Committee Standards Battles in the Era of Convergence: Implications for Smart Systems

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Declarations of interest: none.

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Abstract

By now, there have been many standards battles fought within the same industry or by multiple industries in the market-based standardization. In these battles, incompatible standards compete to win market dominance. While there is some research on standards battles found within a single committee, competitions in the committee-based standardization between standards from different committees or SDOs are underexplored. This paper categorizes the types of standards battles by the mode of standardization and the heterogeneity of actors. A new type referred to as 'committee standards battles for converging systems' is introduced and the dynamics of such battles is explored with two cases. The battle between the electric vehicle charging and the smart meter communication standard and the battle between two different vehicle-to-everything (V2X) communication standards are analyzed. The failure in achieving compatibility between different committee standards on the same frequency bands results in communication interference that adversely affects the operation of smart systems. Social incompatibilities between actors and alliances from a mix of industries with vested interests towards a particular standard complicate the battling scene. The findings provide implications in terms of heterogeneity, actors, and government role in standards battles.

Keywords: standards, standards battles, smart systems, smart grid, electric vehicles, connected vehicles, V2X

Highlights

- Standards battles between standards from different committees or SDOs are underexplored.
- A new type of standards battles emerges in converging sectors where different committee standards compete with each other.
- Two cases are investigated to show the dynamics of these battles.
- The paper has implications for managing smart systems and implementing standards strategies for converging industries.

1. Introduction

Standards are classified into de facto standards and committee standards. The former is made by market forces. The latter is set through a formal coordination mechanism, for instance, in formal standards developing organizations (SDOs). Standardization supports the development of smart technologies and the innovation of complex systems. Independent systems that have existed in silos are now being integrated to create a "system of systems". The integration of systems that originate from different domains is enabled by convergence that frequently occurs between the IT industry and other industries. The concept of smart cities is an example that integrates smart architecture and utilizes information and communication technology (ICT) to improve city operation (Ismagilova, Hughes, Dwivedi, & Raman, 2019). In the transport domain, ICT provides the backbone for innovative services such as autonomous mobility and intelligent transport (Manfreda, Ljubi, & Groznik, 2021).

During the standardization process, competitions inevitably occur to secure national or corporate interests. Battles in market-based standardization occur between incompatible technologies in a quest for the establishment of a de facto standard that secures market dominance (Shapiro & Varian, 1999). Achieving technical and social compatibilities is important in addressing competitions between standards. Compatibility or incompatibility between alternative technological trajectories changes the rules of the game and thereby recontextualizes appropriate strategic choices in standards battles (Shapiro & Varian, 1999). Technical compatibility is achieved by gateway technologies that are a means for effectuating technical connections between subsystems in a large technical system (David & Bunn, 1988). It enables subsystems to be operated as integrated systems of production. Social compatibility refers to the political, regulatory, operational, institutional, and interpersonal features of subsystems (Egyedi & Spirco, 2011). If the technical and social incompatibilities cannot be bridged, a solution that enables flexibilities in large technical systems loses its potential and system entrenchment becomes more likely (Egyedi & Spirco, 2011).

The extant literature is focused on battles between standards for the same products or applications often set forth by actors in the same industry (Cusumano, Mylonadis, & Rosenbloom, 1992; David, 1992; Gallagher & Park, 2002; Puffert, 2000; von Burg, 2001). The literature also explores battles between standards developed and supported by actors in different industries (den Uijl & de Vries, 2013; van de Kaa & de Vries, 2015; van de Kaa et al., 2019). Battles that consist of standards and technologies that originate from multiple converging industries are named as ‘battles for converging systems’ in previous research (van de Kaa, de Vries, & van den Ende, 2015). In these cases, standards are implemented in products or systems that come from different industries but are interconnected into a larger system and a battle is fought in the market for one dominant standard to be used for such converging systems (van de Kaa et al., 2015).

There are many examples of standards battles found in the market-based mode of standardization whether they involve single or multiple industries. Yet the issue of standards battles between different committees is still underexplored. While literature based on de facto standards can be useful to help understand committee standards, theoretical findings from the market-based standardization are often too easily generalized to committee-based standardization (Egyedi, 2010). Since the process of setting standards, the implementation of them, and the consequences of the battles differ among the modes, the dynamics of standards battles for converging systems in the committee-based mode deserves its own attention.

In order to fill this gap regarding committee-based standards battles for converging systems, this article analyzes two cases of committee standards battles. These are battles between different committee standards that originate from heterogeneous industries as solutions for different problems. We analyze the battle between the electric vehicle charging standard and the smart grid communication standard, then analyze the battle between vehicular communication standards that enable the operation of systems for smart transportation.

The purpose of the study is to examine the ensuing dynamics of standards battles that are new in the era of convergence particularly in the context of the committee-based mode of standardization and compare how they differ from the predominant types of battles in the past. In so doing, this paper aims to investigate how the difficulties of bridging technical and social incompatibilities instigate and sustain conflicts between committee standards. We first categorize existing studies on standards battles, then suggest a category of standards battles that is underexplored. Thereby, it will contribute to the literature by highlighting novel and emerging patterns of standards competitions.

This paper has the following structure. Section 2 reviews the literature on standard battles and categorizes them. Section 3 presents the methodology and Section 4 analyzes the two cases. Section 5 discusses contributions, implications, and directions for future research. Section 6 concludes the paper.

2. Literature review and category development

We first review how the coordination of a variety of preferences occurs around three modes of standardization. Then we discuss previous cases of standards battles in different modes. The literature review ends by categorizing standards battles and associating existing cases with each category.

2.1. Modes of standardization

Wiegmann, de Vries, & Blind (2017) grouped existing literature into three modes of standardization, which are committee-based, market-based, and government-based modes. Committee-based standardization takes place in committees of formal SDOs (e.g., International Organization for Standardization (ISO)), consortia (e.g., the Blu-Ray Disc Association, OASIS, the World Wide Web Consortium (W3C)), professional organizations, and trade associations or open source initiatives (Egyedi, 2010; Wiegmann et al., 2017). In market-based standardization, competition between different technologies results in the establishment of a de facto standard that takes over a significant market share. In the government-based standardization, the government develops or imposes a standard so that its use becomes mandatory. A hybrid system that combines various modes is termed as multi-mode standardization, which can be a combination of market and committee, government and committee, government and market, and of all three modes (Wiegmann et al., 2017).

2.2. Standards battles

2.2.1. Market standards battles in a single industry

The earlier studies on standards battles are centered on physical networks and IT. These battles are known as the typical standards battle in which different standards compete for the same systems or applications. Firms or actors often from the same industries develop competing standards. The competition between multiple railway track gauge standards chosen by private companies in North America (Puffert, 2000, 2002; Shapiro & Varian, 1999) and the battle between AC and DC electricity in the 19th century (David, 1992; David & Bunn, 1988) are examples of battles over physical networks. The lock-in into QWERTY as the dominant keyboard arrangement (David, 1985), the rivalry for home videocassette recorders (VCRs) between Sony's Betamax and the Video Home System (VHS) format (Cusumano et al., 1992), and the competitions in the U.S. video game console industry (Gallagher & Park, 2002; Schilling, 2003) are some of the well known examples.

Cases in ICT discuss the importance of creating open standards. The competition between Ethernet and other Local Area Network (LAN) standards later led to the formation of the DIX alliance (DEC, Intel, Xerox) that joined efforts to create an open Ethernet standard (von Burg, 2001). The series of web browser standards battles shows how battles evolve, making the once dominant Internet Explorer to be unseated by Firefox that offered an open program and superior quality (de Vries, de Vries, & Oshri, 2008; Oshri, de Vries, & de Vries, 2010). Standards battles in the generations of mobile telecommunications also point to the adoption of an open standard as a determinant factor to become a dominant global standard (Funk & Methe, 2001).

Factors that drive the selection of a dominant design and thus the "success" in standards battles have been widely assessed in "winner-take-all" markets where technologies incompatible with the dominant design are locked out of the market (Schilling, 2002). Network externalities, path dependency, a large installed base, availability of complementary goods, timing of entry, and a firm's investment in learning play roles in a firm's success in standards battles over a competing technology (Schilling, 2002). The competitor is positioned in the same market with the same product categories.

2.2.2. Market standards battles involving multiple industries

The literature also documents cases of standards battles consisting of established components, products, and subsystems that originate from heterogenous industries and involve players from multiple industries. One of the early examples that illustrate battles for converged systems fought by different industries are battles for stereo systems and microcomputers (Langlois & Robertson, 1992). The battle between Sony's Blu-ray and Toshiba's HD-DVD (den Uijl & de Vries, 2013; Gallagher, 2012; van den Ende et al., 2012) shows the significance of involving supporters from multiple industries (e.g., consumer electronics, film studios, IT, software, retail).

Van de Kaa & de Vries (2015) analyzed three cases of battles fought by diverse industries, which are FireWire vs. Universal Serial Bus (USB), Wi-Fi vs. HomeRF, and MPEG-2 Audio vs. AC-3. In the FireWire versus USB format battle between the consumer electronics and the IT industry, one of the key factors that enabled USB to become the dominant format in the PC market was its high network diversity. There was a network of USB supporters from diverse industries including consumer electronics, IT, and telecommunications. The Wi-Fi versus HomeRF battle and the Dutch e-purse system battle also highlight that the crucial factor determining the dominance of a standard in converged systems is a strong inter-organizational network with many and diverse actors (van de Kaa et al., 2015). It contributes to the availability of complementary goods and thus the increase in installed bases. Forming a coalition of firms, SDOs, and trade associations is a collective action that challenges the dominant standard like Java did against Microsoft's Windows (Narayanan & Chen, 2012). Therefore, the drivers behind winning standards battles are similar to what has been identified in market battles in a single industry. In the battles involving multiple industries, the high availability of complementary goods, high commitment by the actors, and diversity of the network of the format were the factors that contributed to the success of a format (van de Kaa & de Vries, 2015). Like this, the firm-level and environmental factors that determine a winning format or a dominant design have been theorized (den Uijl, 2015; Suarez, 2004; van de Kaa et al., 2011).

In platform and standards competition, user interfaces gain a growing importance as seen in the voice user interfaces in in-vehicle infotainment systems (Kim & Lee, 2016). Platform leaders like Apple and Google can leverage new and easy-to-use user interface standards to expand from the smartphone industry into adjacent industries by extending the functionalities of their mobile platforms into the automobile environment (Kim & Lee, 2016). The interface specified by a format enables technological systems to be interconnected. A diverse network contributes to the success of a format since actors representing each of these systems are included in the network (van de Kaa & de Vries, 2015). Recent studies examine cases such as the battle for smart meter connectivity between power line communication, mobile telephony, and radio frequency (van de Kaa et al., 2019) and the battle between battery technologies used in residential energy systems (van de Kaa, Fens, & Rezaei, 2019) to achieve standard dominance in the area of smart grid.

2.2.3. Committee standards battles

Literature of battles in the committee-based standardization mostly examines battles within a single committee of an SDO. Committees were identified as mechanisms that enable cooperation in the committee-mode itself or through its interplay with other modes (Farrell & Saloner, 1988; Funk & Methe, 2001; Van Wegberg, 2004). Better consensus is reached in committees than the market despite the larger numbers of negotiations required to coordinate (Farrell & Saloner, 1988). The coordination of different proposals of standards in the committees is achieved during the development stage and thus the conflicts are resolved once one standard document is approved as the commonly agreed solution (Jain, 2012; Wiegmann et al., 2017). The literature documents committee-based battles in ISO, the Institute of Electrical and Electronics Engineers (IEEE), and the International Telecommunication Union (ITU).

Competition between the Open Document Format (ODF) and Office Open XML (OOXML), both approved as ISO standards, shows how conflicts occur between standards within the same committee (ISO/IEC Joint Technical Committee 1) in a formal SDO (Blind, 2011; Egyedi & Koppenhol, 2010). Other examples of competitions within ISO technical committees (TCs) include the standardization of pallet sizes in ISO/TC 51 (Eom, Lee, & Ahn, 2016) and of modular containerization in ISO/TC 104 (Egyedi, 2001; Egyedi & Spirco, 2011). In these cases, bargaining worked as a measure to reach mutual agreement in the midst of competing national interests. Before a consensus was reached on the IEEE 802.11 Wi-Fi standard, there were several battles between competing proposals based on incompatible technologies such as Frequency Hopping and Direct Sequence Spread Spectrum (van de Kaa & de Bruijn, 2015). Jain (2012) provides a narrative on the standardization of extensions on Ethernet in IEEE that took place after the market battle on the original Ethernet standard. The example of setting a world production standard for High-definition television (HDTV) illustrates conflicts during standardization in ITU's Radiocommunication Sector (ITU-R) in the presence of strong national interests between the U.S., Europe, and Japan (Farrell & Shapiro, 1992; Grindley, 1995). The proposal and acceptance of the Chinese 3G standard, TD-SCDMA, to the ITU among other options of global standards is another example of national interests involved (Kim, Lee, & Kwak, 2020).

There are only a few cases of battles between different committees or between two or more SDOs in the literature. Egyedi (2001) examined the "competing gateways" developed for the exchange of structured documents and data on the web: Standard Generalized Markup Language (SGML) by ISO and XML by the standards consortium W3C. Wiegmann (2019) showed that standards from converging industries can conflict with each other through the case of micro Combined Heat and Power (mCHP) in the European heating industry. Changes in electricity grid standards affected the development of standards that define the connection of mCHP appliances to the electricity grid, which are formal standards including the European EN and International Electrotechnical Commission (IEC) standards.

2.3. Categorization of standards battles and a new type of battle

Based on the review of literature on standards battles, we classify the types of standards battles by the mode of standardization and the heterogeneity of industries or organizations as shown in Table 1.[1]

Standards-based competitions lie in the context of collective action (Narayanan & Chen, 2012). While organizations collaborate to achieve the common goal of setting a standard, they face collective action dilemmas in standards development and diffusion (Markus, Steinfield, & Wigand, 2006). The heterogeneity of interests is what hinders the success of standards development that meets industry-wide needs for interconnection (Markus et al., 2006). Heterogeneity of interests has been a useful dimension to capture the fragmentation of standardization efforts into rival groups among IT vendors (Greenstein, 1992) and among groups of user organizations (Markus et al., 2006) that go beyond the rivalry found between homogeneous groups competing in the market for product standardization. Despite heterogeneity being a useful instrument to understand the dynamics of competitions, it has been used to examine competitions for one standard and within the boundaries of one organization or industry. The categorization here enables heterogeneous committees, industries, and interests to be incorporated in the analysis of emerging standards battles and allows comparison between market-based and committee-based battles aside from their distinctions in the modes of standardization.

The criterion that divides the two columns in market-based standardization (Sections 2.2.1. and 2.2.2.) is whether the battle involves single or multiple sectors that compete to implement standards for the same product or systems. The left column in committee-based standardization is a competition within a committee that usually involves actors from the same industry (Section 2.2.3.) and the right is a battle between standards developed by different standards committees that are likely to involve actors from heterogeneous industries. Table 2 shows example cases in each type of battle.

Table 1. Types of standards battles

[1] The 'output' (e.g., standard documents) of standardization is the criterion that assigns battle cases into either market-based or committee-based mode. Therefore, if the output is about gaining market dominance, the battle is categorized into market-based mode. If the output is the approval of standards formalized into documents in committees, the battle is categorized into committee-based mode. Since we intend to discuss another dimension, which is the 'heterogeneity' to investigate the implications of industry convergence, a two-by-two table is formed. The process aspects of standards battles are described in our case analysis.

		Heterogeneity of the industries/organizations	
		same/homogeneous	**different/heterogeneous**
Mode of standardization	**market-based**	• de facto standards battle in the same industry • a typical type of battle: compete for the same product, system, or application	• standards battle involving multiple industries • 'standards battles for converging systems'
	committee-based	• standards battle within a single SDO or a single committee in an SDO	• standards battle between different committees or SDOs • a new type of battle

Table 2. Examples of standards battles

		heterogeneity of the industries/organizations	
		same/homogeneous	**different/heterogeneous**
mode of standardization	**market-based**	• competition between railway track gauges: 4'8.5" standard gauge vs. other gauges (Puffert 2000, 2002) • battle between AC and DC electricity (David, 1992; David & Bunn, 1988) • keyboard layout: QWERTY vs. DVORAK (David, 1985) • VHS vs. Betamax in the video cassette recorder industry (Cusumano et al., 1992) • competition in the U.S. video game console industry: Sony Playstation2 vs. Microsoft Xbox vs. Nintendo GameCube (Gallagher & Park, 2002; Schilling, 2003) and PC operating systems (Schilling, 2002) • Ethernet vs. other LAN standards (von Burg, 2001) • web browser: Netscape vs. Microsoft and Microsoft vs. Mozilla (de Vries et al., 2008; Oshri et al., 2010) • battle for global mobile telecommunications standards (Funk & Methe, 2001) • battle between flash memory cards and the coexistence of multiple competing designs (de Vries, de Ruijter, & Argam, 2011)	• FireWire vs. USB for peripheral interconnectivity to the PC (van de Kaa & de Vries, 2015; van den Ende et al., 2012) • MPEG-2 vs. AC-3 for a multi-channel sound format (van de Kaa & de Vries, 2015) • Wi-Fi vs. HomeRF for wireless home networking (van de Kaa et al., 2015; van den Ende et al., 2012) • Chipper vs. Chipknip for a Dutch e-purse system (van de Kaa et al., 2015) • Blu-Ray vs. HD-DVD (den Uijl & de Vries, 2013; Gallagher, 2012; van den Ende et al., 2012) • DVD vs. DIVX (Dranove & Gandal, 2003) • battle for stereo systems (Columbia vs. RCA) and microcomputers (Apple vs. DEC vs. IBM) (Langlois & Robertson, 1992) • color TV: RCA vs. CBS (Farrell & Shapiro, 1992; Shapiro & Varian, 1999) • smart grid: battle between communication technologies for smart meter connectivity and between battery technologies used in residential energy systems (van de Kaa, Fens, & Rezaei, 2019; van de Kaa et al., 2019)
	committee-based	• document format: ODF vs. OOXML in ISO/IEC JTC 1 (Blind, 2011; Egyedi & Koppenhol, 2010) • IEEE 802.11 Wi-Fi in IEEE (van de Kaa & de Bruijn, 2015)	• standard for exchanging structured documents and data on the web: ISO SGML vs. W3C XML (Egyedi, 2001) • conflict between the electricity grid standards and mCHP standards in the

	• Ethernet in IEEE (Jain, 2012) • pallet size standardization in ISO/TC 51 (Eom et al., 2016) • container standardization in ISO/TC 104 (Egyedi, 2001) • HDTV standardization in ITU-R (Farrell & Shapiro, 1992; Grindley, 1995) • facsimile terminals, videotex, and electronic mail standardization within the ITU-T (Schmidt & Werle, 1998) • competition for the adoption of the ITU 3G mobile communication standard (Gao, 2015; Gao, 2014; Kim et al., 2020)	European heating industry (Wiegmann, 2019)

Market battles are discussed between a network of firms in the same industry and in different industries. Committee standards battles are often discussed within a committee, but not much between different standards committees involving heterogeneous industries. In this paper, we identify standards battles between different standards committees as a new type of battle that is under-investigated and deserves further research. It is expected that more standards battles of this new type will take place in the context of convergence in which multiple industries target the implementation of standards to different systems or applications. Committee standards already implemented in each industry during different periods may face conflicts as technologies converge.

3. Research method

The multiple case study method was used to investigate the phenomenon that requires answers to how standards battles occur and work (Yin, 2009). This paper examines two cases of committee standards battles. The two selected cases fit into the category of committee standards battles that involve heterogeneous committees and industries, which are in the fourth quadrant of Tables 1 and 2. Cases in this category are appropriate to understand the commonalities and the differences with market standards battles involving heterogeneous industries and committee battles found in homogeneous settings in terms of actors, path, and outcome of standardization. Committee standards in the cases originate from heterogeneous industries and the conflicts may potentially disrupt the operation of smart systems. One case is on the battle between the electric vehicle charging standard and the smart metering standard found in Korea. The smart metering standard promoted by Korea and made into a formal international standard interfered with another international standard on EV charging. The other case is the battle between Dedicated Short-Range Communications (DSRC) and Cellular Vehicle-to-Everything (C-V2X) over Vehicle-to-Everything (V2X) communication. This battle is a global phenomenon. Many countries including the U.S., Europe, Korea, Japan, and China adopt the same standards or their variants. These cases add a new dimension to the existing literature by exploring the dynamics of the new type of standards battles.

Following Eisenhardt (1989), we wrote up a detailed case study that describes each battle. Combined with within-case analysis, cross-case analysis was conducted. For each case, semi-structured interviews were conducted face-to-face and via online conference platforms. We asked the interviewees to go through the main events throughout the standardization process, manifestation of the conflict, and the current status of the battle. Details about major policies, technical compatibility between the standards, spectrum issues, major stakeholders, and why the battle had happened were communicated as the interview proceeded. Eleven respondents were interviewed. The respondents are experts in the technology area central to the battle cases. They have been participating in the standardization or are well aware of the relevant standards. Profiles of the interviewees are provided in the Appendix. The interviews ranged from 30 minutes to 1 hour 15 minutes. Interview responses were recorded and transcribed.

Triangulation is broadly defined as convergent validation across different methods (Jick, 1979). In our study, data obtained from archival sources and the interviews were employed to triangulate the results from the analysis of the two battles. Secondary data were collected from academic literature, standards in full text, patents, official government documents, documents from governmental organizations and standardization organizations, position papers of key organizations, rules and regulations, reports from public and private organizations, press releases, news articles, and other online sources. An overview of the key secondary sources is provided in the Appendix. Details on the history were retrieved to make chronological descriptions of the cases.

4. Case studies of committee standards battles for converging systems

In this section, we explain the processes and the outcomes of standards battles where standards from different committees run into conflicts in converging systems. To maintain consistency throughout the analysis, we use the concepts of technical and social compatibility (or incompatibility) provided by Egyedi and Spirco (2011). Technical and social compatibilities serve as a source of dynamics in legitimacy battles that manifest themselves in conflicts between alternative technological trajectories.

4.1. Electric vehicle (EV) charging vs. smart meter communication

4.1.1. Overview of technology and standards

EVs derive energy from on-board and off-board chargers that are used to rectify alternating current (AC) to direct current (DC). Electric power is transferred either from the electric vehicle supply equipment (EVSE) to the EV or vice versa. The standard that became contentious is ISO 15118-3 published in 2015. It defines the general requirements for high-level communication between an EVSE and an EV. In the Annex of the standard, HomePlug Green PHY (HPGP) Power Line Communication (PLC) is selected as the normative technology, which means it is used for EV charging when implementing ISO 15118-3 (ISO, 2015; Lampe, Tonello, & Swart, 2016). The Combo charging system[2] for EVs relies on HPGP.

Another PLC standard we examine is ISO/IEC 12139-1 published in 2009 as High Speed Power Line Communication (HS-PLC). It is used for the Advanced Metering Infrastructure (AMI) that collects and processes real-time information on electricity usage (Fig. 1). Using wired or wireless technologies, communication between smart meters and data concentrator units (DCUs) supports functions such as bidirectional metering and billing, fault detection and diagnosis (Bago & Campos, 2015; Martins et al., 2019).

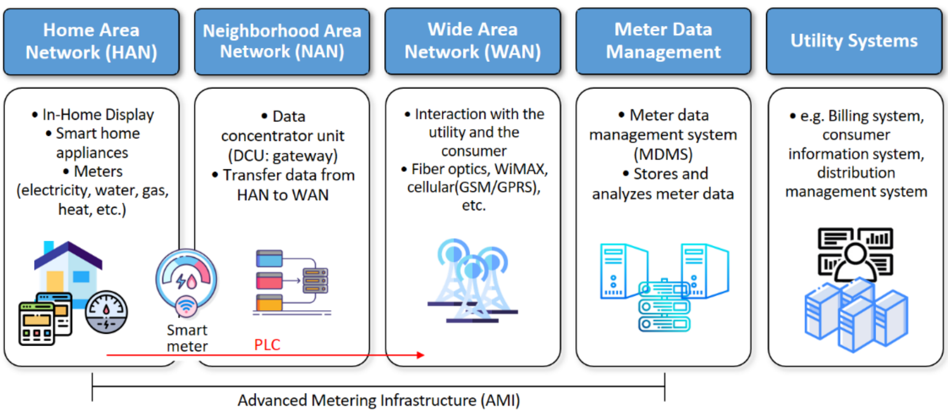

Fig. 1. Components and communications of an AMI

[2] The Combo charging system or the Combined Charging System (CCS) supports both AC and DC charging with a single charging interface. The Combo type uses 5 pin (Combo Type 1) or 7 pin (Combo Type 2) AC inlets and DC inlets that have two additional pins in the same unit.

Source: drawn by the author

4.1.2. Technical compatibility

A standards battle was found between PLC technologies used predominantly by two different industries, which are the automotive and the electric power industries. Both standards were approved by a formal SDO. However, they were developed by two distinct committees each specialized in road vehicles and IT. Simply put, this case is a committee standards battle of EV charging and electric power systems converging under the smart grid or vehicle-to-grid (V2G). Table 3 summarizes the technical features of each standard.

Table 3. Comparison of HPGP PLC and HS-PLC

	HPGP PLC	**HS-PLC**
Standard	Interoperable with IEEE 1901 Developed by the HomePlug Powerline Alliance: released in 2010 Selected for EV communication in ISO 15118-3 in 2015	ISO/IEC 12139-1 published in 2009 Prepared by the Korean Agency for Technology and Standards (KATS)
Type of standard	Committee standard for broadband and high-speed PLC	
Committee	ISO/TC 22/SC 31 - TC 22: Road vehicles - SC 31: Data communication	ISO/IEC JTC 1/SC 6 - Joint TC 1 of ISO and IEC: Information technology - SC 6: Telecommunications and information exchange between systems
Frequency bands	2-30 MHz (as specified in the HPGP Specification)	2.15-23.15 MHz (as specified in ISO/IEC 12139-1)
Data rates	4-10 Mbps	24 Mbps
Connection	Control Pilot lines, earth (ground) lines	Overhead lines
Applications	Smart grid applications on the Home Area Network (HAN), EV communications	Home network, AMI solutions

Source: summarized by the author

The interference of electric signals occurs when the AMI that uses HS-PLC to exchange information on power consumption is connected to the EV charging system that implements HPGP PLC used in Combo Type 1 chargers (Park, Seo, Park, Lee, & Kim, 2014). Interference became an issue in Korea because it developed the HS-PLC standard and implemented it for the AMI. More specifically, interference occurs in the process of automatic metering when

AMI devices like smart meters and DCUs communicate with each other (Park, Lee, & Oh, 2015). It was caused by operations on frequency bands in proximity. A considerable extent of the bandwidth is overlapping (Fig. 2).

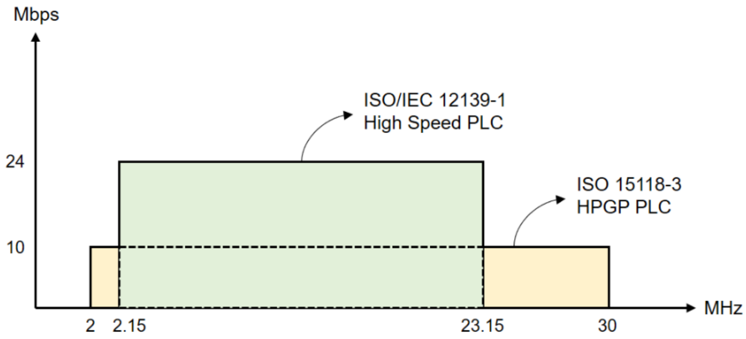

Fig. 2. Frequency band overlap between the PLC standards

Source: drawn by the author

An interviewee confirmed that a series of four coexistence tests conducted by Korea from 2012 to 2014 generated the same results about mutual interference. When both PLC technologies were applied simultaneously, the data rate decreased up to a 64.9% compared to when HS-PLC was solely applied to the AMI (Park et al., 2015). The automatic meter reading (AMR) rate decreased to 50% during AC charging, which is comparable to a 100% reading rate when only HS-PLC signals were injected. These test results indicate the possibility of disruption in the billing and diagnosis processes essential for smart metering.

The interference between HPGP and HS-PLC is likely to affect AMI communication in Korea as V2G technology advances. V2G is anticipated to support the bidirectional transfer of power between EVs and the grid. It enables the EVs to be charged during periods of low energy demand with the surplus power that was injected into the grid through a network of EV batteries at peak times. It is said by experts that the AC charging mode using PLC is the option for charging EVs via V2G communication. In that case, the simultaneous use of HPGP PLC for AC charging and HS-PLC for the AMI in proximity brings about the interference issue in reality.

4.1.3. Social compatibility

This battle involves multiple industries including the automotive, electric power, IT, and telecommunication industries. Reconciliation of social incompatibilities between stakeholders was hard to be achieved because the actors' interests unique to the circumstances in Korea and the coordination with the interests of global car manufacturers posed a challenge. Table 4 outlines the key events and Fig. 3 summarizes the social dimension of this battle.

Table 4. Chronology of key events: HPGP PLC vs. HS-PLC

Year	Event	Associated standard
1999-2005	• National projects on the development of PLC technologies and standards launched in Korea • Standards, patents, chipsets on the Korean-type PLC developed by KEPCO, KERI, Korean chipset and modem manufacturers, electronics companies, and more	HS-PLC
2006	• KS X 4600-1, a Korean standard on HS-PLC, published	HS-PLC
2009	• ISO/IEC 12139-1, the international HS-PLC standard, published	HS-PLC
2010	• IEEE 1901 published (standardization started in 2005) • HPGP PLC released by the HomePlug Powerline Alliance	HPGP PLC
2010	• National Smart Grid Roadmap announced in Korea • KEPCO installs (makes bids and selects AMI device manufacturing companies) smart meters in Korean households in accordance with the roadmap	HS-PLC
2011	• Global car manufacturers agreed to use HPGP PLC as the standard communication protocol for EV charging • The first HPGP solution developed by Qualcomm (for energy management and home automation, later for communication between EV and EVSE)	HPGP PLC
2012	• Standard on broadband PLC for PEVs that incorporates the HPGP published by SAE International	HPGP PLC
2012-2014	• A series of coexistence tests between HPGP PLC and HS-PLC conducted • KATS made requests to include ISO/IEC 12139-1 into the ISO standard on EV communication (proposal, official document of request, discussions during TC meetings)	Both HS-PLC and HPGP PLC
2015	• ISO 15118-3 (HPGP PLC as normative) published • Coexistence statement included in ISO 15118-3 that recognizes HS-PLC as an alternative	Both HS-PLC and HPGP PLC
2020	• KEPCO continues the national AMI installation project • KEPCO expands AMI installations equipped with HPGP PLC	Both HS-PLC and HPGP PLC

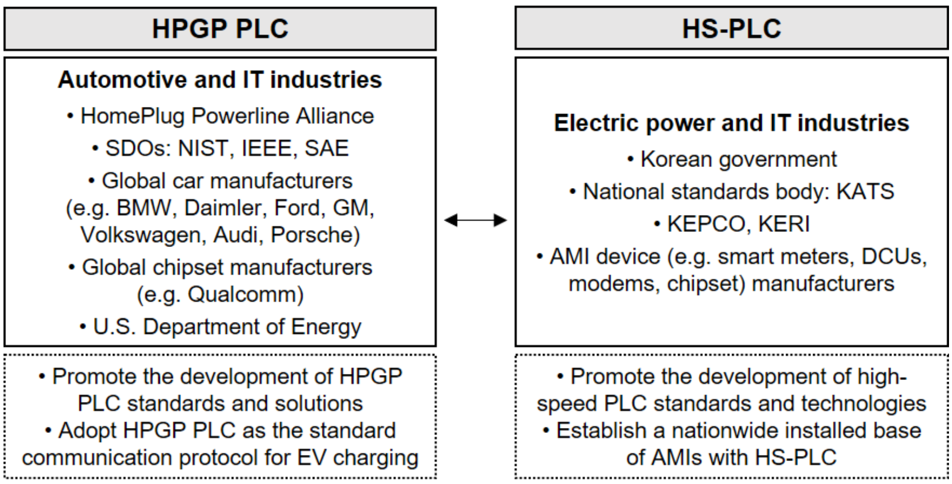

Fig. 3. Social dimensions of the standards battle: HPGP PLC vs. HS-PLC

The actors in Korea, most notably the Korea Electric Power Corporation (KEPCO), Korea Electrotechnology Research Institute (KERI), AMI chipsets and device manufacturers, and the government had a high commitment to the economic interests surrounding the nationwide installation of AMI based on the HS-PLC standard. The publication of the HS-PLC standard itself was largely influenced by the Korean government. The government funded the national standardization, which resulted in the publication of a Korean standard on HS-PLC in 2006. It aimed to transpose this standard into the ISO and succeeded in publishing it as ISO/IEC 12139-1 in 2009. This standard was prepared by the Korean Agency for Technology and Standards (KATS) and adopted under a fast-track procedure by ISO/IEC JTC 1 (ISO, 2009).

Contrary to the circumstances in Korea's electric power industry, the global market for EV charging adopted HPGP PLC and CAN protocols. In 2011, global car manufacturers including BMW, Daimler, Ford Motor, General Motors, and Volkswagen Group uniformly endorsed the Combined Charging System (CCS) as a single interface and agreed to use HPGP PLC as the harmonized communication protocol for EV charging in the U.S. and the European region (LaReau, 2011). The HPGP specification was a product of collaboration between the HomePlug Powerline Alliance, the utility industry, car manufacturers, and coordination with the National Institute of Standards and Technology (NIST) and IEEE as a solution for smart grid applications (HomePlug Powerline Alliance, 2010). The specification is based on the IEEE 1901 standard developed by the IEEE PLC Standards Committee. HomePlug had an installed base of over 60 million devices worldwide in 2010 (Wi-Fi Alliance, 2010). Thus, the alliance and its collaborators such as the Wi-Fi Alliance and those from other industries like the utility and automotive industries had interests in increasing the installed base of devices that adopt HomePlug specifications in order to facilitate the interoperability of smart grid applications. The adoption of HPGP was a means to facilitate the connection of EVs to the grid.

Qualcomm Atheros, a subsidiary of Qualcomm Technologies, is another stakeholder that supported HPGP. It launched the first HPGP solution for energy management (e.g., electric meters, water heaters) and home automation, and later developed a single chip HPGP PLC solution designed into the Plug-In Electric Vehicle (PEV) and the EVSE by 2015 (Qualcomm, 2011; Zyren, 2015). The development of these chipsets was supported by a U.S. Department of Energy grant project. SAE International that publishes ground vehicle standards stood on the side of the HPGP. It published SAE J2931/4 on broadband PLC for PEVs in 2012 that incorporates the HPGP to support high-level communications between the PEV and the EVSE.

KEPCO is a public corporation responsible for the operation of the power grid in Korea and is in charge of a large share of national projects. Its unique position in the domestic electricity market is an important factor that explains its commitment to the Korean-type PLC. It participated in preparing a standard for high-speed PLC with partners including KEPCO Knowledge, Data & Network Co., KERI, and Korean chipset manufacturing companies. They jointly made investments in developing a Korean-type PLC chip. Five technologies were patented as a result of the investments combined with a 6 billion Korean won government budget that was provided as part of a national project during 1999-2005 (Park, 2015). Since KEPCO, KERI, and AMI device manufacturers had been directly involved in setting the HS-PLC standard and making chipsets that conform to it, they were committed to the diffusion of the standard exemplified by the national AMI installation and exports of AMI devices.

The national roadmap on smart grid announced in 2010 outlined a 20-year plan to install smart meters and bidirectional communication systems to Korean households with approximately 1.47 trillion Korean won of government investment and contributions from the private sector (Ministry of Knowledge Economy, 2010). The ultimate plan of the government and KEPCO was to install smart meters in 22.5 million households by the year 2020 (MOTIE, 2018). Although the targeted number has not been reached yet, an installed base of households that have smart meters equipped with the Korean-type PLC has been formed.[3]

The national policy and the economic interests of the actors involved made it difficult to abandon the ongoing measures of adopting the HS-PLC when the interference with HPGP PLC was found. However, the interference problem could not be neglected since EVs and chargers relying on HPGP are imported. To tackle this issue, an interviewee confirmed that the Korean representatives officially made several requests to include HS-PLC into the ISO standard on EV communication. In the end, a coexistence statement was inserted in ISO 15118-3 stating that the application of an alternative PLC standard like ISO/IEC 12139-1 should be considered when there is a coexistence issue with the grid as in the case of Korea. Nonetheless, this does not fundamentally resolve mutual interference. Recently, KEPCO has been carrying out the AMI project that expands household installations equipped with HPGP PLC for ground lines.

[3] As an outcome of the plan, an installed base of 500,000 households had AMIs in 2012, 2.5 million by 2015, and an accumulation of 6.8 million by mid-2018, in the midst of a three-year suspension of the project caused by patent disputes (MOTIE, 2018). By 2019, the accumulated number reached 7.4 million. A portion of the AMI installation is based on HPGP PLC.

4.2. Dedicated short-range communication (DSRC) vs. cellular vehicle-to-everything (C-V2X)

4.2.1. Overview of technology and standards

Vehicle-to-everything (V2X) technologies include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) that connects to roadside units (RSUs), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communications. DSRC is used to support safety critical V2V and V2I applications. It is built upon IEEE Wireless Access in Vehicular Environments (WAVE) and SAE DSRC standards. The former includes the IEEE 1609 family of standards and IEEE 802.11p. IEEE 802.11p is an amendment to the IEEE Wi-Fi standard that establishes a wireless link for V2V and V2I communications, and the IEEE 1609 series establishes protocols for information exchange across the wireless link (Bettisworth et al., 2015). SAE J2735 defines the content of safety messages communicated between devices via DSRC. The equivalent standard in Europe is ITS-G5 developed by the European Telecommunications Standards Institute (ETSI).

Another candidate is the cellular network technology. The 3rd Generation Partnership Project (3GPP) developed the initial C-V2X standard that contains Long Term Evolution (LTE) support for V2X services. LTE-V2X was completed in 2017 and included as a part of 3GPP Release 14. It is focused on V2V, which is based on device-to-device communications specified in the previous releases (Flore, 2016). C-V2X is evolving to include the fifth generation of mobile technologies (5G or New Radio (NR) V2X). The main difference with DSRC is that the lower layers (MAC/PHY) are defined by 3GPP without reliance on IEEE 802.11p.

4.2.2. Technical compatibility

A standards battle is found between wireless standards developed and used by the automotive, IT, and telecommunication industries. The standards were approved by different SDOs, which are the IEEE and 3GPP. The incompatibility derives from the overlap of the frequency bandwidth (i.e., 5.9 GHz band). The differences in the technical features are compared in Table 5. This battle is described in the context of the U.S. and Europe in this section.

Table 5. Comparison of DSRC and C-V2X

	DSRC	**C-V2X**

Standard	• IEEE 802.11p • IEEE 1609 family (IEEE 1609.2 on security, 1609.3 on networking, 1609.4 on multi-channel operation) • SAE J2735, SAE J2945/1 • Europe: ITS-G5 developed by ETSI	• 3GPP: LTE-V2X, 5G-V2X or NR-V2X • Reuses and adapts IEEE, ETSI, ISO standards
Standard development progress	• IEEE 802.11p: released in 2010 and now a part of the IEEE 802.11 base standard • IEEE 1609 family: completed between 2010 and 2013	• LTE-V2X: completed in 2017 (Release 14 focused on V2V) • 5G-V2X: in progress (Release 16)
Spectrum band	• 5.9 GHz band • 5.850-5.925 GHz in the U.S. • 5.855-5.925 GHz in Europe (ITS-G5)	• 5.9 GHz band for direct communication • Commercial cellular licensed spectrum for network-based communication
Applications	• Short-range communication: V2V, V2I	• Short-range direct communication: V2V, V2I, V2P • Long-range network communication: V2N
Advantages	• Ready for deployment: tested and marketed vehicles and equipment, completed field tests, commercially available technology • Basic safety services: suitable for safety critical communications that require low latency • Allocated spectrum bands worldwide	• Off-the-shelf LTE technology, established users, reduction of infrastructure deployment cost by levering existing cellular networks • Evolves into 5G (i.e., LTE-V2X has forward compatibility with 5G-V2X) • Wide coverage range, high bandwidth transmission, low latency • Supports high speed and high density environment • Aims to support advanced safety required for autonomous driving
Disadvantages	• Limited performance in high vehicle density and high data traffic demand situations • Spectrum remains underused	• Lack of use cases • LTE/5G-V2X has yet to reach maturity and large-scale deployment

Source: compiled by the author

In 1999, the U.S. Federal Communications Commission (FCC) reserved 75 MHz of the frequency spectrum in the 5.9 GHz band for the Intelligent Transport System (ITS) and designated DSRC as the standard for safety communications. The band is divided into seven 10 MHz licensed channels to support safety-critical and non-safety services simultaneously (Lu et al., 2014) (Fig. 4). DSRC has been established as an incumbent standard that retains primary allocation for the provision of V2V safety and security services (Harding et al., 2014).

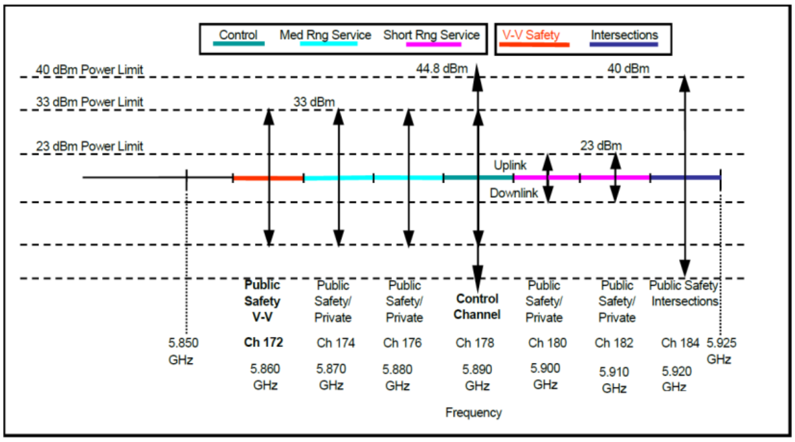

Fig. 4. U.S. FCC 5.9 GHz spectrum allocation

Source: Harding et al. (2014)

Drawing on the same frequency band, C-V2X enables communication over air interfaces defined by 3GPP (Fig. 5).[4] C-V2X 'direct' mode operates in the 5.9 GHz band over the PC5 interface without reliance on a cellular network to enable short range direct communication. V2N enables long range communication by leveraging the licensed spectrum for commercial cellular systems secured for LTE and 5G in each country.

Fig. 5. C-V2X modes: (a) direct communications; (b) network communications

Source: 5GAA (2020)

In principle, IEEE 802.11p and LTE-V2X can coexist if they are placed at different channels in the ITS band (Qualcomm, 2017; Wang, Mao, & Gong, 2017). Interference can be avoided

[4] PC5 and Uu interfaces are included in the 3GPP Release 14 (ITU, 2019). Proximity-based Communication Interface 5 (PC5) is a device-to-device direct link interface and Uu is an interface for the link between base stations and devices.

with the guard band that is set up in adjacent channels where the two systems are used. Nonetheless, experts agree that adjacent channel interference occurs when the IEEE 802.11p-based system and the C-V2X system simultaneously use the same channel in the 5.9 GHz frequency band. In the case of V2V communication, signal interference can occur if non-DSRC devices, whether C-V2X or Wi-Fi devices, operate in the same frequency band with DSRC devices that deter the effective exchange of safety messages (Harding et al., 2014). In short, a battle between committee standards implemented in V2V systems that originate from the IT and telecommunication industries is fought for the converging V2X system.

4.2.3. Social compatibility

In support of DSRC, the U.S. government had been working with the automotive industry. The federal agency entered into a cooperative agreement with ASTM to develop a national standard for DSRC in 1999. Once it was published as the ASTM-DSRC standard in 2003, the FCC adopted it as a prerequisite for DSRC equipment. Another significant decision came in 2017 when the National Highway Traffic Safety Administration (NHTSA) issued a proposed rule to establish a new Federal Motor Vehicle Safety Standard (FMVSS) that would mandate new light vehicles to be capable of V2V communications based on DSRC (NHTSA, 2017). The proposed rule did not become a final rule, but it exemplifies the support for DSRC provided by federal agencies. Similarly, the European Commission (EC) proposed the Delegated Regulation on Cooperative ITS (C-ITS) in March 2019 that required compliance with the IEEE 802.11p-based system (European Commission, 2019). The chronology of key events of the battle is summarized in Table 6.

Table 6. Chronology of key events: DSRC vs. C-V2X

Year	Event	Associated standard
1999	• U.S. FCC reserved 75 MHz in the 5.9 GHz band (5.850-5.925 GHz) for ITS and designated DSRC as the standard for safety communication	DSRC
2003	• ASTM-DSRC standard published and used as the standard for DSRC equipment compliance in the U.S.	DSRC
2010	• IEEE 802.11p released as an amendment to the Wi-Fi standard to support the vehicular environment	DSRC
2017	• LTE-V2X, the first C-V2X standard, released in 3GPP Release 14	C-V2X
2017	• A proposed rule issued by the NHTSA to mandate new light vehicles to be capable of V2V communications based on DSRC	DSRC
2018	• IEEE began the development of IEEE 802.11bd for the next generation V2X technologies	DSRC
2019	• EC Delegated Regulation on C-ITS proposed to require compliance with ITS-G5 for short-range communication, but objected by the	Both DSRC and C-V2X

	Council of the EU later in the same year	
2019	• U.S. FCC Notice of Proposed Rule Making that transforms the 5.9 GHz band plan adopted and comments accepted thereafter	Both DSRC and C-V2X
2020	• U.S. FCC First Report and Order issued that adopts rules to repurpose the 5.9 GHz band by allowing unlicensed operations and requiring the transition of the ITS radio service standard from DSRC-based to C-V2X-based technology	Both DSRC and C-V2X
2021	• U.S. FCC revised rules adopted to split the 5.9 GHz band between unlicensed and ITS uses	Both DSRC and C-V2X

SDOs including SAE and IEEE expressed their support for the NHTSA proposed mandate and the deployment of DSRC devices based on the maturity of DSRC standards (NHTSA, 2017). IEEE began to explore a long-term V2X roadmap leveraging future proof DSRC for new applications in a new study group established in 2018. The activities were taken over by the IEEE Task Group on Next Generation V2X (NGV) that currently works on preparing IEEE 802.11bd that improves the performance of IEEE 802.11p. The IT industry started off with the Wi-Fi standard. The standard evolved into IEEE 802.11p to support ITS applications and is now aimed at supporting V2X with DSRC-based technology.

The automotive industry generally has interests in retaining near-exclusive use of the full 75 MHz of the 5.9 GHz band for ITS (Calabrese, 2016; FCC, 2020). However, there is a disagreement on how the band should be separated into segments that are designated with different technologies. A subset of car manufacturers supported DSRC that can back the implementation of an extended solution with software and hardware add-ons manufactured by themselves (Bischofberger, 2017; Lu et al., 2014). DSRC or ITS-G5 equipment is commercialized and implemented in on-board units (OBUs) and RSUs.

GM 2017 Cadillac-CTS in North America and Toyota models in Japan were some of the first cars equipped with DSRC solutions for V2V communication (Bonelli, 2017; Toyota Motor Corporation, 2015). Some car manufacturers like Volkswagen continue to develop new models based on IEEE 802.11p. Its new Golf 8 model is equipped with Car2X communication technology based on IEEE 802.11p (Volkswagen, 2020). The Crash Avoidance Metrics Partnership (CAMP) formed in 1995 comprised of eight car manufactures including Ford, General Motors, Honda, Hyundai/Kia, Mercedes Benz, Nissan, Toyota, and Volkswagen participated in one of the largest safety pilot deployments in 2012 that was sponsored by the U.S. Department of Transportation (DOT). They developed vehicles to test crash avoidance systems based on DSRC (Gay & Kniss, 2015). CAMP also developed the original draft of the

DSRC standard. The automotive industry was and continues to be involved in promoting DSRC.

The CAR 2 CAR Communication Consortium (C2C-CC) founded in 2002 supports IEEE 802.11p. Members include Volkswagen, Honda, Volvo, Toyota, GM, and Hyundai Motors, and semiconductor companies that supply chipsets such as Autotalks and NXP. The consortium expressed that C-ITS services based on ITS-G5 should be deployed and not be delayed for the purpose of further evaluating LTE-V2X (C2C-CC, 2017). These players do not oppose C-V2X itself but suggest that it be deployed in its assigned spectrum for 4G and 5G where mutual interference can be avoided. If it has to operate in the same spectrum, they insist that coexistence, non-interference, neutrality, and backward compatibility with existing services that use IEEE 802.11p should be ensured. DSRC is also backed by the Association of Global Automakers.

The social incompatibilities between the actors in different industries and SDOs persist because each side claims the technological superiority of its standard over the other. Studies from Autotalks and NXP conclude that IEEE 802.11p outperforms LTE-V2X in important V2V use cases where safety-critical applications must be supported (Filippi et al., 2017). In contrast, lab and field tests performed by the 5G Automotive Association (5GAA) with the support from Ford and Qualcomm find that C-V2X is superior to DSRC in terms of higher reliability and robustness to adjacent channel interference (5GAA, 2018). Fig. 6 illustrates the social incompatibilities of this battle.

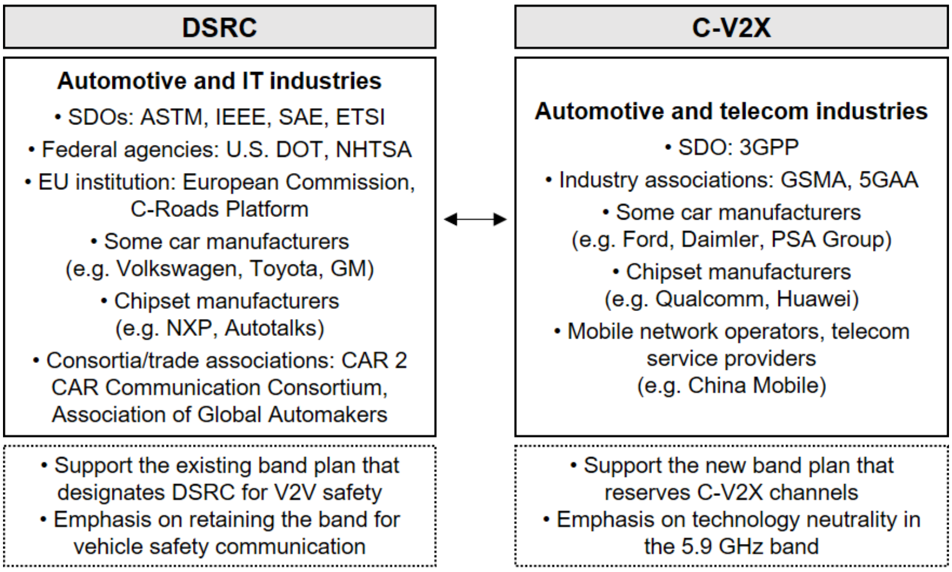

Fig. 6. Social dimensions of the standards battle: DSRC vs. C-V2X

The positions of the actors that promoted the use of DSRC came into conflict with the actors that have a stake in cellular technologies. C-V2X is largely favored by telecommunication service and equipment companies. Qualcomm once provided IEEE 802.11p-based solutions but is now actively driving the C-V2X work in 3GPP. Its C-V2X chipset solution is based on 3GPP specifications and supports direct communication on the 5.9 GHz band (Qualcomm, 2017). In fact, Qualcomm was the only commenter that raised an opposition back in 2002 to 2003 when the FCC sought comments on the adoption of a single standard for DSRC operations (FCC, 2003). Qualcomm urged neutrality and discretion to be given to licensees on their selection of communication technology.

Mobile network operators such as China Mobile collaborate with Qualcomm to launch RSUs for LTE-V2X direct communication. Car manufacturers collaborate with players in the C-V2X field. Ford is Qualcomm's collaborator in conducting field trials in the U.S. with models equipped with C-V2X. Other car manufacturers such as Daimler and PSA Group also support C-V2X. PSA Group collaborates with Qualcomm and Huawei to develop and test its car models equipped with chipset solutions of both partners (e.g. DS model with Huawei in China, Peugeot and Citroen models with Qualcomm in Paris) as use cases of LTE-V2X direct communication (Groupe PSA, 2018). Huawei is the second top contributor to autonomous driving standards by submitting technical contributions to SDOs and is ranked the highest in terms of Standard Essential Patents (SEPs) declared to V2X and 4G/5G standards (Pohlmann, 2019). As a player in the telecommunication industry, it strategically leverages SEPs related to connectivity to increase its presence in the converging system.

The social incompatibilities between the proponents of DSRC and C-V2X were intensified in the course of adopting the EC Delegated Regulation and the U.S. FCC's new rule. The EC Delegated Regulation spurred objections from the supporters of C-V2X because it was considered to be favorable towards the 802.11p-based technology and against technology neutrality. By contrast, the U.S. FCC's new proposed rule, which plans to transform the 5.9 GHz band, was opposed by the sponsors of DSRC. In the U.S., a new Notice of Proposed Rule Making (NPRM) was adopted in December 2019 by the FCC. According to the proposal, unlicensed operations like Wi-Fi will be exclusively designated in the lower 45 MHz of the band that used to be licensed for ITS and the upper 30 MHz of the band will be reserved for ITS needs and safety (FCC, 2019). The First Report and Order adopted in November 2020 specifies a band plan in which the upper 30 MHz will be exclusively retained for use by C-V2X for direct communication. The plan is to entirely change the ITS service standard from DSRC to C-V2X technology after a transition period (FCC, 2020).

Stakeholders with a common interest to support cellular-based solutions push forward C-V2X. In Europe, the GSMA, which is an association of worldwide mobile operators, expressed its objection to the EC Delegated Regulation asserting that it makes a technology choice towards 802.11p and locks out C-V2X de facto to be recognized for C-ITS (GSMA, 2019). It claimed that further incompatibilities can be created if new regulations stipulate requirements for backward compatibility with the current 802.11p at a time when C-V2X will penetrate the market rapidly (GSMA, 2017). 5GAA, created in 2016 to bring together the automotive and ICT industries, promotes LTE and 5G as the platform to enable V2X applications and supports the work carried out by 3GPP. Similar to the GSMA, it called for the EU regulatory framework to be technology neutral meaning that the regulation should be inclusive of all technical solutions for communication on the 5.9 GHz band (5GAA, 2019). It also opposed the 2017 U.S. NHTSA mandate that required other technologies to be backwards compatible with DSRC (5GAA, 2017). In response to the new FCC proposed rule, it expressed support for the allocation of the upper 30 MHz for C-V2X direct operations (FCC, 2020). We have yet to see how this battle unfolds.

4.3. Cross-case analysis

The cases revealed battles that different industries face when technologies converge. Table 7 highlights the main points of the committee standards battles.

Table 7. Summary of the standards battles

	Case 1: EV charging vs. Smart grid AMI	**Case 2: DSRC vs. C-V2X**
SDOs in conflict	ISO/TC 22 vs. ISO/IEC/JTC 1	IEEE vs. 3GPP
Standards in conflict	HPGP PLC (ISO 15118-3) vs. HS-PLC (ISO/IEC 12139-1)	DSRC (IEEE 802.11p) vs. C-V2X (LTE-V2X)
Technical incompatibility	Overlap of the frequency bandwidth between HPGP PLC in EVs and HS-PLC in the AMI that causes communication interference	Risk of channel interference between DSRC and C-V2X simultaneously operating in the 5.9 GHz band in the case of direct vehicle communication
Social incompatibility	Automotive and IT industries vs. Korean electric power and IT industries	Automotive and IT industries vs. automotive and telecommunication industries

There are several similarities between the cases that can be understood as features of the new type of standards battle defined in this paper. First, both cases demonstrate potential communication interference problems that can have adverse effects on the operation of smart systems. They are caused by the use of incompatible standards on the same frequency bands. Unlike existing battles, the consequences of the battles are not limited to the matter of who wins the game because they have an impact on the provision of public services. In the EV case, it is the interruption in the smart meter communication. In the V2X case, it is the channel interference that may cause the disruption of V2V or V2I direct communication. Second, the government influences committee standardization. The committee-based standardization is especially widespread in developing communication standards that are implemented to building an infrastructure of high significance (i.e., physical and network infrastructure for charging EVs, smart metering, and connected vehicles). Government intervention is necessary when the operation of relevant technologies requires frequency spectrum allocation. Our cases show that standards were developed separately with the support of different national governments to address the needs of different industries. Third, international committee standards that originate from heterogeneous industries entered into a battle for converging systems. The EV case shows how the battle emerged as the energy and IT sectors converged to enable smart grid that further extended its integration with the automotive industries. The V2X case shows how the battle was instigated when the existing wireless communication standard was confronted with a new competition as the cellular system integrated with the automotive industry to promote the development of connected and autonomous vehicles. These are outputs of convergence between the automotive and ICT sectors. Similar to the existing battles for converging systems, multiple industries form alliances to support one of the competing standards.

There are some differences too. First, the V2X case is different from the EV case in that the battle takes place at the global level. The battle in the EV case is found in Korea. The contest over V2X is seen in the U.S., Europe, and other countries. Second, the V2X case is more complex because it is difficult to draw a clear line between industries. The automotive industry is divided by the sponsorship of different communication standards. Quite a number of car manufacturers develop car models based on DSRC or ITS-G5, whereas others make models equipped with C-V2X chipsets. Some develop models in parallel. The industry alliances led by car manufacturers, which also include members from other industries (e.g., C2C-CC and 5GAA) have diverging preferences. This explains why the social incompatibilities are analyzed through the divided interests in a mix of industries. In addition, it should be noted that the positions of the actors described in the cases change due to several reasons such as technological evolution, industry commitment, and government support. Third, there are differences in the timing of the standardization and the occurrence of the battle. In the battle between HPGP and HS-PLC, the development of the two standards was initiated in a similar period, which implies a better chance of harmonization if coordination was sought. On the contrary, in the battle between DSRC and C-V2X, there is approximately a 20-year gap in standardization. Back in the late 1990s, DSRC was the only technology available for research and standardization. This implies that it is not an easy task to seek the harmonization of V2X standards and the entire transition of ITS services.

5. Discussion and implications

In this section, we compare the findings of this study with previous studies and suggest how this study adds new insights in terms of heterogeneity, actors, and government role in standards battles. One of the major contributions of this paper is that we categorized existing studies on standards battles into four types by the mode of standardization and the heterogeneity of industries or actors. Based on this categorization, we will be able to identify and examine a new type of standards battles.

5.1. Heterogeneity within and across industries

The cases channel our attention to an emerging phenomenon in which technological convergence facilitates the reconstruction of industry boundaries and thereby enrolls heterogeneous industry players and SDOs into a new playing field for converging systems. Previous studies on standards strategy, including Shapiro and Varian's (1999) seminal work, tend to focus on standards battles within a homogeneous industry. The heterogeneity of interests was identified as a factor that hindered the success of standards development required to meet the needs of industry-wide interconnection (Greenstein, 1992; Markus et al., 2006). Although groups were identified to have diverging interests on whether they support open or proprietary standards, they all remain in the same industry. Therefore, they cannot offer proper guidance for the battles involving different committee standards and heterogeneous sponsors from multiple industries.

As industries and technologies converge, the heterogeneity of interests is not confined to the boundaries of an industry, a committee, or user organizations. Our cases illustrate a higher level of complexity as SDOs and the committees within them that enter into a conflict are not limited to the same industry. Communities in the literature tend to encompass the actors from the same industry as it is implied in Markus et al. (2006)'s connotation of the "industrial community". We identify the changing scope of heterogeneity and community to understand standards battles in the environment of converging industries.

Our cases show that the actors in the same group do not necessarily have a corresponding and unified interest. For instance, car manufacturers may have heterogenous interests or have an interest for both types of competing standards although they are identified to belong to a structurally equivalent group in the same industry. In other words, members of the same group or industry are not always united in the support of standards that span across industries in their applications. We can say that the goal of collective action itself has changed from supporting the development and diffusion of industry-wide standards to that of standards that satisfy the needs of inter-industry connection.

Although typologies developed by de Vries, Verheul, and Willemse (2003) help identify the typologies of stakeholders in the standardization process, the heterogeneity of the types and interests of stakeholders cannot be fully captured under that categorization. The cases analyzed in this study explain the heterogeneity of interests within and across industries. The second case on V2X shows that there are communities composed of standards committees, consortia, industry alliances, government, car manufacturers, telecommunication service and equipment companies on each side of the battle, of which one side advocates DSRC and the other supports the cellular solution for V2X. When simplified, the case can be named as a battle between the IEEE committee-based community and the 3GPP committee-based community. While the high number of industries involved is one of the determinant factors in achieving success in a market battle (van de Kaa & de Vries, 2015), the high number and heterogeneity of actors make it difficult to seek coordination between committees. From this, we generate that as technologies converge, heterogeneity is associated with a higher probability of the occurrence of a standards battle.

We can also identify the paths that lead to the outcome of "unexpected" heterogeneous competitions for converging industries. Most of the existing studies explore the battle over a single standard whether it is in the market for a quest to be a de facto standard or in a committee to reach consensus on a common solution. The battle is known from the outset because a battle is fought to gain dominance for the same standard during the same time period. Our cases introduce battles that were unexpected because of a failure to coordinate in advance or a difference in the timing of standardization. This paper contributes to the existing body of research on standards battles by adding cases of battles between heterogeneous communities that were unexpected. In the battle between smart grid and EV standards, the same PLC technologies were standardized but implemented in different industry applications, of which one applied to the AMI and the other applied to EV charging. As the applications became integrated and requirements of connectivity were realized, interference issues were discovered later.

In the battle between DSRC and C-V2X standards, technical standards that represent disparate tracks of wireless communications were developed in separate committees in different periods. As the different technologies gained similar functions for vehicular communications and both became applicable to an emerging industry of connected and autonomous vehicles, a battle was intensified and interference issues came under scrutiny. In both cases, technological development and standardization of two standards were differently initiated, but battles between the standards took shape due to technological advances into similar functionalities. These conflicts are likely to occur as convergence advances in other sectors.

5.2. Committee as a player in standards battles

Committees are also players in standardization and standards battles. They compete as an industry player in the battle with a standard developed by another committee. Standards committees in voluntary SDOs are analyzed in the literature as a mechanism to achieve coordination between incompatible standards (Farrell & Saloner, 1988; Wiegmann et al., 2017). However, committees are not confined to a mechanism for coordination or a mode of standardization. While previous studies assumed that competitions can be resolved through cooperation before diffusion in the market, the role of committees as a player in the battles has been overlooked.

Our cases reveal that a competition does not necessarily occur within the scope of a committee but can occur between different committees. The battle between smart grid and EV standards sheds light on how a single SDO does not always succeed in the coordination of conflicting interests of heterogeneous players in different standards committees within the same SDO.

In the new type of standards battles, standards setting institutions no longer work solely as an "institutional glue" that links technical and social change (Mansell, 1995) but as a player in the field whose purposive action is centered on legitimizing their own trajectories. Besides committees, the core or periphery firms, government, consortia, alliances can all be composed as actors that form a community supporting a particular standard. As seen in the first case on smart grid and EVs, formal SDOs are important but are not the sole actors that define the communities that enter into rival relationships.

While there is a mixture of cooperation and competition between firms, committees are able to create standards through collective action (Narayanan & Chen, 2012). Markus et al. (2006) found that fragmentation of standardization efforts can be avoided when such efforts encompass heterogeneous groups of users and elicit collective action. However, these prior studies are limited to the context of a single organization; that is, collective action dilemmas can be overcome in a single organizational boundary. Our cases reveal structural challenges in seeking cooperation in the committee-based or the hybrid mode of standardization when committees or SDOs themselves become competitive players. This implies that standardization involving committees and formal standards can no longer be seen only through the lens of cooperation within the boundary of committees especially when competitions occur across industries.

5.3. Changing roles of the government

This study raises the importance of the government's emerging role in managing conflicts. In addition, the government is not a unified actor. The role of the government into incentivizing stakeholders, moderating interests, and facilitating cooperation in the process of standards development, adoption, and diffusion have been widely discussed. The roles are referred to as an interest moderator and collaboration facilitator (Gao, Yu, & Lyytinen, 2014). The most recent discussion emphasizes its roles as a convenor and coordinator that facilitate standardization across domains and sectors (Ho & O'Sullivan, 2019). In the current environment in which rapid convergence is witnessed and conflicts occur accordingly, the role of the government is not restricted in orchestrating conflicts within a single country or a single industry. Moreover, the new types of standards battles that involve heterogeneous industries and SDOs cannot simply be resolved by the government's enforcement of a standard or acting as a sponsor with financial and administrative policy instruments. The roles of engaging and coordinating various stakeholders and SDOs that may exceed existing networks and sectors are indeed important as suggested by Ho and O'Sullivan (2019). The roles examined in the literature and in our paper may refer to the same term ‘coordinator’. However, the meanings differ in that the cases in this paper imply the importance of the role in ‘conflict management’ that goes beyond the role as a coordinator.

Managing conflicts is not only important during the standardization process but also at the post-implementation phase because unexpected conflicts can be newly discovered afterwards. Since a synthesis of observations from earlier studies shows that the impact of the government’s position is focused on the early stages of the standardization process in solving wars of attrition and creating favorable conditions for a proposed solution (Wiegmann et al., 2017), the cases in our study provide implications on the government’s role and its interaction with other actors in the later stages of the standardization process. Coordination problems arise from committee standards and involve issues on spectrum allocation. The activities of the public and the private sectors are influenced by government policies and regulations especially related to frequency spectrum allocation. Thus, the government should play the role as a coordinator to promptly respond in the management of the spectrum.

Furthermore, there is an additional level of complexity. In our cases, the government does not function as one unified agency or an impartial umpire. Instead, heterogeneous government agencies compete against each other in sponsoring different committee standards to legitimize their position in the playing field. In the same country, departments can have heterogeneous agendas as we see in the case where the U.S. DOT had been supporting DSRC and the FCC has shifted its agenda to promote C-V2X. The findings are similar to a study that found misaligned interests between ministries in a single country in their support for a particular standard and implied that the government is not seen as a “large monolithic entity” (van de Kaa, Greeven, & van Puijenbroek, 2013). Interests and roles also diverge between the governments of different countries as seen in the case of smart grid and EV charging standards where the Korean government agency faced oppositions from other countries when attempting to include the HS-PLC standard into the ISO standard on EVs. These changes in role identities call for a new standards strategy. One lesson learned from our cases is that a standards strategy that includes specific standards committees and government agencies as potential partners should be developed.

5.4. Limitations and future research direction

This study has some limitations. One of them would be that it is based on two cases. However, the cases of committee standards battles from heterogeneous industries and SDOs are not much researched yet although there are signs that they are increasing. When more committee battles are discovered in the future, a higher level of generalizability in the mechanism and the dynamics of the phenomenon can be achieved. Additional cases would validate the categorization and identification of properties of committee standards battles formulated in this study. This study does not find a causal relationship on the factors that cause a battle or determine the outcome of a battle because the purpose is not to find who wins the battle. Nonetheless, this topic can also be explored as an extension to the existing literature on the winning factors of standards battles. Considering that new smart systems will emerge, existing smart systems will converge, and a "system of systems" will further complicate the scene, more research is required to explore emerging cases of standards battles that involve heterogeneous industries and committees.

6. Conclusion

This study introduced a new type of standards battle to discuss cases that cannot be fully explained by the existing literature on standards battles. While previous research was centered on battles that occur in de facto standardization, we found that standards battles occur between heterogeneous players in standards committees and industries. Committees function not only as a mechanism for coordination but have a role as an industry player that compete in the battle with a standard developed by another committee. The cases illustrate that the battles caused by technological convergence are not only found in the market but also in the institutionalized mechanisms of standardization. Explorations of the battle between EV charging standards and smart meter communication standards and the battle between DSRC and C-V2X provided an understanding of how the inability to achieve technical compatibility regarding the operation of standards on the same frequency bands influences the standardization of smart systems and the provision of smart services. The inability to bridge incompatibilities between actors with vested interests towards a particular standard also complicates the battling scene. This could make a system to be entrenched and make it difficult to flexibly adapt to new circumstances spurred by technological developments. Overall, the socio-technical incompatibilities created and intensified in the standardization process affect the processes and the outcome of standards battles.

Appendix

Table A.1. List of key secondary data sources

Case	Type	Specific data source
EV vs. AMI	• scientific papers	• coexistence test results and the interference found in Korea (C. Park et al., 2015; J. H. Park et al., 2014)
	• government documents	• national roadmap and basic plan for the smart grid in Korea (Ministry of Knowledge Economy, 2010; MOTIE, 2018)
	• governmental and standardization organizations	• national infrastructure, national and international standardization for EV charging (Kim, 2016), white paper on HPGP (HomePlug Power Alliance, 2010), NIST guideline for the coexistence of broadband PLC standards (Su & Galli, 2012)
	• standards in full text	• ISO 15118-3 on EV communication (ISO, 2015), ISO/IEC 12139-1 on high speed PLC (ISO, 2009)
	• patents	• method for interference suppression within the AMI system (J. H. Park et al., 2015)
	• reports	• report on the output of the development of a national PLC standard (KERI, 2002)
	• news articles, press releases, other sources	• adoption of the EV charging standard by global car manufacturers (LaReau, 2011), launch of the first HPGP solution (Qualcomm, 2011), V2G communication interface and the coexistence issue between HS-PLC and HPGP PLC (J. S. Park, 2014), HPGP applied to the EV combined charging system (Zyren, 2015)
DSRC vs. C-V2X	• scientific papers	• V2X wireless technologies, DSRC and 3GPP C-V2X standards (Lu et al., 2014; Wang et al., 2017)
	• government documents	• U.S. DOT document on the DSRC and V2V technology including standards and spectrum operations (Bettisworth et al., 2015; Harding et al., 2014; Gay & Kniss, 2015)
	• standardization organizations	• World Radiocommunication Conference (WRC-19) final acts on radio frequency spectrums management (ITU, 2020)
	• standards	• IEEE 1609 and 802.11p standard, ITU recommendations on ITS (ITU, 2019)
	• rules and regulations	• FCC rules on DSRC services in the 5.9 GHz band (FCC, 2003; FCC, 2006), proposed rules for the technology-specific operation in the 5.9 GHz band (NHTSA, 2017; FCC, 2019; FCC, 2020), EC Delegated Regulation on C-ITS European Commission, 2019)
	• reports	• position papers by C2C-CC and 5GAA (C2C-CC, 2017; 5GAA, 2017), white paper by chipset manufacturers on IEEE 802.11p vs. LTE-V2X (Filippi et al., 2017), test report on C-V2X and DSRC performance (5GAA, 2018), report on C-V2X (GSMA, 2017; Qualcomm, 2017), report on patent and SEP analysis for autonomous driving (Pohlmann, 2019)
	• news articles, magazines, press releases, other sources	• battle for the connected vehicles (Bischofberger, 2017), completion of the initial 3GPP C-V2X standard (Flore, 2016), objection to the EC Delegated Regulation (5GAA, 2019; GSMA, 2019), car manufacturers' installation of technology (Bonelli, 2017; Toyota Motor Corporation, 2015; Volkswagen, 2020)

Table A.2. List of interviews

Title	Interviewee information
• director of the standardization division in an SDO	• participates in the standardization of mobile communications (e.g. 3GPP, ITU-R)
• researcher in a standards organization	• an expert in radio standardization
• executive director in a smart grid solution company	• participated in the standardization of broadband PLC
• professor in automotive engineering	• participates in the development of EVs and is an expert in EV standardization
• head of the standardization center in a non-profit organization for ITS	• expert of standardization in ITS
• professor in electrical and electronic engineering	• researches 5G-V2X and connected mobility, a committee member of the public-private forum on 5G
• head of connected car business in a major telecommunications service company	• has a career in both the automotive and telecommunications private sector
• director of technical standards in a global telecommunications company	• has experience in a wide range of SDOs such as 3GPP, IEEE, ITU-R, 5GAA
• executive director of platform business in a global car manufacturer	• has a career in both the automotive and telecommunications private sector
• head of a center for autonomous driving in a transport institute	• participates in C-ITS projects
• researcher and chief director in a transport institute	• participates in the international standardization of ITS, convenor of a working group in the ISO Technical Committee on ITS (TC 204)

Table A.3. List of standards

PLC and V2X Standards
• ISO 15118-3:2015, Road vehicles — Vehicle to grid communication interface — Part 3: Physical and data link layer requirements.
• ISO/IEC 12139-1:2009, Information technology — Telecommunications and information exchange between systems — Powerline communication (PLC) — High speed PLC medium access control (MAC) and physical layer (PHY) — Part 1: General requirements.
• IEEE 1901-2010 - IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications. It covers high-speed communication devices via electric power lines.
• SAE J2931/4, Broadband PLC Communication for Plug-in Electric Vehicles.
• 802.11p-2010, IEEE Standard for Information technology – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments.
• SAE J2735, V2X Communications Message Set Dictionary.
• SAE J2945/1, On-Board System Requirements for V2V Safety Communications.
• ASTM E2213-03, Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5-GHz Band Dedicated Short-Range Communications (DSRC), Medium Access Control (MAC), and Physical Layer (PHY) Specifications.

Glossary

3GPP: 3rd Generation Partnership Project
5G: fifth generation of mobile technologies
5GAA: 5G Automotive Association
AC: alternating current
AMI: Advanced Metering Infrastructure
AMR: automatic meter reading
C2C-CC: CAR 2 CAR Communication Consortium
CAMP: Crash Avoidance Metrics Partnership
CCS: Combined Charging System
C-ITS: Cooperative ITS
C-V2X: Cellular vehicle-to-everything
DC: direct current
DCU: data concentrator unit
DSRC: Dedicated Short-Range Communications
EC: European Commission
ETSI: European Telecommunications Standards Institute
EV: electric vehicle
EVSE: electric vehicle supply equipment
FCC: Federal Communications Commission
FMVSS: Federal Motor Vehicle Safety Standard
HS-PLC: High Speed Power Line Communication
HPGP: HomePlug Green PHY
ICT: information and communication technologies
IEC: International Electrotechnical Commission
IEEE: Institute of Electrical and Electronics Engineers
ISO: International Organization for Standardization
ITU: International Telecommunication Union
ITS: Intelligent Transport Systems
ITU-R: ITU Radiocommunication Sector
ITU-T: ITU Telecommunication Standardization Sector
KATS: Korean Agency for Technology and Standards
KEPCO: Korea Electric Power Corporation
KERI: Korea Electrotechnology Research Institute
LTE: Long Term Evolution
MAC/PHY: medium access control and physical layer
NHTSA: National Highway Traffic Safety Administration
NIST: National Institute of Standards and Technology
NGV: Next Generation V2X
OBUs: on-board units
PEV: Plug-In Electric Vehicle
PLC: Power Line Communication

RSUs: roadside units
SDO: standards developing organizations
SEP: Standard Essential Patent
U.S. DOT: United States Department of Transportation
V2G: vehicle-to-grid
V2I: vehicle-to-infrastructure
V2N: vehicle-to-network
V2P: vehicle-to-pedestrian
V2V: vehicle-to-vehicle
V2X: vehicle-to-everything
WAVE: Wireless Access in Vehicular Environments
WRC: World Radiocommunication Conference

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