Electric vehicle charger management system for interoperable charging facilities

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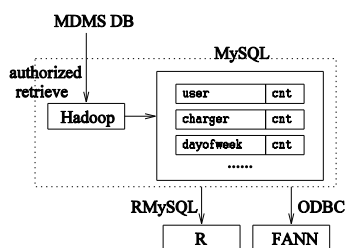
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Graphical abstract

Abstract

This paper designs and develops a real-time charger management system which keeps collecting the status information from chargers and converts control messages from the total operation center to a command predefined for charger control. RF cards complete the service chain from electric vehicles to the operation center, making the information flow bidirectional. The extended coverage of the operation control over the charging infrastructure allows an easy payment for the charging fee, based on the membership management and personalized services. A web application is implemented on the digital map of the target city for users to retrieve necessary information from the system and find the best service and chargers. The massive amount of real-time charger monitoring data is being accumulated in the database, and big data analysis will allow us to make intelligent plans for future smart grid city services.

Keywords: Electric vehicle, charging facility management, total operation center, big data processing, interoperability

1.0 INTRODUCTION

Smart grids are pursuing energy efficiency and electrifying as many entities as possible, while EVs (Electric Vehicles) make even the transport systems as a part of the power network [1]. EVs are powered by electricity stored in their batteries, so it is not necessary to burn fossil fuels if the energy does not come from thermal power generation. However, due to current battery capacity limitation, EVs' driving range still remains at about 100 km in practice, so they must be charged more often than their counterparts, namely, ICEV (Internal Combustion Engine Vehicle) [2]. Hence, this green technology demands a lot of charging facilities be constructed to be comparable to gas stations for ICEVs. Chargers currently under construction are digitally controlled and managed. Yet, their interfaces are not fully standardized for complete interoperability. Even though we expect that a strict standard will be specified and become mandatory for all chargers, there exist a variety of heterogeneous chargers from many different manufactures.

Basically, a smart grid is designed so that its TOC (Total Operation Center) takes the control of every feasible element. This policy is also effective to charging facilities. That is, respective chargers, charging stations, and other facilities are also required to be managed by the authorized TOC [3]. Then, the power system provides not just an on-site or isolated charging service but also a grid-wide charging coordination such as charger reservation [4], price policy announcement, and intelligent scheduling mechanisms [5]. Moreover, the membership management can allow efficient authentication and more personalized services. In this regard, this paper designs and develops a charger management system working between chargers and the TOC. It continuously monitors the status of chargers and abstracts the low-level interface for the TOC, relaying control commands and operation results between both parties.

The rest of this paper is organized as follows: Section 2 shows the details on our charger monitoring system. Section 3 shows the analysis result of the data which is being accumulated in our system. Finally, Section 4 concludes this paper with an introduction of future work.

2.0 SYSTEM DEVELOPMENT

Figure 1 shows the module by module architecture of our charger management system and how each module cooperates. Named EV-MDMS (Meter Data Management System), it is developed under the *industrial technology innovation project* sponsored by Korean government.
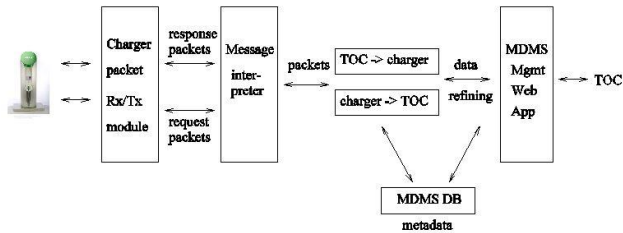

Figure 1 Functional architecture of EV-MDMS

Two interfaces are provided, one for the charger-side and the other for the TOC-side. Previously, chargers and its own management system exchange messages according to the protocol specified by the Ministry of Environment, Republic of Korea. Now, the *charger packet Rx/Tx module* abides by this protocol to receive messages from chargers. Then, the *message interpreter* converts the message into the proprietary form by which the MDMS can manipulate efficiently. Here, the real-time status reports, generated every 5 minutes from each charger, are stored in MDMS database. In addition, the MDMS web application is implemented to allow human operators and other applications to access the database and update the control logic on MDMS. It is also through this application that the TOC-side interface works with the core of MDMS.

Now, TOC is extended to support more comprehensive charger-related functions as shown in Figure 2. First of all, drivers can pay their EV charging fee by diverse methods pre-registered in the system irrespective of charger types. To this end, chargers recognize the membership ID of the EV   driver when connected, and sends to the charging company through MDMS and TOC. The company manages all necessary information on membership, charging history, charger type, and so on.
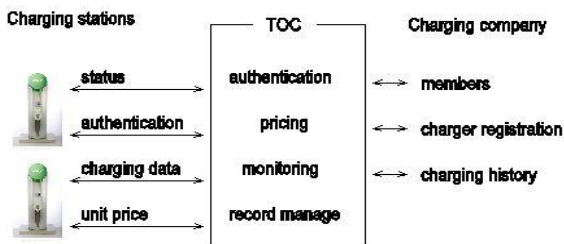

Figure 2 TOC operation

Not just the common payment method across different chargers, this service architecture opens the way to more personalized charging such as discount coupons, charging spot recommendation, and the like [6]. Moreover, the charging company can notify the real-time price change to the charger via this system [7]. In addition, TOC, combined with our MDMS, can create many useful statistics on the charging transaction, failure alarm history, per-charger as well as per-station power consumption amount. Such information will enrich the management application by intelligent planning and fast response to abnormal conditions [8].

Figure 3 depicts the web interface for EV-MDMS. It is built on the GIS (Geographic Information Service) layer, marking chargers on the digital map of Jeju city. User actions such as mouse click is delivered to the system and converted to an appropriate query to the database.

Figure 3 Charger monitoring display

Then, the retrieved information is forwarded towards and displayed on the map. Basically, this web application displays the current status of each charger, namely, in-charge, in-test, rest, or disabled, periodically updating the page. In addition, an Android application retrieves the locations of chargers and informs the user of the closest available one. Via this mobile application, drivers can be aware of their charging history and update his preference on payment methods. In the other side, an RF card is issued to an EV driver, and this card can be used on any chargers. Every charger installs an RF card reader to take information embedded in the attached RF card.

3.0 DATA ANALYSIS

Figure 4 shows how our framework conducts a charging data analysis. After retrieving the temporal stream records from the MDMS, Hadoop Pig scripts cooks the raw data to filter necessary fields [9]. At this stage, the fields of user id, chargerid, and battery consumption are extracted. Preliminarily, Pig scripts calculate the number of records, which shows the operation status of each charger, per-user, per-charger, and daily basis using the primitive Pig commands. In addition, the day-of-week is calculated by means of *DaysBetween* and modulo functions. Here, Hadoop efficiently handles the massive amount of stream data without managing them in a database system. Now, the utility program converts the Pig script result to SQL commands to insert them to MySQL running in our Linux machine. Then, the R statistical package get those results via the RMySQL library for further data processing. In addition, any application can retrieve them via an appropriate X-DBC(Data Base Connectivity) mecha-nism. Here, we will combine a neural network library, specifically FANN (Fast Artificial Neural Network) [10].
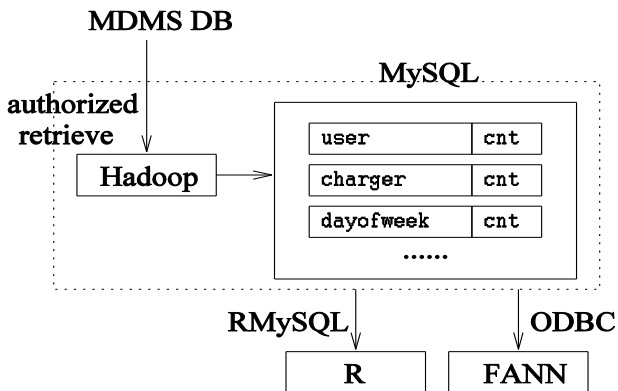

Figure 4 Data analysis framework

Chargers are set to send reports only when they are supplying energy to an EV. Our monitoring system has begun working in the last year, but it has undergone an intensive test process, during which the system is temporarily shutdown, some chargers are dis-connected from the system, and the data management policy is fixed [11]. Hence, the status reports are not stable and their analysis results are not so meaningful. Since August2015, MDMS is accumulating the data consistently, and the number of records reaches about 100,000 and keeps growing exponentially. Figure 5 shows the per-charger number of records, which indicates the operational status of each charger. The number of rigorously reporting chargers is 42 and it will also increase. The charger ID is not continuous, as some chargers are excluded due to its limitation in reporting capability and membership change. As can be seen from the figure, there exists hot chargers many EVs visits. The main reason of the significant demand difference will be the geographic aspect, but MDMS does not publish the exact location of each charger for security reasons, even though it is displayed on the real-time map display.
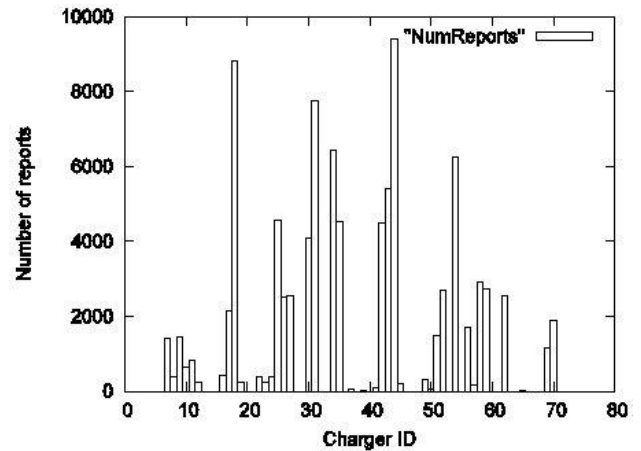

Figure 5 Per-charger statistics

Figure 6 plots the per-user number of reports. The Pig script groups the whole records by the user ID and counts the number of records in each group. As the user ID is not an integer, only the count field is generated without any specific order option.48 users (EV drivers) have been connected to our charger monitoring system at least once. Here again, intensive users are identified and they are likely to usually use the same charger. Here, 14 users have 100 or less reports. Their connection day is concentrated to a specific interval. On the contrary, 4 users have more than 5,000 records. They seem to have found an available charger when necessary.
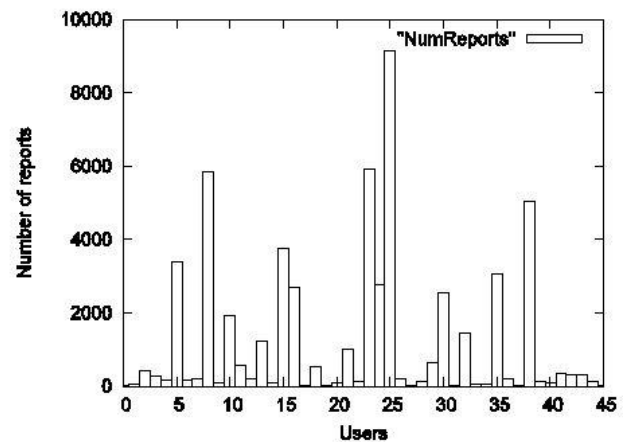

Figure 6 Per-user statistics

Next, Figure 7 investigates the effect of the day-of-week to the charger utilization. Even if the number of records decreases during the weekend, the difference remains at just 14 %. This result indicates that EVs are used during both weekdays and weekends evenly, while charging facilities should not be closed

during weekends. Here, the MDMS records include only the date field and time information is not stored for user privacy protection. Hence just the day-by-day statistics is allowed.
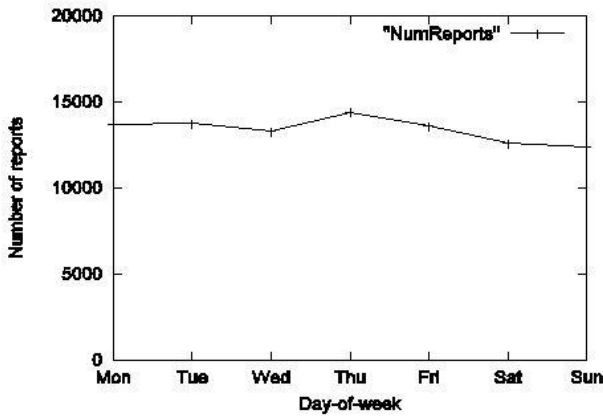

Figure 7 Effect of day-of-week

Figure 8 is the probability distribution for the user data. To this end, the per-user counts in downloaded by the R package running a Windows PC via RMySQL library. The, the R script call the *hist* function with the size of breaks set to 50. A sthe number of users is not sufficiently large yet, the probability distribution cannot be specifically characterized. However, any other analysis functions abundantly provided in the R package can be exploited.
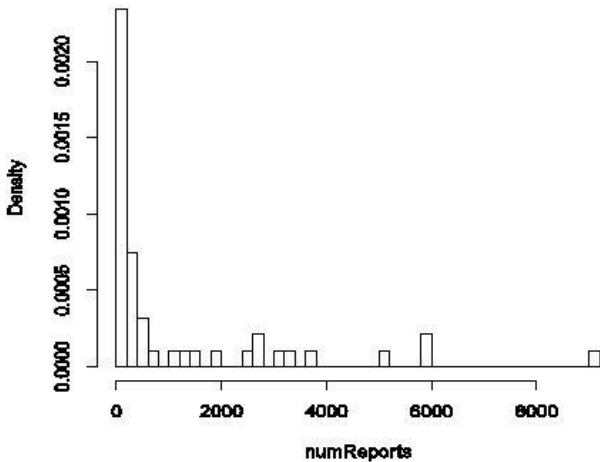

Figure 8 Probability distribution function for user records

Finally, Figure 9 shows 2 curves. The first one is the daily number of records in MDMS, and it is created by running a Pig script. As contrast, the second one is the fitted curve created by a C language program combining the FANN libraries. The C program retrieves the information stored in a remote MySQL database via ODBC (Open DBC) using the regular SQL queries

embraced in the ODBC function calls. The time series of currently 78 days is converted to a set of learning patterns of a neural network model. The FANN library defines the text file format for learning patterns and trace sequences. Based on this forecast model, we trace the previous behaviors of the number of daily records. Here, the solid line is the traced utilization pattern, and it finds the overall trend in the time series. It is expected that the forecast model will be improved with more data.
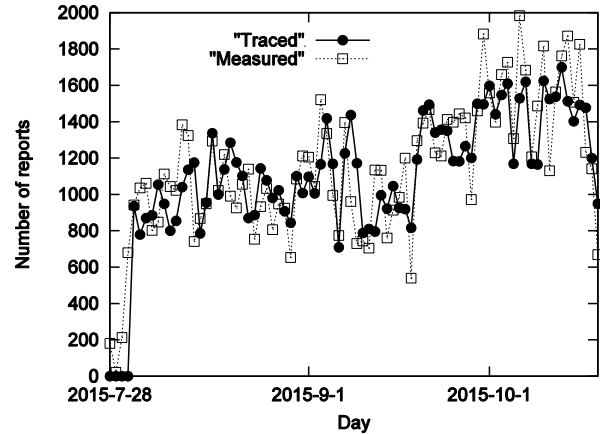

Figure 9 FANN-combined analysis

4.0 CONCLUDING REMARKS

In this paper, we have presented the design and development of EV-MDMS which works between the chargers and TOC, improving the interoperability of heterogeneous chargers. EV-MDMS consists of message interpreter, database, web application support, and two interfaces for chargers and TOC. Taking advantage of EV-MDMS, TOC extends its control over the charging infrastructure. It can implement additional services for the sake of user convenience. Currently, the main benefit lies in the easy payment for the charging fee, based on the membership management and personalized services. However, this service architecture will host both web-based and mobile applications which basically retrieve relevant information and find the best service or charger across the city-wide charging framework. To this end, web and Android applications have been implemented upon the city map, while RF cards and their readers are deployed in chargers, creating an integrative service chain connecting both end points. In addition, the real-time monitoring data from chargers are being accumulated in MDMS database. A sophisticated analysis of this time series will give us valuable information in power provisioning, energy consumption estimation, and new business model design [12]. We are now making an effort to build an efficient V2G (Vehicle-to-Grid) system upon this service architecture. The system can coordinate the electricity trade between chargers and the grid via bidirectional chargers. The big data analysis, possibly

taking advantage of Hadoop and R, is now in progress [13].

Acknowledgement

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