Electric Vehicle Route Assistance Using Forecast on Charging Station

Marie Nestor Mariyasagayam and Yuichi Kobayashi
Information and Communication Technologies Lab.
Hitachi Europe SAS - ERD - Sophia Antipolis
Valbonne, France
e-mail: marienestor.mariyasagayam@hitachi-eu.com, yuichi.kobayashi@hitachi-eu.com

***Abstract*—This paper presents a method to provide route assistance for electric vehicles by forecasting availability of charging spots in a charging station. The method uses location and reachability information of other electric vehicles along the route in order to estimate charging spot occupancy ratio at the charging station. By using such information, a risk factor for charging at a station along a planned route of an electric vehicle is calculated. The risk factor is continuously monitored, and when risk becomes high, a new route based on other charging stations located along the route is proposed to the driver. By dynamically monitoring travel routes based on charging station capacity and population of electric vehicles around the charging station, a prediction can be made about the availability of charging stations. Thus, in order to have faster travel times, electric vehicle drivers can be opportunistically advised to take appropriate routes with less crowded charging stations.**

Keywords-Electric Vehicle; Charging Station; Route Assistance; Telematics Service

I. INTRODUCTION

Electric Vehicle (EV) enables pollution-free and noiseless driving. But, they come at a cost when compared to vehicles with combustion engine: the range (distance) of driving [1]. The actual distance traveled by an electric vehicle without recharging its battery is relatively lesser when compared to driving distances of vehicles based on gasoline. It was one of the prime reasons for electric vehicles to lose the race when they were already deployed in the 19th century, even before vehicles with internal combustion engines came into consumer market [2].

In the 21st century, with growing interest from consumers, and policy makers, the EV market is beginning to see growth again. EV manufacturers are at their initial stages of deploying fully electric vehicles. Many efficient battery usage mechanisms [3], [4] are being developed in order to increase the range of an EV, and on-going collaborative research efforts [5] aim at improving charging station infrastructure in order to have faster charging. Nevertheless, a level of incertitude still exists about destination reachability [6], especially when routes involve longer distances, or even shorter routes which are troubled by traffic incidents such as traffic jam, road blockade, etc.

In the current scenario, one of the solutions prime to the successful deployment of electric vehicles on a large scale is to providing route assistance services taking into account charging stations along the traveling route. It helps to extend the actual range of an EV by planned stopovers for charging at a charging station along a travel route. As charging infrastructure deployments are rapidly growing, routing EVs via charging station has gained considerable importance in the recent years [7], [8], and has become a prime factor for wide-spread the deployment of electric vehicles.

At present, the number of electric vehicles is not so large compared to vehicles based on combustion engines [9]. Soon, this number is seen to increase steadily [10]. When the numbers of EVs increase on a route, the probability for an EV to find a spot immediately, upon its arrival at a charging station decreases. Also, there is high potential for a charging station to remain fully occupied due to increased demand for charging. Thus an EV driver may encounter one or more combination of the following problems:

- The EV driver may be made to wait in order to get charged due to queuing of electric vehicles at a charging station. Depending on the vehicle type, battery requirements, and charging infrastructure capabilities, present fast-charging infrastructure services require anywhere between 10 to 60 minutes [11] for a full battery re-charge. Thus, when compared to gasoline stations, the order of waiting time is relatively higher for an EV driver to get re-charged at a charging station. It can ultimately lead to additional delay in the driver's planned journey, in case there is a necessity for re-charging along the travel route.
- Increased charging demand at one station can lead to gradual overloading of subsequent charging stations along the route because drivers tend stop for charging at the subsequent stations when charging is not possible at the current station. As a result, an EV driver may not be able to find a suitable charging station at all for a considerable length of the planned route.
- It might also happen that the driver can be charged at a higher price per unit of electric power, e.g., a charging station may propose to charge EVs using their stand-by power during times of overloading and power shortage. This may not be appreciated by drivers who are concerned about cost-factor.

Apart from EV drivers, simultaneous charging demand from large number of electric vehicles on a particular section of route can lead to breakdown of conventional power grid. Field tests [12] and results based on analytical framework [13] show current grid architecture is unable to cope with peak charging demands especially when large numbers of EVs try to charge simultaneously via several charging stations controlled by a particular grid. This can disturb smooth functioning of electric power distribution and operation. However, to tackle such problems, large-scale research collaboration [14] are on-going to demonstrate power grid operational stability and address issues such as power voltage, surplus electricity and frequency fluctuation.

Taking into account the above-mentioned problems, to provide route assistance to an electric vehicle through a charging station that is susceptible to overloading by surrounding electric vehicles becomes risky for destination reachability of the EV driver.

The rest of the paper is organized as follows: Section II presents the prior works that are relevant to the subject of electric vehicle route assistance. Section III describes the overall system architecture. Section IV introduces the parameters necessary for risk factor calculation. Section V provides a set of rules for deciding whether to re-route over other optimal paths. Example calculations are provided in Section VI. Section VII identifies a set of features relevant to electric vehicle route assistance mechanisms, and provides a comprehensive list of availability of such features in the route assistance methods discussed in prior works. Section VIII shows a simple evaluation of the proposed method. Finally, Section IX provides concluding remarks and further extension for future work.

II. RELATED WORK

At present, route assistance services are generally performed independently for each electric vehicle [7], [15], [16], taking into account a navigation route from a start location to a destination location traveled by the electric vehicle, considering location of charging stations along the travel route.

Kobayashi et al. [7] proposed a route search method which calculates routes with stop-overs at charging stations according to the available range of EVs. This is done to have extra battery charge when current remaining charge is not enough to reach the destination. Eisner et al. [15] considered a mathematical model for optimal routing of EVs using battery capacity constraints in order to have energy-efficient routing. This method exploits energy recuperation capacity of EVs during deceleration phases or when going downhill along the travel route. It has been observed through experiments that such mathematical model gives rise to several optimal paths especially considering battery constraints. An optimal routing method [16] based on energy consumption rather than just using shortest route to destination is proposed. The method takes estimated the energy consumption of vehicle when traveling along different routes towards a chosen destination, and selects the most economical route in terms of energy consumption. By selecting most economical routes, the necessity to re-charge at a charging station can decrease or at least the number of stop-overs along the route can be decreased relatively. Nevertheless, in order to have extended range and when distance to destination is longer than actual range possible with current battery level of an EV, re-charging remains inevitable. Thus a viable option is to calculate routes such that there are charging stations near-by in case there will be a need for re-charging.

There are other route search algorithms not specific to electric vehicles, but can be eventually applied to EVs as well. Faez et al. [17] proposed a route search algorithm based on real-time traffic information provided by a sensor network consisting of road side terminals. Having real-time traffic information gives an idea of how long a vehicle can stay in a particular route segment under current traffic conditions. Services for EV route assistance can use such information to estimate how long an EV will approximately take, in order to travel a section of the road under actual traffic conditions. Kono et al. [18] proposed a route search system which uses information such as real-time traffic information and geometric information such as inclination of the route, then calculates optimum route in terms of not route distance but gas consumption by avoiding congested points or ascending slope. Such idea can be applied to electric vehicle, by making EVs to take routes that have relatively lesser ascending slopes or can be coupled with the idea presented by Eisner et al. [15] to increase the range of an electric vehicle.

In the prior works, it can be observed that route planning for electric vehicles is typically based on the shortest distance to the charging stations or by selecting route that consumes least amount of electric power. There is no account of other EVs planning to use the same charging station, nor is the actual availability of charging spot in a charging station, upon the arrival of an EV, considered. When many EVs are planning to use the same charging station, and if route plans are made without considering such information, it is highly likely that one or more EV users may suffer due to problems mentioned in Section I.

This paper presents a method to enable route assistance to an EV user, by taking into account the population of other electric vehicles in the vicinity of a charging station, and also by predicting the availability of charging spots in the station.

III. OVERALL SYSTEM ARCHITECTURE

The overall system is illustrated in Fig. 1. It consists of the following components:

1. A service center.
2. Charging stations.
3. Traffic centers.
4. Electric vehicles.

Service center: This is the main component that provides route assistance service to the electric vehicles. It is connected to the traffic centers, charging stations and electric vehicles through a communication network, and can exchange data with them through the network. The service center contains one or more servers that are used to provide the service. For the purpose of description, the “server of the service center” will be known as “server” in the rest of this document. The service center has access to the location information of the charging stations. It can either store such information in a database, or can request for update from the traffic centers or directly from the charging station. The service center has also location information about electric vehicles, which is received from the traffic centers and/or directly from the electric vehicles through the communication network.

It is important to note that privacy and data protection remain an open issue, and there are claims [19] that location sensing methods are a threat to privacy of the driver participating in the service. Several debates and related developments are taking place at different levels through industry-academia partnership projects [20], [21] and government reforms [22] in order to address issues related to privacy and data protection. Until proper consensus is reached at all levels, this work assumes that such issues can be handled using known privacy-preserving [23], [24] or service subscription by having consent of the participating entities, etc.

Charging station: It contains one or more charging spots. A charging spot is used by an electric vehicle to charge its battery. The charging station provides information to the server through the communication network about current charging conditions such as maximum number of charging spots, currently occupied spots, rate at which charging is being carried out at a particular charging spot, the current battery level of the electric vehicle, the maximum battery charge capacity or the intended level of charging at the charging spot. Such information is used by the server to estimate availability of charging spots for other electric vehicles reaching the charging station.

Traffic center: This component manages road traffic related information collected from roadside sensors and/or vehicles through communication network. It is capable of providing road traffic related information to the server through the network. The traffic related information consists of collection of localization data, speed, direction of travel, estimated traveling time between geographic locations, and location of charging stations. Such information is used by the server to estimate the time required by an electric vehicle to reach a particular charging station, under actual traffic conditions. In addition, location information of electric vehicles along the route, and status of their battery charges are also provided by the traffic center to the server. This additional information is used by the server to predict likelihood of occupying a charging spot at a charging station by other electric vehicles.

Electric vehicles: These are the beneficiaries of the route assistance service provided by the service center. They are connected to the network by wired or wireless means. From the electric vehicle, the service center can receive location information, status of battery charge, and intended travel route or destination. With help of such information, the server identifies charging stations that are located along the travel route of the electric vehicle.

IV. FORECASTING OF CHARGING STATION AVAILABILITY

The principle idea behind the route assistance method is to associate a risk factor (RF) for charging at a charging station (CS) along the travel route. The RF is calculated based on charging station availability (i.e., absence or presence of charging spots), a time-to-reach factor calculated based on travel duration of other electric vehicles along the route to reach the charging station, and a ratio between the EV population traveling towards the charging station and the total EVs within a perimeter of the charging station. The server uses the current position of the ego-EV (i.e., the electric vehicle to which the route assistance service is offered) to calculate a risk factor for charging at the next intended charging station. For its calculation it uses data from the charging station, the electric vehicle and the traffic center.

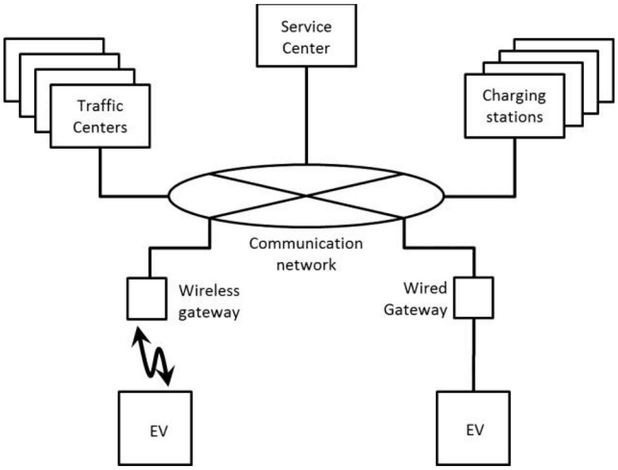

Figure 1.Overall System Architecture.

Figure 2 shows the flowchart of the route assistance process. In order to calculate the risk factor for charging at a particular station, the server needs to compute the following parameters:

- Charging station capacity (P_{CAP})
- EV population (EV_{POP} and $EV_{POP\text{-}EGO}$)
- Time-To-Reach Factor (TTRF)

In addition to the above factors, the server calculates the following factors that are used during the re-route decision making process:

- Free Charging Spots (FCS)
- Minimum Queueing Time (MQT)

The use of above parameters and the method by which they are calculated are shown from sections IV-A to IV-E.

A. *Charging Station Capacity(P_{CAP})*

With the help of location information received from the vehicle, the server can identify the nearest charging station along the traveling direction (S1) from its database. The server then queries the following information from the charging station (shown in steps S2 and S3 of Fig. 2):

- Maximum number of charging spots (FC)
- Currently occupied spots (OC)

Subsequently, the charging station capacity P_{CAP} (S4) can be calculated using (1):

$$P_{CAP} = OC / FC. \tag{1}$$

P_{CAP} is inverse to the risk factor for charging. For values approaching towards 1, the availability of a charging spot in a charging station decreases. Hence, the risk factor for charging at a charging station for an EV increases.

B. *Estimation of EV Population*

With the help of the location information of the charging station, a perimeter is constructed. The perimeter is a midway-distance between the next charging station and the previous charging station (example available in Section VI). The server gets information of the number of EVs that are present within the perimeter (step S5), along with their respective location and moving direction. It then calculates the EVs that are located within the perimeter EV_{POP} and the number of EVs traveling towards the charging station of the ego-vehicle ($EV_{POP-EGO}$) in step S6. The population of electric vehicles has a direct effect on the charging spot availability at a charging station. If more vehicles travel towards the charging station, the risk that the charging station can get occupied is also higher. $EV_{POP-EGO}$ is the actual number of electric vehicles that travel in the direction of the charging station. The value EV_{POP} is used as a weighting factor when calculating the risk factor.

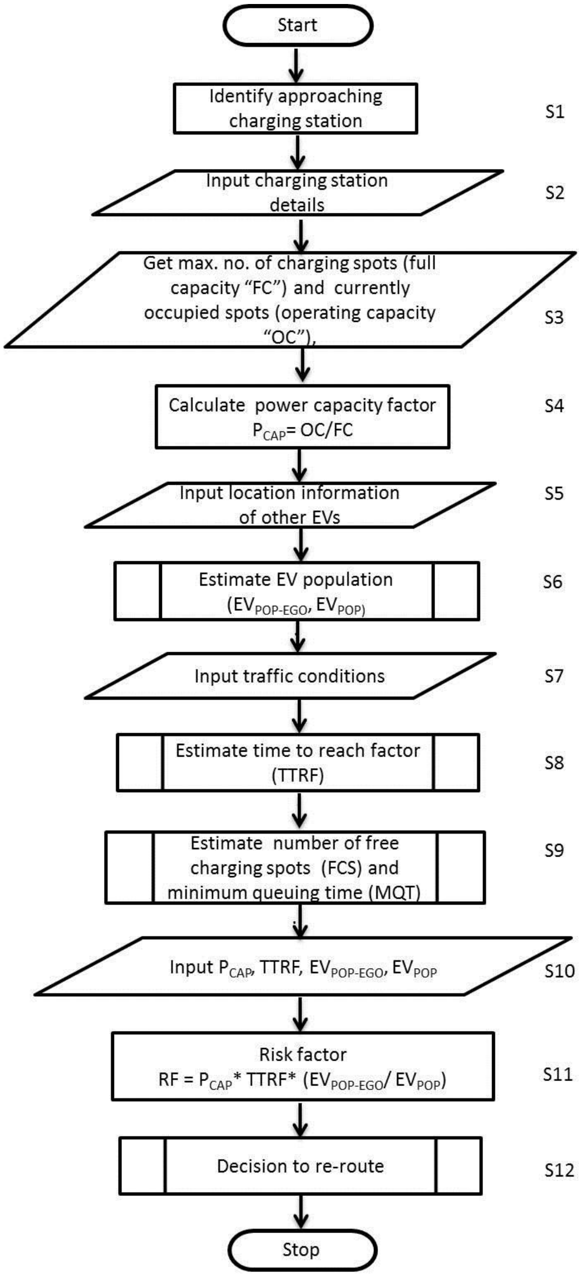

Figure 2. Route Assistance Process

C. *Time-To-Reach Factor (TTRF)*

The server receives information about traffic conditions from the traffic center (step S7). It contains current traffic information of vehicles, speed of the traffic flow and the status of the route (accident, road works, etc.) along the traveling direction of the electric vehicle. The data is used to calculate the instantaneous travel time along a certain section of the planned route. This is equivalent to the time duration that an EV can take to reach a charging station along its route depending on the existing traffic conditions. Also, with the input received in step S5 on the location information of other EVs, the server estimates the time taken by other vehicles located within the perimeter and driving towards the location of charging station. This time taken to reach is called as "Estimated Time-to-Reach" (ETR). An average and the standard deviation of the ETR are calculated. Then a Time-To-Reach Factor (TTRF) is given using Table I.

TABLE I. A Mapping of TTRF Values for Different ETR_{EGO} Values Based on Mean and Standard Deviation of ETR Values Of EVs.

ETR_{EGO} value	**TTRF**
$ETR_{EGO} \leqslant \mu - 3\sigma$	1/7
$\mu - 3\sigma < ETREGO \leqslant \mu - 2\sigma$	2/7
$\mu - 2\sigma < ETR_{EGO} \leqslant \mu - \sigma$	3/7
$\mu - \sigma < ETR_{EGO} \leqslant \mu + \sigma$	4/7
$\mu + \sigma < ETR_{EGO} \leqslant \mu + 2\sigma$	5/7
$\mu + 2\sigma < ETR_{EGO} \leqslant \mu + 3\sigma$	6/7
$ETR_{EGO} > \mu + 3\sigma$	1

The logic of the table is such that for higher ETR values, a higher TTRF value is chosen, i.e., vehicles which are far away from the charging station have lower probability (higher risk) to find a charging spot because of other vehicles which may be closer to the charging station. For lower values of ETR, a lower value of TTRF is selected, which in turn provides a lower risk factor: vehicles closer to the charging station. This time factor is used as a simple measure of likelihood of occupancy of a charging spot in a charging station. Within the perimeter of a charging station, the more time it takes for an ego-EV to reach the charging station, the higher is the probability for a charging spot to be occupied by another electric vehicle, traveling in the direction of the charging station, and ahead of the ego-EV.

D. *Free Charging Spots (FCS)*

The server receives information about the number of charging spots occupied (S61 of Fig. 3). The information contains current charging station information and conditions such as:

- Number of charging spots (N).
- Rate of charging at Nth charging spot (R_N).
- Maximum charge required by EV (Ch_{maxN}) at Nth charging spot.

- Current charge level in EV (Ch_{currN}) at Nth charging spot.

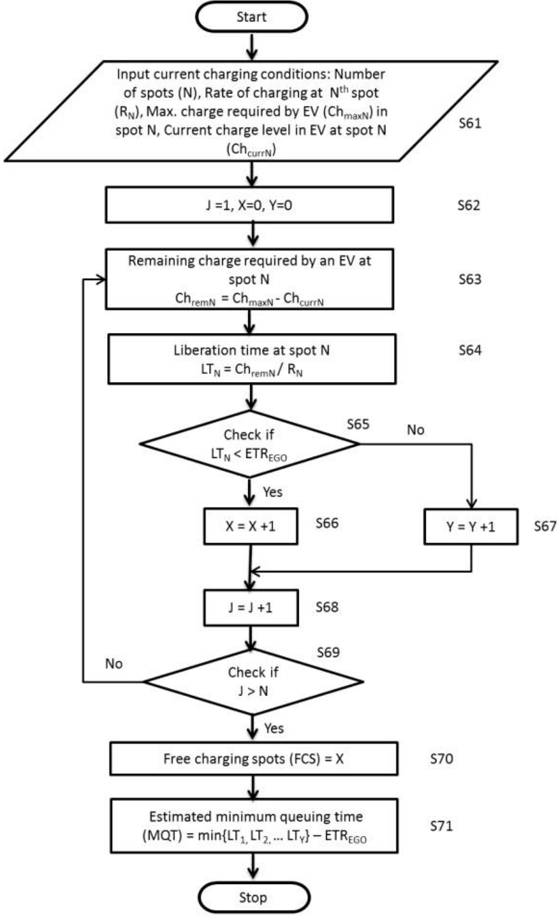

Figure 3. Estimation of Free Charging Spots (FCS) and Minimum Queuing Time (MQT).

With the above information, the server estimates a liberation time for each charging spot at the station. Liberation time (LT) is an estimate of the time duration until which a charging spot will be occupied by an electric vehicle. It is the ratio of the charge required by an electric vehicle to the rate of charging provided by the charging spot. The calculation procedure is shown from steps S62 through S69 of the flowchart in Fig. 3.

E. Minimum Queueing Time (MQT)

Assume that a charging station consists of N charging spots, and their respective liberation times are LT_1, LT_2, LT_3… LT_N. Let X be the total number of spots that have liberation time (i.e., they become free) less than the arrival time of the ego-vehicle (i.e., ETR_{EGO}), and Y be the number of spots that have liberation time greater than ETR_{EGO}.

$$MQT = \min \{LT_1 , LT_2 , LT_3 , . . . LT_Y \} - ETR_{EGO} \qquad (2)$$

For the ego-vehicle to queue at the time of its arrival, X=0. In order to estimate how long an electric vehicle has to wait just after its arrival at the charging station, a set of liberation times that have values greater than ETR_{EGO} have to be formed. From this set, a minimum value is selected. The difference between the minimum value and the ETR_{EGO} gives an estimate of the minimum queuing time.

F. Risk Factor (RF)

The risk factor is calculated using parameters obtained in Sections IV-A, IV-B and IV-C. Equation (3) is used to calculate the risk factor.

$$RF = P_{CAP-EGO} * (EV_{POP\text{-}EGO} / EV_{POP}) * TTRF \qquad (3)$$

RF value lies between 0 and 1, where 0 means no risk and 1 means maximum risk. This can also be expressed in terms of percentage. The risk factor associated with the charging station is continuously monitored, and when the risk factor exceeds a given threshold, decision making process is initiated (details in Section V).

V. DECISION TO RE-ROUTE

This section presents a set of conditions that need to be checked after the risk factor goes beyond a determined threshold and before advising a new route to the driver. This is the last step (S12) of the route assistance process shown in Fig. 2. The flowchart of the decision making process is shown in Fig. 4.

The server assumes a threshold factor for risk (RF_{TH}). If the calculated risk factor is greater than threshold, a decision to re-route using new charging station is based on the following conditions (step S12 of Fig. 2):

1. The server estimates the number of electric vehicles that will reach the current charging station before ego-EV. If this number is greater than the estimated free charging spots, then it can be known whether there will be any immediate spot for charging at the arrival of the ego-EV.
2. The location of subsequent charging station CS_{NEW} in the traveling direction of the ego-EV is identified (S84). The current battery level of the EV is used to check reachability to the newly identified charging station in S85. A new time to destination is calculated via CS_{NEW}. From this it can be known whether the electric vehicle is able to reach the new charging station if proposed.
3. Then it is checked whether the sum of MQT and time to destination via current charging station, is greater than the new time to destination via charging at CS_{NEW} (and its MQT_{NEW} if required). From such comparison, it can be known whether passing by new charging station is faster than by just using the current charging station (even though it involves a minimum waiting time). This condition check is also used to void routing vehicles through CS_{NEW}, when waiting times at CS_{NEW} are larger than the current station (i.e., already many vehicles are being queued at CS_{NEW}).

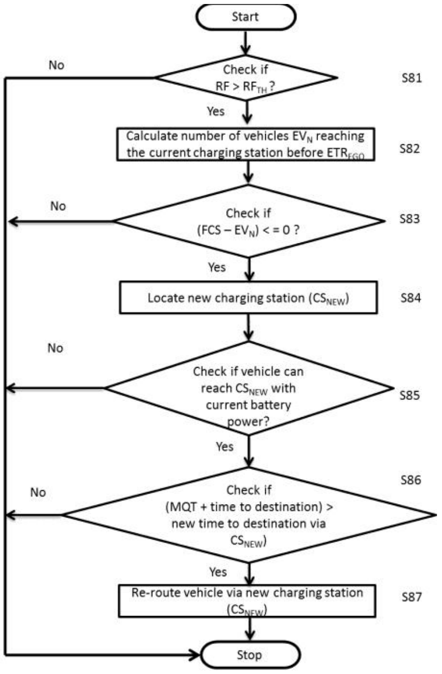

Figure 4. Deciding to re-route.

When conditions 1, 2 and 3 are true, the user is informed of new route by the server through the communication network.

VI. ROUTE ASSISTANCE SERVICE EXAMPLE

In this section, an example of route assistance service is shown along with a sample calculation for risk factor using four electric vehicles: ego-EV, EV_1, EV_2 and EV_3 as shown in Fig. 5. Only vehicles ego-EV, EV_1, EV_2 are moving in the direction towards the charging station CS_2, which is the charging station being targeted by ego-EV.

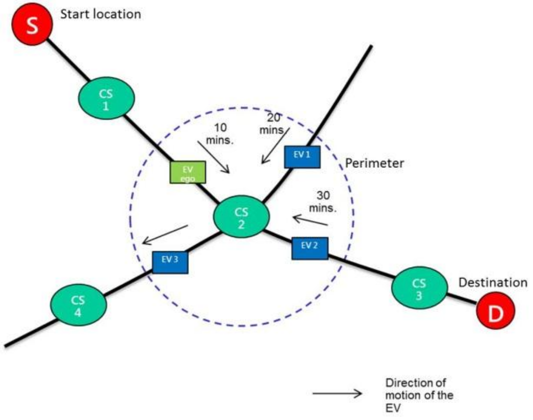

Figure 5. Example calculation of Time-To-Reach Factor (TTRF)

Assume ETR of ego-EV, EV_1 and EV_2 are 10, 20 and 30 minutes respectively, in order to reach CS_2. Then the TTRF value for ego-EV can be calculated according to explanation in Section IV-C and Table I as follows:

$$TTRF = 3/7 \tag{4}$$

where, $\mu = 20$, $\sigma = 8.16$, $\mu - 2\sigma < ETR_{EGO} \leqslant \mu - \sigma$

Assume that CS_2 has 3 charging spots out of which 2 are occupied by EVs for charging, then charging station capacity calculated according to (1) as follows:

$$P_{CAP-EGO} = 2/3 \tag{5}$$

$$EV_{POP} = 4 \tag{6}$$

$$EV_{POP-EGO} = 3 \tag{7}$$

Then, the risk factor calculated according to (3) will evaluate to

$$RF = 0.214 \tag{8}$$

In other words, the risk percentage for charging at CS_2 for the ego-vehicle is about 21% when it reaches the charging station in 10 minutes.

In the example used, the time to arrival of EV_{EGO} (10 minutes) < EV_1 (20 minutes) < EV_2 (30 minutes). Table II gives risk percentages calculated for all vehicles charging at CS_2 for various power capacity levels (P_{CAP}) at the charging station.

TABLE II. RISK PERCENTAGE OF EV_{EGO} EV_1 AND EV_2 FOR VARIABLE P_{CAP} VALUES AT CHARGING STATION CS_2

Vehicle	**P_{CAP} = 0**	**P_{CAP} = 1/3**	**P_{CAP} = 2/3**	**P_{CAP} = 1**
EV_{EGO}	0%	11%	21%	32%
EV_1	0%	15%	28%	43%
EV_2	0%	18%	35%	54%

Assuming a threshold of 50% for risk, the server does not initiate any route re-calculation neither for EV_{EGO} nor for EV_1. But, when EV_2 is considered, for the case when $P_{CAP-EGO}$ is 1 (i.e., when all charging spots are occupied at CS_2), the risk percentage is more than 50%. So, for EV_2, the server identifies a subsequent charging station along the travel route, and re-calculates route towards the destination using the newly identified charging station. Then a decision is made whether to propose this new route to the EV_2 driver based on the following conditions (as explained in Section V):

1. Can EV_2 reach the next charging station with the current battery capacity (i.e., whether vehicle able to reach newly chosen charging station)?
2. If the estimated number of available charging spots at CS_2 are more than the number of electric vehicles reaching the charging station before EV_2 (i.e., whether vehicle is unable to have a free charging spot upon arrival)?
3. Whether passing via another charging station is faster than passing via current station, taking into account the minimum queuing time required?

When the above conditions evaluate to true, the new route is advised to the driver.

VII. SUMMARY OF FEATURES RELATED TO EV ROUTE ASSISTANCE

This section summarizes a list of features that are relevant to electric vehicle route assistance, and the advantage of using such features in optimizing route search for electric vehicles. Table IV shows a listing of the features, their corresponding advantage in optimization of route search for electric vehicles, and their availability in the method M1 described in this paper, and other methods M2 [7], M3 [15] and M4 [16] presented in the prior works under Section II. From Table IV, it can be observed that some features are also used for route assistance of non-electric vehicle as well, and hence are not new. But, given a limited range of electric vehicles, these features have much more impact, and a stronger role to be play while providing route assistance. In general, the features used for optimization target mainly two metrics for efficient route assistance: (i) travel time and (ii) energy consumption. Methods 1 and 2 focus on the first metric in order to minimize travel time when passing by charging stations. Methods 3 and 4 focus on the second metric in order to minimize energy expenditure while traveling along a route. For a given a set of routes, methods 3 and 4 prioritize route selection based on the estimate of the total amount of energy spent while traveling along the route. When battery level in an EV is such that there is enough range to reach destination, methods 1, 2, 3 and 4 can be conveniently used for route assistance of the electric vehicle. When several routes are available with enough battery range for each route, methods 1 and 2 can provide the shortest route towards destination, whereas methods 3 and 4 can select the route with lowest energy consumption.

On the other hand, when routes are similar (i.e., in terms of energy consumption), and when the distance to destination is longer than range that could be achieved with current battery level of an EV, there is no option left, but to re-charge. In such situation, it is advantageous to consider route navigation passing by charging stations. As previously mentioned in the introductory section, the order of waiting times in a charging station are relatively larger for an EV when compared to vehicles based on combustion engines. When charging is imminent to continue an onward journey, route planning via charging stations becomes a viable option. By forecasting and continuous monitoring of the charging stations along the route, drivers can be advised to take different optimal routes in order to pass by charging stations with lower or zero waiting time.

VIII. EVALUATION OF THE PROPOSED METHOD

This section evaluates the proposed route assistance method using travel time and energy consumption metrics. For the purpose of a simple hypothetical evaluation, consider Fig. 6. There are three possible routes to a destination D from start position S of an electric vehicle. They are:

- **Route 1**: S→C1→D
- **Route 2**: S→C2→D
- **Route 3**: S→C3→D

C1, C2 and C3 are the charging stations that are located along the routes. Routes 1 and 2 partly include passage via hilly areas where the energy expenditure for a vehicle can become higher when compared to traveling over a flat plain. Each of the routes is divided into segments based on the location of charging stations. Traveling via each segment on a particular route will incur a certain amount of energy expenditure (E), segment travel time (ST), charging time (CT) and queuing time (QT) in a charging station.

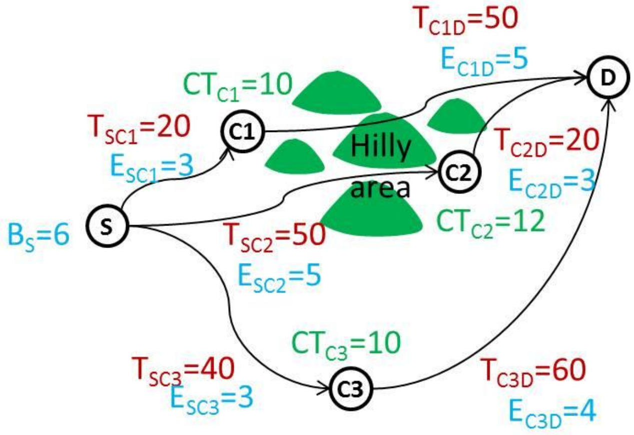

Figure 6. Evaluation of proposed method using energy expenditure and travel time metrics

The total travel time for each route is equivalent to the sum of the segment travel times, charging times and the queuing times at the charging station.

$$\text{Travel Time TT} = \sum ST_n + \sum CT_{x,} + \sum QT_x \tag{9}$$

where ‘n’ is the number of segments and ‘x’ is the number of charging stations.

The energy expenditure for each route can be calculated by summing up the individual energy expenditures of each segment for that particular route.

$$\text{Energy Expenditure EE} = \sum E_n \tag{10}$$

Using (9) and (10), the total travel time and the energy expenditure for each of the routes are calculated respectively for the case presented in Fig. 6, and are shown in Table III. It is assumed that the initial available charge (B_s) is at least enough to reach a charging station along the given route. In this evaluation, time is expressed in minutes and energy expenditure in kWh. Two cases are considered: Case A: Without knowledge of QT; Case B: With knowledge of QT.

TABLE III. EVALUATION RESULT BY PROPOSED METHOD.

Case		Route #	QT (min)	TT (min)	EE (kWh)
A	When QT = 0 or no queuing time is considered	1	0	80	8
		2	0	82	8
		3	0	110	7
B	When QT is considered	1	5	85	8
		2	2	84	8
		3	5	115	7

TABLE IV SUMMARY OF FEATURES RELATED TO EV ROUTE ASSISTANCE AND THEIR AVAILABILITY IN DIFFERENT METHODS
(O: AVAILABLE; X: NOT AVAILABLE)

Feature	**Advantage**	**M1**	**M2 [7]**	**M3 [15]**	**M4 [16]**
Charging spot availability	Enables to predict if an EV requires queuing when reaching a charging station, and eventually choose stations without any queues in order to minimize travel delay.	O	X	X	X
Queuing time in a charging station	Minimize queuing delay in a charging station (when queuing cannot be avoided). When several charging stations are present along the route of an EV, this feature allows selecting the charging station with least amount of queuing time.	O	X	X	X
Shortest travel time to charging station (including time to charge)	Allows having faster route towards destination.	O	O	X	X
Real-time traffic information	Enables to estimate extra energy consumption due to idle times and traffic incidents (e.g., traffic jam) along the route, and thereby allows predicting charging necessity or route diversion according to situation.	O	X	X	X
Include routes based on lesser EV population	Allows route traveling via possibly less-crowded charging stations, and as a result an EV may find a charging spot easily upon its arrival at a station along the travel route which is sparsely populated with EV traffic.	O	X	X	X
Shortest path to charging station	Allows having lesser total traveling distance at the end of the journey, in case a vehicle has to deviate from its route in order to find a charging station, when no suitable charging station is available along the route.	X	O	X	X
Battery range check	Enables appropriate selection of charging stations (for methods M1 and M2) or selection of appropriate route segment (for method M3) when multiple routes with several charging stations are available towards a destination.	O	O	O	X
Use descending routes	EVs can recuperate energy by using downhill slopes to augment battery charge in order to extend their range.	X	X	O	O
Avoid ascending routes	Driving uphill on a steep road requires higher power from the engine, which increases vehicle energy consumption. By avoiding such routes, energy consumption can be reduced.	X	X	O	O
Select lowest energy consumption route	When several routes are possible towards a destination, selecting a route with lowest energy consumption can reduce demand for re-charging.	X	X	O	O

Considering case A, methods M1 and M2 will select route 1 (i.e., the route with the least travel time) and methods M3 and M4 will select route 3 (i.e., the route with least energy consumption).

Considering case B, since method M1 is aware of the queuing time at the charging stations, it will select route 2, method M2 will still select route 1 because it does not have knowledge about the queuing time at the charging stations, and methods M3 and M4 will select route 3.

Thus by knowing queuing time in addition, the proposed method is able to provide a more optimal route in terms of travel time.

IX. CONCLUSION AND FUTURE WORK

This paper presented a method to provide route assistance for electric vehicles taking into account the availability of a charging station and other EVs that are susceptible to use the charging station. An approaching charging station, along the route of an electric vehicle, was associated with a risk factor for charging based on: EV population within a perimeter of the charging station, estimated arrival times of the EVs to the charging station, and the availability of charging spots in the station. By continuous monitoring of the estimated risk factor, alternative routes or charging stations were advised to the EV driver when risk percentage to charge at a station became greater. This was done to reduce delay in the EV driver's journey when a stopover is required for getting charged. Thus, by predicting risk percentages for charging at a station, EV drivers can be advised to take alternative routes that have lesser risk percentages, and which are comparatively faster for destination reachability. In Section I, the pros and cons of electric vehicle were discussed and route assistance via charging stations were shown as a promising approach to speed-up the deployment of EVs on a large scale. Some of the problems that an EV driver can encounter while driving via charging station were also discussed. Existing methods for route assistance were discussed as prior works in Section II. Section III showed the overall architecture needed to realize the route assistance service. The parameters necessary for calculating risk factor, and the decision making process for new route selection were explained in Section IV, and Section V, respectively. In Section VI, exemplary risk factor calculation, and the conditional checks that were required to re-route an electric vehicle were shown. For the reader's digest, a tabular summary of features that are used in optimization and their advantages were presented in Section VII. Observing the list of features, two principal metrics were identified for route assistance of EVs: travel time and energy consumption. EV route assistance methods can use these two metrics to trade-off and optimize route search for electric vehicles. Based on the two metrics, a simple evaluation of the proposed method was shown in Section VIII.

A detailed comparison of the proposed method with other route assistance methods using real time data is reserved for future work.

REFERENCES

[1] J. Larminie and J. Lowry, “Electric vehicle technology explained,” Wiley, 2012.

[2] E.H. Wakefield, “History of the Electric Automobile,” The Society of Automobile Engineers, SAE International Publishing, 1994.

[3] N. Kutkut, H. Wiegman, D. Divan, and D. Novotny, “Design considerations for charge equalization of an electric vehicle battery system,” IEEE Transactions on Industry Applications, 1999, vol. 35, no. 1, pp. 28–35.

[4] L. Lam and R. Louey, “Development of ultra-battery for hybrid-electric vehicle applications,” Journal of power sources, vol. 158, no. 2, August 2006, pp. 1140–1148.

[5] NissanNews.com. (September) GE, Nissan sign R&D agreement to fast track broader adoption of electric cars. http://www.nissan-global.com/EN/. Retrieved: January 2013

[6] T. Franke, I. Neumann, F. Bühler, P. Cocron, and J. Krems, “Experiencing range in an electric vehicle: Understanding psychological barriers,” Applied Psychology: An International Review, 2011, doi: 10.1111/j.1464-0597.2011.00474.x

[7] Y. Kobayashi, N. Kiyama, H. Aoshima, and M. Kashiyama, “A route search method for electric vehicles in consideration of range and locations of charging stations,” in IEEE Intelligent Vehicles Symposium (IV), Baden-Baden, Germany, 2011, pp. 920–925.

[8] J. Ferreira, A. Silva, and J. Afonso, “EV-Cockpit–Mobile Personal Travel Assistance for Electric Vehicles,” Advanced Microsystems for Automotive Applications, Springer Berlin Heidelberg, 2011, pp. 247–257, doi: 10.1007/978-3-642-21381-6_24

[9] U. Eberle and R. von Helmolt, “Sustainable transportation based on electric vehicle concepts: a brief overview,” Energy & Environmental Science, 2010, vol. 3, no. 6, pp. 689–699.

[10] M. Tran, D. Banister, J. Bishop, and M. McCulloch, “Realizing the electric-vehicle revolution,” Nature Climate Change, 2012, vol. 2, no. 5, pp.328–333.

[11] C. Botsford and A. Szczepanek, “Fast charging vs. slow charging: Pros and cons for the new age of electric vehicles,” The International Electric Vehicle Symposium and Exposition, EVS24, Stavanger, Norway, May 2009, pp. 1-9.

[12] W. Kempton, et. al, “A test of vehicle-to-grid (V2G) for energy storage and frequency regulation in the PJM system,” Results from an Industry-University Research Partnership, University of Delaware, Pepco Holdings, Inc PJM Interconnect, and Green Mountain College, November 2008.

[13] J. Taylor, A. Maitra, M. Alexander, D. Brooks, and M. Duvall, “Evaluation of the impact of plug-in electric vehicle loading on distribution system operations,” In Power & Energy Society General Meeting, July 2009, PES'09, IEEE, pp.1-6, doi: 10.1109/PES.2009.5275317

[14] Hitachi Press Release, “U.S. and Japan Companies Collaborate on Smart Grid Project in Hawaii - Hitachi to Serve as Project Leader”, May 17, 2011.

http://www.hitachi.com/New/cnews/110517b.html. Retrieved: January 2013.

[15] J. Eisner, S. Funke, and S. Storandt, “Optimal route planning for electric vehicles in large networks,” in Proc. 25th Assoc. Advancement Artificial Intell. Conf., San Francisco, CA, August, 2011. https://www.aaai.org/ocs/index.php/AAAI/AAAI11/paper/view/3637/4005. Retrieved: January 2013.

[16] A. Artmeier, J. Haselmayr, M. Leucker, and M. Sachenbacher, “The optimal routing problem in the context of battery-powered electric vehicles,” in Workshop: CROCS at CPAIOR-10, Second International Workshop on Constraint Reasoning and Optimization for Computational Sustainability, Bologna, Italy, June 2010.

[17] K. Faez and M. Khanjary, “Utospf: A distributed dynamic route guidance system based on wireless sensor networks and open shortest path first protocol,”. ISWCS’08. IEEE International Symposium on Wireless Communication Systems, 2008, pp. 558–562.

[18] T. Kono, T. Fushiki, K. Asada, and K. Nakano, “Fuel consumption analysis and prediction model for eco route search,” in 15th World Congress on Intelligent Transport Systems and ITS America’s Annual Meeting, New York, November 2008, pp. 1-9.

[19] B. Parno and A. Perrig, "Challenges in securing vehicular networks." In Workshop on Hot Topics in Networks (HotNets-IV), College Park, MD USA, November 2005, pp. 1-6.

[20] SeVeCom (Secure Vehicular Communication) http://www.sevecom.org/. Retrieved: January 2013

[21] PRESERVE: Preparing Secure V2X Communication Systems http://www.preserve-project.eu/. Retrieved: January 2013

[22] European Commission, “How will the EU’s reform adapt data protection rules to new technological developments?”, January 2012. http://ec.europa.eu/justice/data-protection/document/review2012/factsheets/8_en.pdf Retrieved: January 2013

[23] P. Papadimitratos, L. Buttyan, T. Holczer, E. Schoch, J. Freudiger, M. Raya, Z. Ma, F. Kargl, A. Kung, and J-P. Hubaux. “Secure vehicular communication systems: design and architecture,” Communications Magazine, IEEE, 2008, vol. 46, no. 11, pp. 100-109.

[24] R. Lu, X. Lin, H. Zhu, P. H. Ho, and X. Shen, “ECPP: Efficient conditional privacy preservation protocol for secure vehicular communications,” In INFOCOM 2008, The 27th Conference on Computer Communications, IEEE, 2008, pp. 1229-1237.