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SBUS: Smart e-Bus Battery Substitution Scheme in Vehicular Networks

Jihyeok Seo*, Jaehoon (Paul) Jeong†, Hyoungshick Kim*, and Jung-Soo Park‡
* Department of Computer Science & Engineering, Sungkyunkwan University, Republic of Korea
† Department of Interaction Science, Sungkyunkwan University, Republic of Korea (Corresponding Author)
‡ Electronics and Telecommunications Research Institute (ETRI), Republic of Korea
Email: {seojh43,pauljeong,hyoung}@skku.edu, pjs@etri.re.kr

***Abstract*—This paper proposes a Smart e-Bus Battery SUbstibution Scheme (called SBUS), tailored and optimized for the commute service of e-Buses using a cloud-based management system. To the best of our knowledge, our scheme is the first attempt to investigate the efficient battery replacement of e-Buses in road networks, based on the trajectories (i.e., travel routes) of e-Buses in road networks. Through simulations, it is shown that our SBUS scheme outperforms baselines in a road network with multiple bus lines.**

I. Introduction

Recently, Smart e-Bus Systems have been actively developed as an alternative transportation system to reduce the dependency on fossil fuel [1]. Also, Vehicular Ad Hoc Networks have been researched and developed for the driving safety and efficiency through the communications among vehicles and infrastructure in vehicular networks [2]–[6]. With these two trends, a natural research question is *how to use vehicular networks to support the operations of the Smart e-Bus Systems via cloud*.

Among the operations of the smart e-Bus systems, this paper focuses on the battery replacement of e-Buses during their services, considering the waiting time at e-Bus stations for the battery replacement. Thus, we define a new optimization problem to minimize the waiting time at e-Bus stations and propose a greedy algorithm called SBUS with e-Buses' service routes, trajectories (i.e., navigation paths), and battery replacement reservations at e-Bus stations that are maintained by the cloud-based management system called Traffic Control Center (TCC). TCC can estimate waiting time for battery replacement at each e-Bus station, so it allocate the best battery-replacement station to each e-Bus in terms of waiting time. Since our SBUS scheme considers the estimated waiting time for e-Buses that are waiting for battery replacement at each e-Bus station or reserved an e-Bus station for their future battery replacement.

The remaining of the paper is constructed as follows: Section II describes problem formulation for e-Bus battery replacement. Section III explains the travel time prediction of e-Buses. Section IV describes the design for our smart e-Bus battery substitution sheme. Section V discusses research issues. Section VI evaluate the performance of SBUS along with baselines. Finally, Section VII concludes the paper along with future work.

II. Problem Formulation

In this section, we articulate the goal, assumptions, and formulation for the battery replacement of e-Buses in the smart e-Bus systems. Given trajectories of e-Buses in a target road network, our goal is to determine the battery replacing station of each e-Bus in order to minimize the waiting time at each e-Bus stations.

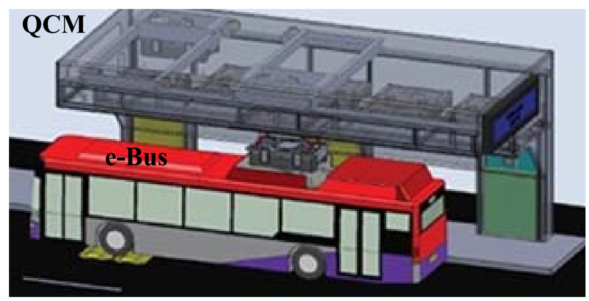

Fig. 1. Quick Battery Changing Systems [1]

A. Smart e-Bus Systems and Assumptions

In this subsection, we articulate the architecture of Smart e-Bus Systems and also assumptions. The following defines the system nodes for Smart e-Bus Systems:

- **Electric Bus (e-Bus)**: e-Bus is a bus running by the rechargable battery that is installed on the top of the e-Bus [1].
- **Quick Battery Changing Machine (QCM)**: QCM is a bus station that replaces a used battery with a charged battery for e-Buses [1].
- **Traffic Control Center (TCC)**: TCC is a cloud-based management system to collect the status of e-Buses and QCMs [7]. Also, TCC collects vehicular traffic statistics, such as (i) vehicle average speed and arrival rate for each road segment and (ii) vehicle branching delay and branching probability from one road segment to another road segment at each intersection. TCC schedules the battery replacement time and QCM station to each e-Bus, considering the QoE of passengers.
- **Road-Side Unit (RSU)**: RSU is a gateway between the wired network and the vehicular ad-hoc network [8]. RSU has a DSRC wireless interface to

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communicate with mobile vehicles and an Ethernet interface to communicate with other RSUs and TCC. As a gateway, RSU allows vehicles to communicate with TCC via them. RSUs collect vehicular traffic statistics from passing vehicles and report them to TCC.

The following assumptions are made for SBUS:

- TCC, RSUs, and e-Buses are equipped with GPS navigation systems.
- QCMs, RSUs, and e-Buses are equipped with Dedicated Short Range Communications (DSRC) [9] device for the wireless communications in vehicular networks.
- Each e-Bus needs only one battery replacement to cover its service route. Most service routes have about 40 km and one fully charged battery allows an e-Bus to run up to 20 km in road networks [1].
- QCMs have enough batteries for the battery replacement of e-Buses.

III. Travel Time Prediction

In this section, we model the travel time on both road segment and End-to-End (E2E) travel path (i.e., e-Bus trajectory) along the service route of an e-Bus.

A. Travel Time through Road Segment

Let $G = (V_G, E_G)$ be a road network graph where V is a set of intersections and E is a set of directed road segments. It is proved that the travel time of one vehicle over a fixed distance in light-traffic vehicular networks follows the Gamma distribution [10] [11]. Thus, the travel time through a road segment i in the road network is defined as *link travel delay* d_i such that $d_i \sim \Gamma(\kappa_i, \theta_i)$ where κ_i is a shape parameter and θ_i is a scale parameter. Note that $d_i \sim \Gamma(\alpha_i, \beta_i)$ where $\alpha(=\kappa_i)$ is a shape parameter and $\beta(=1/\theta_i)$ is an inverse scale parameter [12]. To calculate the parameters κ_i and θ_i, the mean μ_i and the variance σ_i^2 can be used for the link travel delay [12] on the given road segment $e_i \in E_G$. The traffic statistics of μ_i and σ_i^2 is available from a commercial navigation service provider (e.g., Garmin [13]).

Let the mean of d_i be $E[d_i] = \mu_i$ and the variance of d_i be $Var[d_i] = \sigma_i^2$, the formulas for κ_i and θ_i are as follows:

$$\theta_i = \frac{Var[d_i]}{E[d_i]} = \frac{\sigma_i^2}{\mu_i} \tag{1}$$

$$\kappa_i = \frac{E[d_i]}{\theta_i} = \frac{\mu_i^2}{\sigma_i^2} \tag{2}$$

In addition to the above mathematical model for link delay distribution on a road segment, our SBUS can accommodate emprical measurements for the distribution of link delay. This empirical measurements can be performed by the report of vehicles (passing through the road segment) to the RSU taking charge of the road segment. Thus, a more accurate link travel delay distribution will allow SBUS to predict the travel time more accurately for the QCM allocation for the battery replacement.

B. Travel Time on End-to-End Path

The End-to-End (E2E) travel delay in a road network can be modeled with the link delay model in Section III [10]. As the link travel delay is modeled as the Gamma distribution of $d_i \sim \Gamma(\kappa_i, \theta_i)$ for road segment i, the E2E travel delay can be modeled with a sum of Gamma distributions of the link delays. Given a specific traveling path, it is assumed that the link travel delays of different road segments for the path are independent. With this assumption, the mean (or variance) of the E2E travel delay is approximately calculated as the sum of the means (or variances) of the link travel delays for the links along the E2E path. Assuming that the traveling path consists of N road segments, the mean and variance of the E2E travel delay D are computed as follows:

$$E[D] = \sum_{i=1}^{N} E[d_i] = \sum_{i=1}^{N} \mu_i \tag{3}$$

$$Var[D] = \sum_{i=1}^{N} Var[d_i] = \sum_{i=1}^{N} \sigma_i^2 \tag{4}$$

With (3) and (4), the E2E travel delay D is approximately modeled as a Gamma distribution as follows: $D \sim \Gamma(\kappa_D, \theta_D)$ where κ_D and θ_D are calculated using $E[D]$ and $Var[D]$ using the formulas of (1) and (2). Note that if a more accurate distribution for the E2E path is available from the measurements or another mathematical model, our SBUS can use this distribution for the E2E travel time estimation.

Let's discuss the relationship between the arrival time (denoted as T_{ak}) of vehicle V_a at a target intersection n_k and the E2E travel delay (denoted as $D_{a,jk}$) from V_a's current position n_j to the target intersection n_k. Let T^* be the current time. Let $T_{a,jk}$ be the arrival time at n_k for vehicle V_a's E2E travel from the current position n_j to the target intersection n_k. The arrival time $T_{a,jk}$ can be modeled as a Gamma distribution with Equations (3) and (4) such that $T_{a,jk} = D_{a,jk} + T^*$. This is because $T_{a,jk}$ is a linear combination of a Gamma random variable $D_{a,jk}$ and a constant value T^*. For simplicity, we denote $T_{a,jk}$ as T_{ak} where the vehicle V_a's current position is implicitly known by the GPS navigation systems.

IV. The Design of Smart e-Bus Battery Substitution Scheme

In this section, we show our design of Smart e-Bus Battery Substitution Scheme (SBUS). The goal in SBUS is to assign an appropriate QCM station to each e-Bus for battery replacement to minimize the overall waiting time of each e-Bus caused by the battery changing. Fig. 2 shows a target road network for Smart e-Bus Services. In this figure, an e-Bus $eBus_1$ needs to replace its battery at one of QCMs (i.e., QCM_1 and QCM_2) on its service route. The question is *at which QCM $eBus_1$ should replace its battery with the remaining battery energy, considering the overall waiting time of the Smart e-Bus System*. In this paper, we measure the waiting time of each e-bus caused by the battery changing. We show two QCM allocation scenarios for eBus battery replacement in Fig. 3. In Fig. 3(a), $eBus_3$ of Route-2 and $eBus_1$ and $eBus_2$ of Route-1 are trying to replace their

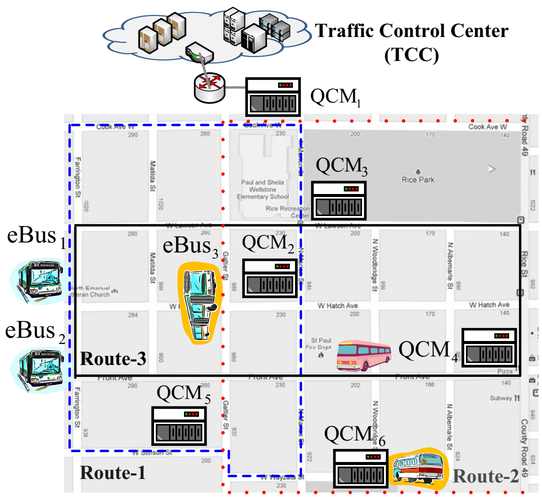
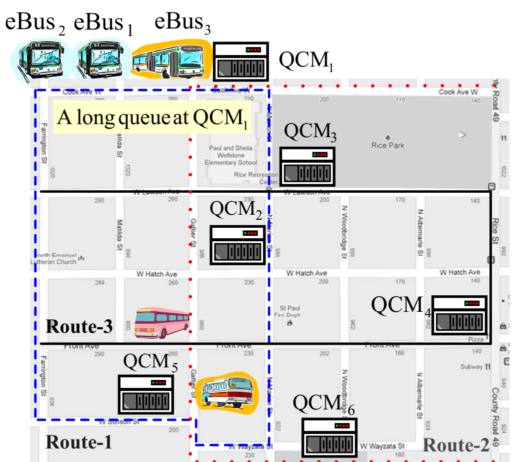
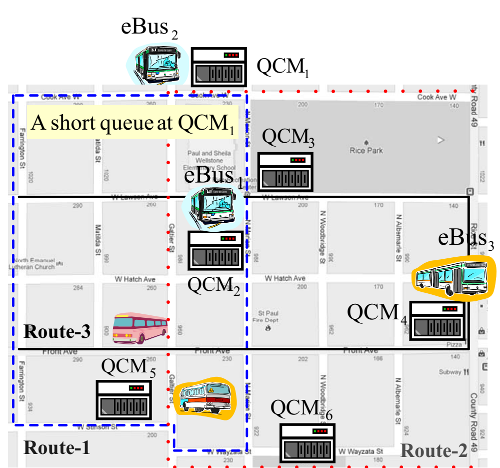


Fig. 2. Target Road Network for Smart e-Bus Services



(a) Bad QCM Allocation to cause a Long Queue at QCM_1



(b) Good QCM Allocation to cause a Short Queue at QCM_1

Fig. 3. QCM Allocation Scenarios for Battery Replacement

battery at QCM_1. Since they arrive at QCM_1 with a short interval, they make a long queue for battery exchange at QCM_1, as shown in Fig. 3(a). This long queue may cause the waiting time of $eBus_2$ for a long stopping time at QCM_1. On the other hand, $eBus_1$ and $eBus_3$ will select each QCM_2 and QCM_4 rather than QCM_1 to decrease the queue length at QCM_1. As a result, the $eBus_2$ will be waiting at a short stopping time at QCM_1 for battery exchange. Thus, it is seen that a smart QCM allocation is required to satisfy the QoE of passengers. In this paper, we will propose an algorithm for our Smart e-Bus Battery Substitution Scheme and will compare our method with baseline methods.

For the QCM allocation, we calculate distance that can be reached through the redundant battery for each e-Bus and formulate an optimization by minimizing the aggregated waiting time of each e-Bus in the e-Buses running in a target road network. so, we select the QCM to minimize the waiting time from the QCM in reachable distance. We define a wait function w_i for the *waiting time* of $eBus_i$ where b_i and q_i are the numbers of e-Buses and QCMs on its route, respectively and $interval_t$ is the interval departure time of e-Buses.

$$w_i = f(b_i, q_i, interval_t), \tag{5}$$

where f is the wait function actually measured by queueing system for QCM, such as follows:

$$f(b_i, q_i, interval_t) \propto \frac{b_i}{interval_t * q_i} \tag{6}$$

The overall waiting time W in the Smart e-Bus System is the sum of all the waiting time of m e-Buses, that is, $eBus_i$ for $i = 1..m$:

$$W = \sum_{i=1}^{m} w_i. \tag{7}$$

Our goal is to minimize this overall waiting time W, considering the arrival time of e-Buses at QCM stations for the current road traffic conditions.

A. The Algorithm for Smart e-Bus Battery Substitution Scheme

In this subsection, we describe a scheduling algorithm for Smart e-Bus Battery SUbstitution Scheme (called *SBUS*) to minimize the waiting time of each e-Bus. Note that this algorithm is performed by TCC.

The algorithm of *SBUS* is specified as follows. Let $G = (V, E)$ be a directed graph for a target road network (called road network graph) where V is a set of intersections and E is a set of road segments. Let QCM be the set of n QCMs. Let B be the set of m e-Busses to need battery replacement. Let s be the battery replacement time.

In the for-loop from line 2 to line 6, each e-Bus in B is assigned to an appropriate QCM, considering the reachable distance and the waiting time for battery exchange. In line3, we can obtain the reachable QCMs with its redundant battery. In line 4, we can select the QCM on which the e-Bus would the least wait for battery exchange service with battery replacement time s. In line 5, we can insert the schedule for the e-Bus into q^* and assign its QCM to q^*. This algorithm is finished at the end of for-loop about all e-Buses. The proposed algorithm runs in O($m \cdot n$) time – the operation Extract-Reachables can be performed in O(n) with m iterations; line 4 to find the QCM having minimum waiting time with greedy algorithm takes O(n).

Algorithm 1 SBUS Algorithm

procedure CONSTRUCT-SBUS(G, B, QCM)
  for $i \leftarrow 1, m$ **do**
    $Q[i] \leftarrow$ Extract-Reachables($QCM, B[i]$) ▷ get QCMs Q which the e-Bus $B[i]$ could run up to with its redundant battery.
    $q^* \leftarrow \arg \min_{q \in Q[i]} \{w(q) + s\}$ ▷ select the QCM on which the e-Bus $B[i]$ would the least wait for battery exchange service with battery replacement time s
    Insert($q^*, B[i]$) ▷ insert the schedule for the e-Bus $B[i]$ into q^* and assign its QCM to q^*
  end for
end procedure

B. Baseline Algorithms for the comparison with SBUS Algoritm

For the evaluation of SBUS algorithm, we show the following baseline algorithms: (i) Reachable and Random-QCM Algorithm and (ii) Reachable and Farthest-QCM Algorithm. The baseline algorithms are similar to SBUS algorithm, however, we will show the following main differences:

- In Reachable and Random-QCM Algorithm (called **Random**), we have three steps. First, we calculate the reachable distance with redundant battery of e-Bus. Second, we get the QCMs on reachable distance. Third, we select a QCM randomly among the QCMs that are selected in the second step.
- In Reachable and Farthest-QCM Algorithm (called **Farthest**), we have three steps. First, we calculate the reachable distance with redundant battery of e-Bus. Second, we get the QCMs on reachable distance. Third, we select a QCM farthest away among the QCMs that are selected in the second step.

V. RESEARCH ISSUES

We have the following research issues related to the optimization for e-Bus battery replacement in SBUS.

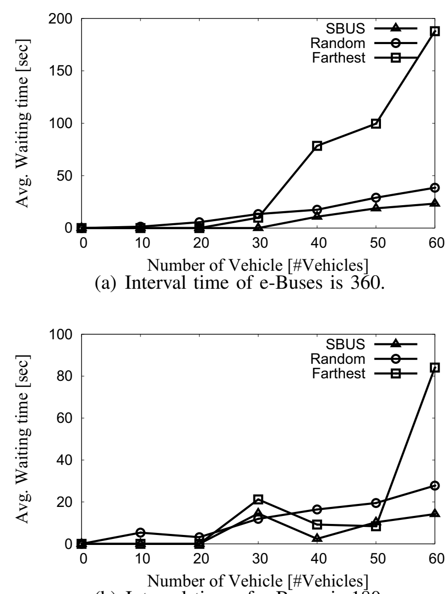
1) How to select a QCM for an e-Bus requiring battery replacement, considering both (i) the traffic congestion caused by the e-Bus's stopping for battery replacement and (ii) the minimization of passenger complaint?
2) Are there more constraints to consider? For example, (i) each e-Bus stops at every stop along its service route and (ii) a fully recharged battery allows an e-Bus to run up to the distance of δ without recharging or visit the number of stops, N.
3) How to implement the priority queue for Algorithm 1, considering the time-dependent graph for the battery exchange time interval? We can illustrate the QCM allocation using a bipartite graph $K_{m,n}$ where B is a set of m e-Buses requiring battery exchange and Q is a set of n QCMs for battery replacement. This bipartite graph is a time-dependent graph whose edge is related to the battery exchange time interval.

VI. PERFORMANCE EVALUATION

In this section, we evaluate the performance of *SBUS* in the overall waiting time of e-Buses. The evaluation setting is as follows:

- **Baselines**: We compare our SBUS algorithm with two baselines algorithms, such as Random and Farthest.
- **Parameters**: To run simulations, we set routes and service interval time of e-Buses and the number of e-Buses.

We have implemented our *SBUS* and two baseline algorithms on top of a popular mobility simulator called Simulation of Urban MObility (SUMO) [14]. A road network with 12 intersections and 4 e-Bus lines is used in the simulation. We let all of the road segments have the same speed limit (i.e., 24MPH) in the road network for the simulation. Fig. 4 shows average waiting time of e-Buses using three algorighms, such as SBUS and two baseline algorithms as the number of e-Buses (denoted as Vehicles) increases over time. The battery replacement time is constant, so it is excluded from the waiting time.



(b) Interval time of e-Buses is 180.

Fig. 4. Number of Vehicles vs. Waiting Time for Battery Replacement

Reachable and Random-QCM algorithm (called Random) randomly allocates QCMs to e-Buses as long as the e-Buses can reach them. Reachable and Farthest-QCM algorithm (called Farthest) allocates the farthest QCMs to e-Buses as long as the e-Buses can reach them. As shown in Fig. 4, the baselines Random and Farthest can make some QCMs have a long queue of e-Buses for the battery replacement because they do not perform load balancing for the battery replacement at QCMs. This long queue of e-Buses leads to a longer waiting time according to the increase of the number of e-Buses.

Thus, it can be seen that SBUS has shortest waiting time from Fig. 4. On the other hand, Farthest and Random algorithms have a long waiting time than SBUS because they do not consider estimated waiting time due to the queue of e-Buses for battery replacement. Therefore, SBUS can achieve better performance than Farthest and Random algorithms through the prediction of waiting time at e-Bus stations for the battery replacement.

VII. Conclusion

In this paper, we proposed our scheduling algorithm for Smart e-Bus Battery SUbstitution Scheme (called *SBUS*) for the efficient battery replacement. Our SBUS algorithm aims at the minimization of the waiting time for the battery replacement at QCM stations. SBUS takes advantage of the trajectories of e-Buses and the reservation information of battery replacement at QCM stations along with travel time prediction, based on road traffic information. We believe that our SBUS algorithm will improve traffic flow in road networks where e-Bus systems are deployed to save fossil fuel and also improve atmosphere. The effectiveness of SBUS is shown through performance comparison with two baseline algorithms, such as Random and Farthest algorithms. As future work, we will evaluate the performance of our SBUS algorithm in a realistic road network, based on a road map along with actual bus lines in the road network, and enhance our SBUS algorithm.

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References

[1] Electric Vehicle Transportation Safety System Convergence Research Consortium, "Smart e-Bus," http://www.smart-e-bus.com/eng/index.asp.

[2] Q. Xu, R. Sengupta, and D. Jiang, "Design and Analysis of Highway Safety Communication Protocol in 5.9 GHz Dedicated Short Range Communication Spectrum," in *VTC*. IEEE, Apr. 2003.

[3] J. Zhao and G. Cao, "VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks," *IEEE Transactions on Vehicular Technology*, vol. 57, no. 3, pp. 1910–1922, May 2008.

[4] A. Skordylis and N. Trigoni, "Delay-bounded Routing in Vehicular Ad-hoc Networks," in *MOBIHOC*. ACM, May 2008.

[5] J. Ott and D. Kutscher, "Drive-thru Internet: IEEE 802.11b For "Automobile" Users," in *INFOCOM*. IEEE, Mar. 2004.

[6] J. Eriksson, H. Balakrishnan, and S. Madden, "Cabernet: Vehicular Content Delivery Using WiFi," in *MOBICOM*. ACM, Sep. 2008.

[7] Philadelphia Department of Transportation, "Traffic Control Center," http://philadelphia.pahighways.com/philadelphiatcc.html.

[8] A. Abdrabou and W. Zhuang, "Probabilistic Delay Control and Road Side Unit Placement for Vehicular Ad Hoc Networks with Disrupted Connectivity," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 1, pp. 129–139, Jan. 2011.

[9] Y. L. Morgan, "Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics," *IEEE Communications Surveys & Tutorials*, vol. 12, no. 4, pp. 504–518, Oct. 2010.

[10] J. Jeong, S. Guo, Y. Gu, T. He, and D. Du, "Trajectory-Based Statistical Forwarding for Multihop Infrastructure-to-Vehicle Data Delivery," *IEEE Transactions on Mobile Computing*, vol. 11, no. 10, pp. 1523–1537, Oct. 2012.

[11] A. Polus, "A Study of Travel Time and Reliability on Arterial Routes," *Transportation*, vol. 8, no. 2, pp. 141–151, Jun. 1979.

[12] M. DeGroot and M. Schervish, *Probability and Statistics (3rd Edition)*. Addison-Wesley, 2001.

[13] Garmin Ltd., "Garmin Traffic," http://www8.garmin.com/traffic/.

[14] SUMO, "Simulation of Urban MObility," http://sumo-sim.org.