Vehicle-to-Vehicle Charging Coordination over Information Centric Networking

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Abstract—**Cities around the world are increasingly promoting electric vehicles (EV) to reduce and ultimately eliminate greenhouse gas emissions. A huge number of EVs will put unprecedented stress on the power grid. To efficiently serve the increased charging load, these EVs need to be charged in a coordinated fashion. One promising coordination strategy is vehicle-to-vehicle (V2V) charging coordination, enabling EVs to sell their surplus energy in an ad-hoc, peer to peer manner. This paper introduces an Information Centric Networking (ICN)-based protocol to support ad-hoc V2V charging coordination (V2V-CC). Our evaluations demonstrate that V2V-CC can provide added flexibility, fault tolerance, and reduced communication latency than a conventional centralized cloud based approach. We show that V2V-CC can achieve a 93% reduction in protocol completion time compared to a conventional approach. We also show that V2V-CC also works well under extreme packet loss, making it ideal for V2V charging coordination.**

I. INTRODUCTION

With electric vehicle (EV) adoption on the rise along with estimates of their increasing integration into smart cities, charging demands of these vehicles will also increase. This new increasing electric load can be supported only by the largest and most modern power grids.

Previous studies have shown that even a 10% increase in EV load concentration can significantly stress the power grid and result in blackouts [1]. To compound this issue, EV charging tends to occur in bursts, where many EV owners all start and complete their charging around the same time, placing an extreme load on the grid.

An appealing solution to this problem is to coordinate the charging requests of EVs either temporally for parked EVs or both spatially and temporally for mobile EVs [1] in order not to stress the power grid. To better serve the expected charging load, we need not only stationary charging stations but also vehicle-to-vehicle (V2V) charging mechanisms that allow one EV to sell its surplus energy to other EVs. Adhoc V2V charging not only reduces the load on the grid infrastructure but also allows the users to avoid bottlenecks imposed by the power grid technical limits during high demand intervals.

To support efficient V2V charging coordination, rapid message exchanges among EVs are required. This message exchange protocol should offer high flexibility, scalability, and low communication latency while serving *mobile* EVs. Unfortunately, the conventional IP-based centralized protocols cannot offer such desirable features when mobility is introduced. Hence, in this paper, we introduce V2V-CC, a communication protocol for V2V charging coordination based on Information Centric Networking (ICN). We show that V2V charging coordination over ICN happens much faster compared to a centralized approach. In addition, the consumer enjoys more control over the seller selection process.

II. BACKGROUND

Electric Vehicle Charging Coordination: Three modes can be distinguished for EV charging coordination, namely, grid-to-vehicle (G2V), vehicle-to-grid (V2G) [2], and V2V [3]. For this work, we only focus on the V2V charging coordination where EVs exchange energy in an adhoc manner among sellers and buyers via bidirectional chargers without the need to go through the power grid [4]. When EVs are stationary at smart parking lots, only temporal coordination of charging requests is needed. In the context of this work, we need to coordinate the charging requests of *mobile* EVs both on spatial and temporal dimensions so that we can reach consensus between buyers and seller on where and when to exchange energy. To do so, we need to gather information from the vehicles including the amount of charging request from demanding EVs, the amount of surplus energy from supplying EVs, and state-of-charge (SoC) of the EVs.Some work have even looked at P2P charging coordination before [5] [6], none have explored ICN in this context.

Named Data Networking: Named Data Networking (NDN) is a clean-slate redesign of the Internet and its networking protocols as an implementation of ICN. For the rest of the paper, we refer to ICN and NDN interchangeably. In NDN, a consumer can construct Interest packets with a given name in order to request a Data packets with the same name that is hosted by a producer. Several previous work have looked into NDN for vehicular communication - both for in-vehicle [7] [8] [9] and intra-vehicle communications [10].

III. PROTOCOL DESIGN

V2V-CC allows EVs to communicate with each other in an adhoc manner. Based on an NDN protocol, there is no need for addressing individual EVs. The EV willing to provide charge (the seller) can simply announce a name prefix such as "$/\mathrm{FastCharging}$" indicating it is willingness to sell energy. A prefix can potentially be reserved specifically for charging coordination. Once a namespace is agreed upon (this is outside the scope of our paper), the producer and the consumer can start exchanging messages.

We logically break down the protocol into five phases - seller discovery, verification, negotiation, coordination, and confirmation phases. However, multiple phases can be combined for optimization. For example, discovery, verification, and (potentially) negotiation can all be done with one Interest/Data exchange. Similarly, coordination and confirmation phases can be combined together. In this paper, we keep these phases separate for showcasing the different phases of the proposed protocol. When phases are combined, the performance of the proposed protocol will further improve.

A. Seller Discovery Phase

In order to begin V2V charging, a consumer needs to know which suppliers exist in the nearby area. To find such available suppliers, the consumer sends an initial discovery interest, which in its most basic form is constructed as: "/FastCharging/Discovery/Timestamp". Any supplying EVs that want to sell energy can respond with a similarly constructed data packet: "/FastCharging/Producer's Identifier (PID)/Discovery". Using NDN's stateful forwarding plane and native multicast, many suppliers can be reached at once. While only one data packet is needed to satisfy the interest, any other packets that are sent in reply can be cached in nearby NDN nodes, reducing the amount of hops it takes for subsequent requests to get a reply.

A consumer is also able to insert a number of filters to their interest to find suppliers that meet certain requirements. A consumer may choose to limit their discovery search to a specific geographical area, or any number of other attributes in a single interest. For example, if a consumer wanted to discover supplying EVs that are within a 2km radius, with an available time slot between 14:00 and 15:00 hours, with a cost per kWh no more than $0.10, and no less than 25 kWh of charge available, as well as a reputation of no less than 7, the interest would be constructed as such: "/FastCharging/Discovery/Current Location+2km2/0.10 /25/7/1400/1500/Timestamp". Once a single supplier is discovered, it is up to the consumer to decide whether to move on to the verification step of the protocol or if the consumer wants to discover more suppliers. Currently, the protocol defaults to searching for three suppliers before moving onto the verification phase, however, this number can be changed by the consumer at any time. By the end of the discovery phase, a consumer will have a selection of suppliers with whom to continue on to the verification phase.

B. Verification Phase

After the discovery of suppliers, the verification phase begins. This phase is designed to ensure that any information that arrives to a consumer is correct. By default, the consumer chooses the "best" supplier with whom to communicate based on the information that was received during the discovery phase. Currently, the best supplier is determined by the lowest cost, breaking ties using the shortest distance and, if needed, reputation. These weights may be adjusted at any time by the consumer to match what is needed at the time of the coordination. For example, if a consumer needs charge urgently, they may choose to prioritize closest distance above all or if a consumer has a tight schedule, any supplier with an open time slot that best fits the consumers needs can be selected. Any information that was not given during the discovery phase can be requested during the verification phase as well.

Verification interests are constructed as such by default: "/FastCharging/PID/Verification/Timestamp". This naming construct allows for only the supplier with the PID in the name to respond to the request, essentially enabling point-to-point communication. The supplier will respond with the corresponding data packet: "/FastCharging/Verification/PID". In this phase, the consumer will want to verify supplier's signature (enabled by default in NDN), verify additional data, and get new data that the consumer does not have.

By the end of the verification phase, the consumer will have accurate and fresh data on one or more suppliers with whom the consumer can communicate during the next phase. This phase can also uncover some malicious suppliers that provide incorrect data during the discovery phase. The information requested or double checked during this phase can be as minimal or detailed as the consumer desires.

C. Negotiation Phase

After all the data from the supplier is confirmed, the negotiation phase begins. This phase is the most variable of all phases due to its monetary nature. This phase can be as short as one interest and one data response or as many rounds of communication as it takes to come to some form of agreement. A negotiation interest looks like: "/FastCharging/PID /Negotiation/Suggested Price/Suggested Charge Amount /Timestamp". Since the consumer has the base price and the amount of charge that the supplier is offering as a baseline from either the discovery phase, negotiation phase, or both, the consumer can ask for a lower price.

A supplier's response at its core is sent as such: "/FastCharging/PID/Negotiation/CounterPrice /CounterChargeAmount/Timestamp". If the counter price and charge amount are the same as the consumers offer, the negotiation phase comes to an end. If it is not however, the consumer may respond with another constructed counter offer and the cycle continues. One way this can be limited is the addition of the "hard offer" flag, which then concludes the negotiation.

By the end of the verification phase, the consumer and suppliers will have a charge amount and a cost per kWh for that charge that has been agreed upon by both parties. Once the negotiation phase is complete and a charge amount is agreed upon, a supplier may choose to reserve that charge for a certain period of time while the next two phases complete.

D. Coordination Phase

After a suitable price has been negotiated between a consumer and producer, the coordination phase can begin. This phase has one main objective, to find place, or both time and place for the supplier to transfer energy to the consumer.

For V2V charging, both spatial and temporal coordination need to happen. The base form of the Interest in our protocol is : "$/\mathrm{FastCharging}/\mathrm{PID}/\mathrm{Coordination}/\mathrm{Spatial}/\mathrm{Temporal}$ $/\mathrm{Time\ Frame}/\mathrm{Location}$" with time frame being the start of when the consumer is available and by when they wish to be done and the location being either empty or contain the suggested location for the energy to be exchanged. If the location is empty, it is up to the supplier to choose a location, which it will do selfishly. Since the supplier is mobile, it may choose a location that is close to other charging sessions that are just before or just after, a charging location it is familiar with like a parking lot, or simply its current location. If the location component is populated, the consumer is offering to meet at the listed location. The supplier can choose to meet there or counteroffer with a different location. In some cases, it may be advantageous for a supplier to travel to the consumer's location, especially if the consumer is offering to pay extra for the charge. If the supplier is mobile, it must take into account the travel time between two locations when responding to a consumer's temporal interest. Most of these calculations can be offloaded to an on board GPS, but we leave this for a future work. After coordination is completed, both the consumer and supplier have decided on a time and place to exchange energy, and the final protocol phase in V2V-CC can be started.

E. Confirmation Phase

The purpose of the confirmation phase is to double check all of the information that was sent throughout the entire protocol and create a single point for logging the transaction if memory is limited. Since all of the data needs to be checked and not all charging coordination communication will be the same, the information in this phase will differ from confirmation to confirmation. The generic form for the name is "$/\mathrm{FastCharging}$ $/\mathrm{PID}/\mathrm{Coordination}/\mathrm{Negotiation}/\mathrm{Timestamp}$" where coordination includes the the time and location as obtained from the coordination phase and negotiation consists of the amount of charge and the cost per kWH, from the phase with the same name. Any other information that is agreed upon during these two phases would also be included in their respective locations.

IV. EVALUATION

A. Simulation Setup

To evaluate the feasibility of V2V-CC, we utilized ndnSIM, a custom fork of NS-3 network simulator. We designed and implemented custom suppliers and consumers. The suppliers are EVs that are selling energy and the consumers are EVs requesting charge. In the current setup, V2V-CC uses ad hoc Wi-Fi as the wireless medium for communication in the simulation since 5G or LTE models are not available with the current version of ndnSIM. We paid close attention to the parameters to create a realistic scenario according to 4G-LTE deployment requirements.

TABLE I: Simulation Parameters

Number of Suppliers	$1 - 10$
Number of Consumers	$1 - 21$
Supplier to Consumer Ratio	1 Supplier to 3 Consumers
Wi-Fi Bandwidth (links never fill)	24 Mbps
Number of Suppliers Discovered	1, 3
Timeout Wait Duration (ms)	30, 50
Artificial Loss	0%, 20%
Mobility Speed (mph)	$0, 10, 30, 50, 70$
IP Bandwidth (links never fill)	24 Mbps
IP Connection Delay (ms)	$25, 50, 100$
IP Error Rate (minimal effect on results)	0.05%
IP Number of Charge Suppliers	$1 - 3$
IP Number of Clients	$1 - 30$

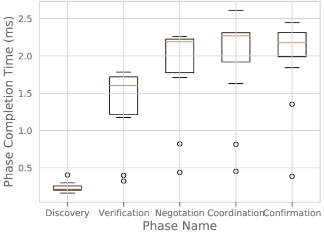


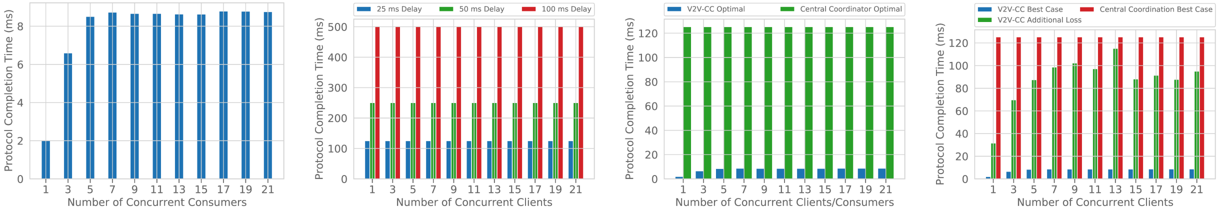
Fig. 1: Average phase completion time in optimal V2V-CC environment with increasing concurrent consumers as variable.

B. Results

In this section, we first establish a baseline of the V2V-CC performance. We then investigate the behavior of the proposed protocol as the number of consumers increases. Once the baseline is established, we compare the proposed protocol with a centralized (IP-based) approach where the EVs communicate with a central controller to find potential seller(s).

Figure 1 shows the completion time of each protocol phase. Note that we could combine some of the phases but kept them separate for simplicity. In this experiment, we do not use any artificial losses, we consider minimal mobility speed, and we adopt an optimal consumer to supplier ratio of one supplier for every three consumers. The consumer also discovers a single supplier. As Figure. 1 shows, each phase is complete within less than 2 ms on average. With a low number of concurrent consumers, the completion times are reduced to below 0.5 ms. Since NDN allows packet reuse through in-network caching, V2V-CC is able to reuse data packets both in the discovery and verification phases. The negotiation, coordination, and confirmation phases take longer times since they need to happen directly between the consumer and the seller. Even then, the average time for each of these phases is less than 2 ms. We then tested V2V-CC with an increasing number of concurrent consumers. Figure 2a shows that as the number of consumers increases, the protocol completion time increases.

Once we establish the baselines, we compare our protocol with an IP based central coordination approach. Figure 2b shows the base cases for a central coordinator. We run tests using three types of delays in reaching the central coordinator, namely, 25, 50, and 100 ms, respectively. These values



(a) (b) (c) (d)

Fig. 2: (a)V2V-CC completion time in optimal environment with increasing number of concurrent consumers (b) Three tests of IP-based central coordination. Each test is run with differing latency between the client and central coordinator (c) V2V-CC completion time in optimal environment compared with central coordination base case (d) V2V-CC completion time in optimal environment and V2V-CC in an environment with 20% additional loss

represent typical delays to cloud computing platforms that we observed in our previous work [11]. Each client begins by connecting to the central coordinator hosted in the cloud server taking one and a half round trip time (TCP handshake) and use a single packet to request the data that the server holds taking an additional RTT. Note that this time does not include any processing time at the central coordinator, which is likely to be an additional several hundred milliseconds. In the best case (with 25 ms one way delay), this approach takes over 125 ms and in the worst case (with 100 ms delay), it takes around 500 ms. We observe that even in the best case for the central coordination server, the additional latency of going to the cloud requires at least 125 ms, while V2V-CC requires 8.79 ms for 21 concurrent consumers, a 93% reduction in time to complete charging coordination as Figure 2c shows. The reduction in latency is due to the peer-to-peer nature of V2V-CC.

Even in the case of very high loss, V2V-CC remains scalable as shown in Figure 2d. Each set of loss tests were run with an added 20% of artificial losses. Figure 2d shows that even with an extremely high packet loss rate, V2V-CC preforms similarly to a central coordinator that is working under ideal conditions (minimal delay and no losses). This is due to the fact that NDN uses in-network caching, which helps with fast retransmissions after packet loss. Additionally, serving content from cache reduces network congestion and also aggregates (using multicast and Interest aggregation) duplicate requests. Figure 2d shows that even with 20% loss, V2V-CC works as well as the central controller's best case (25ms latency and no loss). It is well documented that any loss in TCP/IP will severely increase the total delay. In those scenarios, V2V-CC will further outperform the central coordinator approach. However, we omit those results for brevity.

V. CONCLUSION

In this paper, we propose V2V-CC, a peer-to-peer charging coordination protocol over ICN. The V2V-CC uses named services to facilitate communications between the EVs that might be interested in selling and buying Using simulation studies, we show that V2V-CC is extremely fast and the whole protocol takes less than 10 ms. We also compared V2V-CC with a centralized approach and we found that V2V-CC is orders of magnitude faster than an approach based on a central controller even in a lossy environment, paving the path for a faster, simpler, more flexible, and open charging marketplace.

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