumption of proposed work is far good. This indicates that the periodic communication with GC under the proposed work has a good impact. One immediate advantage is to balance load across all BSS because of enabling reservation scheme and maintaining heterogeneous battery stock availability.

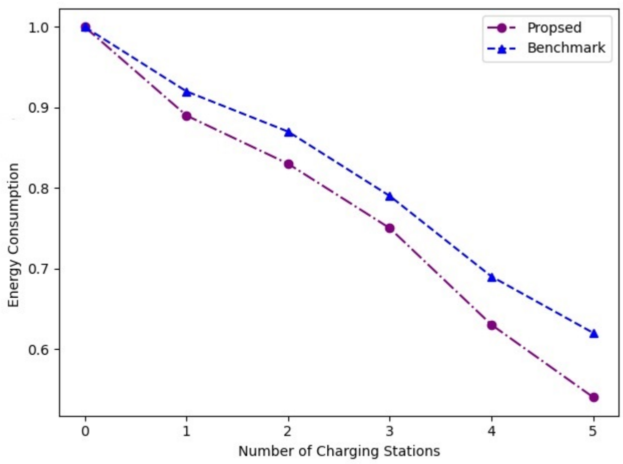

Figure 6. Total Energy Consumption.

As shown in Figure 6 there is a slight increase in benchmark results as compared to the proposed work. The reason is huge EV density and a limited number of charging slots at BSS. According to EV battery switch cycle, the depleted battery will charge again in the charging factory and will take 40 min on fast charging technology. Thus, because of a high number of EV switching depleted batteries with fully charged and readily available charged batteries are running out from BSS.

4.4. Influence of Optimally Charging Scheduling

According to Algorithm 2 the vehicle density is managed and treated at BSS according to its SOC to minimize waiting time. The depleted batteries are sorted according to the charging discipline (discussed in Section 3) and run the operation loop for recharging the battery until all batteries are not fully charging. As shown in Figure 7 the waiting time at BSS of the vehicles is reduced more than 90% under the battery switching scenario. Intuitively, the more arriving density of vehicles seems to be less affected as compared to the benchmark result. This is because of managing different types of batteries variety (battery heterogeneity) at BSS concern in this work.

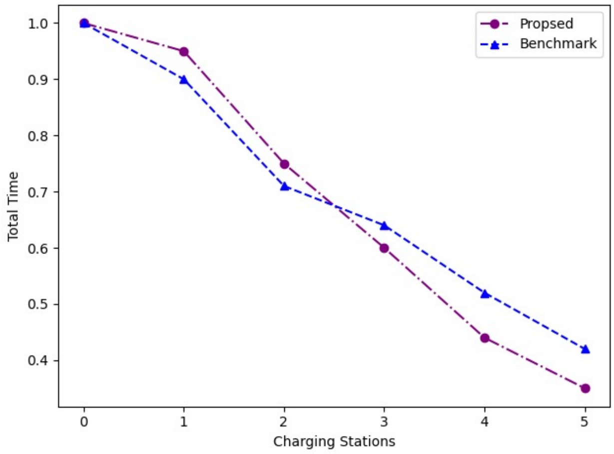

Figure 7. Total Time.

As observed, average waiting time to switch (AWTS) is slightly increased when the bulk of R_V is sending a reservation request to GC for battery switching. This is because of specific battery type under BS scenario. In traditional trends under plug-in charging mode arriving the bulk of EV seems to be less affected because the R_V is charged up regardless. While under heterogeneous BS technology the vehicle needs a particular type of battery and sometimes it is not readily available or runs out from BSS due to high demand.

As shown in Figure 8 the performance of the proposed work is achieved good results because of the centralized mode. Since R_V communicate frequently with GC and clear all queries about switching reservation and reported GC for the selection of BSS. While GC also takes an update from mobile EV about mobility uncertainty and calculates AWTS. The result of Figures 7 and 8 implies that the desired performance is achieved under heterogeneous battery switching. This is mainly the benefit from reservation making and scheduling techniques for depleted battery recharging.

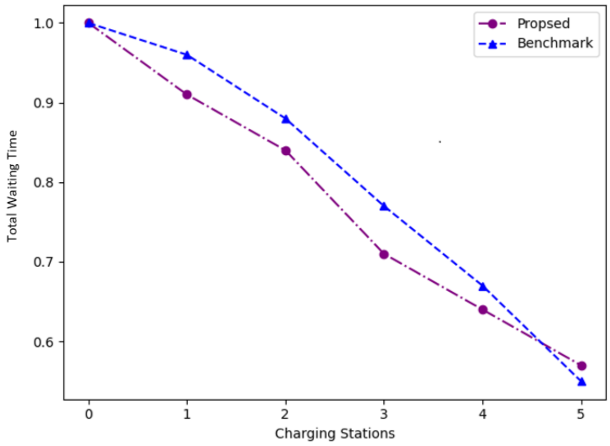

Figure 8. Total waiting time.

4.5. Performance under Heterogeneous BS of Charged EV

As shown in Figure 9, due to the proposed scheme more efficient performance is achieved. This is because of considering the SOC of R_V and estimating AWTS of each BSS across the network. With this updated information the proposed scheme is able to predict the BSS condition (congestion at BSS and queuing time) and select one BSS that has the least potential congestion and is near to the requested vehicle. The R_V is travels toward the selected BSS for achieving the services.

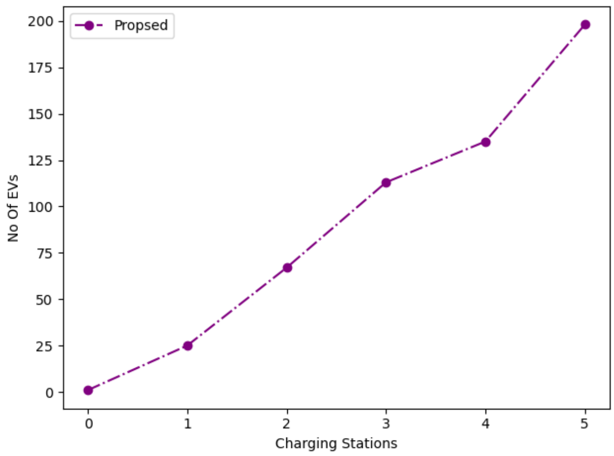

Figure 9. Number of EV.

Thus, due to this function and quality, the proposed scheme under reservation base and optimally charging scheduling (OCS) achieve overall desirable results. However, Figure 9 present that, the number of vehicles serviced across CS in 12 h of simulation to achieved service under proposed scheme efficiently. Since EV will switch batteries with a high priority which have a minimum SOC. This implies that the proposed scheme under heterogeneous BS is achieved overall a efficient and satisfactory level of results.

5. Conclusions

In this paper, we have proposed optimal charging scheduling and enabling BS reservation under heterogeneous battery switching services. The proposed scheme is able to compute congestion and queuing time at each BSS in the network and knowledge about how many vehicles have a reasonable distance to BSS and make a reservation for BS. Furthermore, by comparing with other benchmarks, results show that the load of R_V is well balanced across the network and select optimal BSS for R_V. Meanwhile, the proposed scheme addresses the scheduling algorithm for a fast recharging cycle of depleted batteries to facilitate efficiently the incoming vehicle. The evaluation results of our proposed work are evaluated under the Helsinki city scenario in Finland, by considering traffic jams and other mobility uncertainty and have confirmed that our proposed scheme can minimize average waiting time and switch battery number of EV efficiently at BSS.

Future Work

Integration of BS and plug-in charging: There is a need for efficient integration of BS and plug-in charging technology. Thus, for efficiency, it requires the provision of a strategic service and performance servicing. The research work is left for future work regarding this issue.

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