The Electric Vehicle–A Sacred Treasure Supporting a Smart Community

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ABSTRACT

In this paper, we present the concept of a smart community for an aging, sustainable, and low-carbon producing society, and discuss the essential roles of electric vehicles (EVs) in such a community. In particular, we emphasize that a small EV with one or two seats is a convenient vehicle for the elderly to use when moving around their community. We focus on two roles of EVs for their possible contributions to a smart community. First, EVs can be used for charging the batteries of base stations for sensor and communication networks when a lengthy and large-scale blackout occurs. Second, EVs can be used to form a mobile ad-hoc network, called an EVANET. An EVANET can be used for safety and convenience of community life, as well as a rapid emergency network deployment after large-scale disasters. Finally, we emphasize the need of a driving assistance system, especially for the elderly in a smart community, and as a way to overcome some of the technical challenges of such a system, we present an efficient medium access control technique called "Random Slot Selection with Reservation."

Keywords: Smart community, Electric Vehicle, Ad hoc network, VANET, Power supply

1   INTRODUCTION

Three sacred treasures, a sword, a mirror, and a fortune stone imitating the shape of both the sun and moon, appear in a Japanese myth. It is said that these treasures were handed down from the gods and preserved in the imperial tradition. The Japanese like to compare three precious things in life to these three sacred treasures. In the late nineteen-fifties, the precious items were a black and white television, a refrigerator, and a washing machine. In the late nineteen-sixties, they were a color television, an air conditioner, and a family car. These were indeed symbols of a happy and wealthy life for ordinary people, brought about by a rapid and continual growth in the Japanese economy.

Presently, there is an urgent need worldwide for an evolution into low carbon and resource sustainable societies. Clean energy development has been considered as an obvious solution to this need, and nuclear power has been included as one source of clean energy. However, the recent nuclear power plant accident that occurred after the Great East Japan Earthquake has raised significant concerns regarding the safety of nuclear power plants. This has in turn raised the urgent and controversial questions of how to adapt various social systems for use in energy-efficient societies. In this light, we need to examine new approaches and guidelines for redesigning society. A smart community is one such approach.

What then are the three sacred treasures in a smart community? In our view, they are an energy infrastructure, an information and communication infrastructure, and the electric vehicle (EV). The energy infrastructure can be represented by the sword, which is a tool for hunting and implies food and energy. The information and communication infrastructure can be represented by the mirror, which is a tool for both visualization and optical communication. Finally, the EV can be represented by the fortune stone, which in this case is used to call forth good fortune in a smart community.

The remainder of this paper is organized as follows: Section 2 presents the concept of a smart community and the role of EVs in such a community. Section 3 discusses the use of EVs for charging the base stations of sensor and communication networks. Section 4 considers new potentials of mobile ad-hoc networks composed of EVs. Section 5 discusses a driving assistance system in an aging society and a wireless medium access control technique that supports this system. Section 6 provides some concluding remarks.

2   A SMART COMMUNITY AND THE ELECTRIC VEHICLE

The term "smart community" has been used in various contexts. These days, it is often used in connection with smart grids and related areas [1]. The major interests in this context include the energy efficiency and self-sufficiency of a community. In this study, we use the term smart community in connection with both energy efficiency and self-sufficiency, and improving the quality-of-life (QOL), particularly for the elderly. Food security is also a major concern with an increasing circulation of food contaminated with dangerous chemicals and bacteria under a global market economy. Consequently, the food self-sufficiency of a community has attracted considerable attention worldwide [2], [3]. In this study, we characterize a smart community as follows [4]:

- Efficient supply and consumption of all necessities and energy supporting human life and livelihood, including food, water, electricity, and gas
- Efficient processing of garbage and unclean water

-Efficient and low-carbon transportation of people and materials

-Maximum use of clean energy

-Simple and energy-saving lifestyle with a lesser load on the environment

-Safe and secure life

-Comfortable relationships among residents

-High QOL for the elderly

-Self-sufficiency of food and energy

-Disaster tolerance and resilience

Automobile exhaust has been a major cause of air pollution worldwide, particularly in large cities. The EV is being considered as an attractive alternative to cope with this problem. The major automobile manufacturers have been developing EVs that are competitive with conventional gasoline-powered automobiles in terms of cost and continuous driving distance, thereby aiming to eventually replace gas-powered vehicles. Though these goals have not yet been fully achieved, the EV market has recently witnessed significant growth.

The essential advantages of EVs over gasoline-powered vehicles are considered ideal to realize the concept of the smart community introduced above. One of the serious problems in many communities in an aging society is the inconvenience caused by changes in public transportation, such as a withdrawing or reduction in the frequency of non-profitable bus lines. In this context, the availability of a personal vehicle without CO_2 emissions is indispensable in a smart community. A personal EV may be conveniently used to support personal daily mobility for activities such as shopping and visiting nearby locations, particularly for the aged who may have difficulty walking. Thus, personal EVs can improve the QOL for the aged and contribute to the realization of a lively and vivid community. Unlike gasoline-powered vehicles, an EV has no mechanical engine and requires less maintenance, which is convenient for the aged. It has been reported that elderly drivers typically have one or two passengers, and their driving

distance is generally less than average. In this sense, a small-sized EV with one or two seats, called a "Mini-EV" in this paper, is a promising vehicle for older drivers. Having to refuel at a gas station is unavoidable for gasoline-powered vehicles, and can be a significant burden for aged drivers. In contrast, a Mini-EV may be powered solely from a solar battery, thereby removing the cost and time required for charging, which may significantly mitigate the need for vehicle maintenance. Thus, Mini-EVs may potentially create a new EV market in an aging society. In summary, the three sacred treasures supporting a smart community are illustrated in Fig. 1.

3 USE OF AN EV FOR CHARGING BASE STATIONS OF COMMUNICATION NETWORKS

3.1 Power supply alternatives and the potential of EVs

The Great East Japan Earthquake on March 11, 2011 reinforced the fact that the power supply for communication networks is extremely fragile. It was reported that around a thousand telco-buildings lost power and three-hundred or so were put out of service owing to a fuel shortage for power generation. Twelve-thousand base stations of cellular networks also lost power and were eventually put out of service, although most of them continued to work for a few hours on battery power after the initial power failure.

Let us consider a power supply to the base stations for sensor and communication networks. Several available power-supply alternatives are listed in Table 1. A Type A power supply cannot cope with a power failure. Type B uses a base station with its battery charged overnight at a lower price, and can cope with a power failure within the limit of its battery capacity. Type B is popularly used for cellular phone base stations, but its continuous operation under a power failure is typically only for a few hours; extending the base station battery power supply to 24 hours
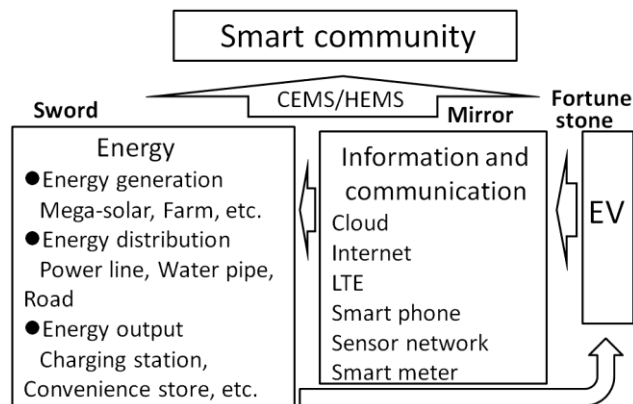

Figure 1: Three sacred treasures supporting a smart community.

Table 1: Power supply for base stations

	Power supply alternatives	Cost	Space	Blackout resistance
A	Commercial power	Satisfactory	Satisfactory	Poor
B	Commercial Power + Battery	Acceptable	Acceptable	Only short time
C	Solar panel + Battery	Limited	Limited	Satisfactory
D	Commercial power + Solar panel + Battery	Limited	Limited	Satisfactory
E	Commercial power + Battery + EV charging	Acceptable	Acceptable	Satisfactory
F	Battery + EV charging	Acceptable	Acceptable	Satisfactory

has been an option under investigation since the March 11th quake. Type C does not suffer from power failures [5], but its solar panels require relatively open and wide spaces, which may not be feasible under economic and space constraints. Type D provides advantages of both Types B and C [6]. Types E and F are novel approaches using EV charging [4]. An EV has a large-capacity battery, and can be conveniently used to supply electrical energy. Type E is similar to Type B except for the addition of EV charging. EV charging is performed before a base station battery runs down after a power failure. The base station battery in Type F depends on periodical EV charging instead of the solar panels used in Type C. In Type E, EV charging is performed only during a power outage, while charging is regularly performed in Type F. A Type F power supply does not depend on a commercial power distribution infrastructure, and this option is promising when an energy generation infrastructure such as a mega-solar plant is available near a smart community.

3.2 Evaluation of EV performance for charging base stations

Let us focus on a Type F power supply and consider how many base stations can be operated without a battery shortage when charged by a single EV. We introduce the following variables.

Battery capacity of an EV: E_v (Wh)
Battery capacity of a base station: E_b (Wh)
Number of base stations that can be charged for continuous operation without a battery shortage by a single EV: N
Power consumption of a base station: P (W)
Amount of energy consumed when driving for 1 km: E_r (Wh/km)
Round-trip distance between the location of the energy source used for charging an EV battery and a base station: d_1 (km)
Average distance between base stations: d_2 (km)
Average driving speed: S (km/h)
Charging time per base station, assumed to be proportional to the battery capacity: C (h)　= kE_b
Average hours of EV operation per day: T_v (h)
Number of base stations charged per day: n

The number of days when a base station that is fully charged can continue to operate without charging, D, can be represented by the following equation.

$$D = E_b / P / 24 \qquad (1)$$

T_v is given by Eq. (2) and upper-bounded by the maximum allowable EV operation hours (8 h as an example).

$$T_v = (d_1 + nd_2)/S + nC < 8 \qquad (2)$$

By solving Eq. (2), n is upper-bounded in Eq. (3), which represents the time constraint.

$$n < n_1 = (8S - d_1)/(d_1 + CS) \qquad (3)$$

On the other hand, assuming that an EV can be charged once a day at night, the total energy consumption of an EV including both driving and charging each day is upper-bounded by the EV battery capacity, as shown in Eq. (4).

$$(d_1 + nd_2)E_r + nE_b < E_v \qquad (4)$$

By solving Eq. (4), n is upper-bounded in Eq. (5), which represents the energy constraint.

$$n < n_2 = (E_v - d_1E_r)/(d_2E_r + E_b) \qquad (5)$$

Taking the minimum of n_1 and n_2, n is given by Eq. (6).

$$n = Min(n_1, n_2) \qquad (6)$$

Since each base station needs to be charged every D days, N is given by Eq. (7).

$$N = nD = nE_b / 24P \qquad (7)$$

Figure 2 shows a numerical example of N for increasing E_b with parameters (E_v, k), where d_1, d_2, S, E_r, and P are 10 km, 1 km, 20 km/h, 100 Wh/km, and 50 W, respectively. With increasing E_b, N also increases owing to a charging efficiency. In (20, 0.4) and (40, 0.2), the time constraint is the dominant factor in determining the performance over the entire range of E_b. The cases (40, 0.2) and (20, 0.2) give exactly the same results when the battery capacity of the base station is lower than 3 kWh owing to the time constraint. When E_b is greater, an energy constraint becomes the dominant factor in determining the performance and (40, 0.2) gives a higher performance than (20, 0.2). This numerical example implies that the time and
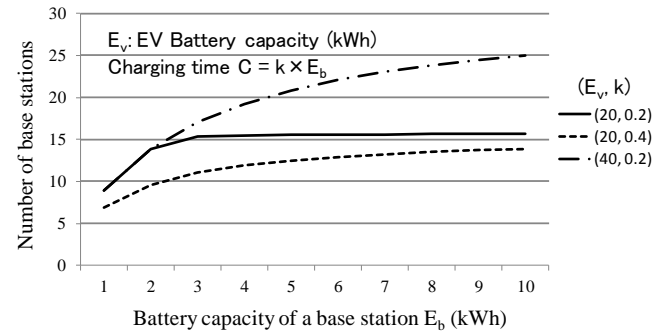

Figure 2: Number of base stations that can be charged for continuous operation by a single EV: N.

energy constraints need to be carefully designed by taking into account technological advancements in the battery energy density of the EVs and base stations, as well as the charging speed.

When an EV is used for charging base stations, it is essential to know the remaining battery power at each base station to ensure efficient travelling, scheduling of the EV, and timely charging of the base stations to avoid a run-down of the battery. The sensor and communication network itself can be used to collect such information.

4 EV-BASED MOBILE AD-HOC NETWORK (EVANET)

In the research and development of a mobile ad-hoc network (MANET), a vehicular ad-hoc network (VANET) has been particularly studied within the framework of an Intelligent Transport System (ITS) [7]. In a VANET, a vehicle is equipped with a communication device, and the vehicle itself acts as a communication node, forming a mobile ad-hoc network with other vehicles. The presence of gasoline-powered vehicles has been implicitly assumed in VANET research, and the applications of a VANET while driving are of major interest. As mentioned in Section 2, the Mini-EV may be prevalent in almost every household in a smart community. Under such circumstances, the Mini-EV can be a principal node in the formation of a VANET. An EV-based VANET is called an EVANET [4]. It is noteworthy that an EV can work as a communication node regardless of driving or parking by using its abundant battery, while a gasoline-powered vehicle cannot operate as a node while parking when its engine is switched off. Therefore, EVANET applications may not be limited to only driving situations.

Broadly speaking, an EVANET can be used to improve the QOL in a smart community. As an example, a number of Mini-EVs may park in an individual household parking spot overnight and form an EVANET in a smart community; in such a scenario, the EVANET can act as a sensor network to detect and prevent crimes such as burglaries. In addition, it is not always easy to find one's car in a large parking lot at a shopping center, airport, etc, and an EVANET can be used to locate a car in such a case.

Further, an EVANET can be a crucial component during disaster recovery. When telecommunication services are degraded or disrupted from damage to network facilities and/or traffic congestion, an EVANET can function as a secondary telecommunication infrastructure in a smart community. Additionally, no time is wasted when forming an EVANET. Public Mini-EVs owned by community government offices, together with those volunteered by individuals, can be distributed to form an EVANET. The surplus battery power available can be remotely monitored using the EVANET itself, and Mini-EVs that have

exhausted their batteries can be easily replaced with other Mini-EVs.

5 DRIVING ASSISTANCE SYSTEM

5.1 System outline

It is essential to support safe and convenient driving, particularly for aged drivers in an EV-based smart community. Let us consider an example of a driving assistance system, in which EVs, Mini-EVs, and other moving objects such as pedestrians and bicycles periodically send their location information, measured using a GPS, to nearby base stations through a wireless channel. A base station at a cross-road collects the location information of nearby moving objects, estimates possible collisions, and provides alarm signals if necessary. In this system, efficient medium access control for location information transmission to the base station and congestion control are essential. The next section focuses on the former issue.

5.2 Efficient access method

5.2.1. Mechanism

To realize efficient wireless medium access control to a base station for a considerable number of moving objects, we present the concept of Random Slot Selection with Reservation (RSSR). In this system, a base station periodically broadcasts beacon signals. The beacon interval is divided into beacon, reservation, and free-access intervals. The duration of the reservation interval is not fixed, but increases as the number of moving objects with a reservation increases. The reservation and free-access intervals are further divided into timeslots. The duration of the timeslot during a reservation interval may be shorter than that during a free-access interval, as will be explained later. The configuration (such as the duration of the timeslots in the reserved and free-access intervals, and the number of timeslots in the reserved and free-access intervals) of the subsequent beacon interval is included in each beacon signal and sent to the moving objects. Each moving object periodically transmits its location information to a base station. It initially selects a timeslot randomly during the free-access interval and starts the CSMA/CA-based transmission process, that is, carrier sense, backoff, and data transmission. When the data transmission is successful, the base station reserves a timeslot during the reservation interval and includes the reserved timeslot number in its acknowledgment. During the subsequent beacon interval, the moving object starts the

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data transmission in the reserved timeslot, where it immediately initiates a data transmission without a preceding carrier sense or backoff. Since no other moving objects compete for data transmission in this reserved timeslot, the carrier sense and backoff can be skipped, thereby improving the transmission efficiency. The base station conducts a timeslot assignment on a FIFO basis for moving objects that succeed in a data transmission during the current beacon interval. The earlier the assignment is, the smaller the timeslot number during the reservation interval. The number of timeslots during the reservation interval of the subsequent beacon interval corresponds to the number of moving objects with a reserved timeslot. Ideally, each data transmission regardless of whether during a reservation or free-access interval will be completed during the current timeslot in which the CSMA/CA-based transmission process started. However, this is not a requirement. When the CSMA/CA-based transmission process takes a long time owing to a lengthy medium access wait time and/or a collision, the transmission process may extend to the succeeding timeslot. Such overlapping can be allowed and resolved based on the basic CSMA/CA mechanism, which is different from TDMA-based mechanisms.

5.2.2. Performance evaluation

The performance of the proposed Random Slot Selection with Reservation (RSSR) and Pure Random Slot Selection (PRSS) are preliminary evaluated through a simulation. In the latter, the beacon interval is composed of beacon and free-access intervals. During a free-access interval, each moving object selects a timeslot at random and starts the CSMA/CA based-transmission process. We have made several assumptions to simplify the simulation. Objects are stationary and distributed within the transmission range of the base station, and new data to send to the base station are gained during every beacon interval. The process for receiving beacon signals from a base station and time required to receive a beacon signal are not considered in the simulation program. All objects are assumed to successfully receive a beacon signal from the base station at the start of each beacon interval. This assumption can be rationalized by taking the following two points into consideration. The dedicated time slot can be reserved and used for the base station to send beacon signals. A base station can use a higher transmitting power than mobile hosts for transmitting beacon signals including control messages. Finally, a propagation delay is neglected. The simulation conditions are summarized in Table 2.

The performance is compared in terms of the average transmission time, which is the total time consumed by the CSMA/CA transmission process including the time required for the inter-frame space, carrier sense, backoff, packet transmissions and retransmissions, and ACK waiting

Table 2: Simulation parameters

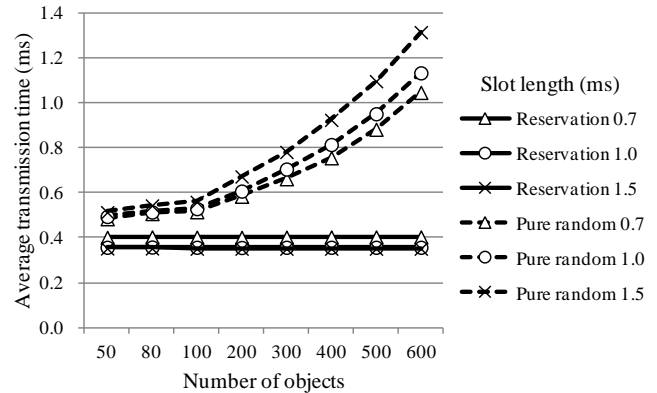| Parameters	Values
Beacon interval	1 s
Simulation time	100 s
Header size	56 bit
Data size	160 bit
ACK size	48 bit
Transmission speed	1 Mbps
Bit error rate	10^{-3}
Contention window slot length	0.0015 ms
Initial contention window slot number	32
Maximum retransmission number	3

Figure 3: Performance comparison of medium access control techniques.

regardless of a successful or failed transmission divided by the total number of originated packets (the number of objects multiplied by the number of beacon intervals during simulation). The results are shown in Fig. 3. In PRSS, the average transmission time rapidly increases as the number of objects increases, thus increasing competition for medium access. On the other hand, such increase is completely suppressed in RSSR as such competition is reduced by means of slot reservation for initiating medium access process.

It is noteworthy that the performance for slot length 0.7 ms is worse than that of slot length 1.0 ms in RSSR, while shorter slot length consistently improves the performance in PRSS. Packet transmission sometimes takes longer than 0.7 ms owing to retransmission and is not completed within the reserved slot in RSSR, which makes the performance of slot length 0.7 ms worse than that of slot length 1.0 ms. This observation suggests that slot length needs to be carefully selected to achieve a higher performance in RSSR.

6   CONCLUSION

In this paper, we presented the concept of a smart community for an aging, sustainable, and low-carbon producing society, and discussed the essential roles of electric vehicles (EVs) in such a community. In particular,

we emphasized that a small EV with one or two seats is convenient for elderly users to move around their community. We focused on two roles of EVs for their possible contributions to a smart community. First, EVs can be used for charging the batteries of base stations of sensor and communication networks when a lengthy and large-scale blackout occurs. Second, EVs can be used to form a mobile ad-hoc network, called an EVANET. It should be emphasized that an EVANET can be used anytime, including while driving or parking, whereas a conventional vehicular ad-hoc network (VANET) can only operate while driving. This feature of an EVANET brings about its possible use for community safety and rapid emergency network deployment under large-scale disasters. Finally we presented the concept of a driving assistance system, which is indispensable for elderly drivers. Additionally, as way to overcome the technical challenges of such a system, we presented an efficient wireless medium access control technique called Random Slot Selection with Reservation (RSSR).

We only highlighted some of the essential roles of EVs in a smart community, and extensive research on the technical and application aspects is further required. The interaction and integration between an information and communication infrastructure and EVs, which are essential tools for conveying information, and for transporting people and materials, respectively, will create new opportunities and challenges in realizing the social infrastructure of a smart community. Research and development based on collaboration between the relating technical disciplines are needed to achieve such goals.

ACKNOWLEDGMENT

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