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Wireless Communication Technologies for Connected Electric Vehicles: A Review of 5G, IoT and OFDM-Based V2X Systems Toward 6G Mobility

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Abstract: Electric vehicles have become increasingly common in recent years, and electricity consumption patterns have significantly changed, which has greatly transformed the communication systems, specifically within the transport sector. Connected Electric Vehicles (CEVs) rely heavily on the steady, accurate transmission of data to enable safety, operate intelligently, and make smart decisions fast. This study covers the communication technologies that feed into this ecosystem – 5G networks, IoT integration, Orthogonal Frequency Division Multiplexing (OFDM)-based V2X systems. Rather than approaching these technologies as standalone innovations, this review analyses their interactions in real-world vehicular applications, where practical constraints on mobility, interference, and heterogeneous network environments are encountered. The approach goes so far as to consider newer 6G networks, including AI networking approaches and more advanced integrated communication architectures. Finally, the paper addresses the challenges and gaps for further research leading to an end-to-end response in delivering connected electric mobility system deployment into a secure environment.

Keywords: Connected Electric Vehicles, V2X(Vehicle to Everything) Communication, OFDM, 5G Networks, IoT, 6G Mobility

I. INTRODUCTION

The shift to electric vehicles is often framed as a response to sustainability goals, but from this perspective, what is happening only begins to make sense. Vehicle integration into communications networks is a big piece of the puzzle, too. It means that an electric vehicle is not just a mechanical device that relies on electricity for its operation; it is the product of a data-driven entity that engages with the real-world ecosystem, which is dynamic and responds to changes. This collective transformation has been followed by the advent of Connected Electric Vehicles (CEVs). In these systems, communication is not second-order; it is core. Here, vehicles join up with other cars, roadside data, and connected platforms to execute applications as varied as collision avoidance and routing optimisation. This transition is closely linked to new cell-based communication technologies, which, as described in [1] [2], have led us to the emerging field of 5G, specifically 5G-capable networks. On the other hand, it would be disingenuous to assume that better communication standards alone solve the problem of data transfer. Vehicular situations are always going to be unpredictable. As a fast-moving car drives through a noisy urban setting, the channel conditions change rapidly, the signals reflect differently, and the interference varies greatly. And all of those are new complexities that are not typically present in cases of stationary or low-mobility communication. What's especially interesting — while very troublesome — about this problem, however, is that it sits atop many domains. Communication theory, signal processing, networking, and even energy systems all contribute. This paper aims to fill the gap between this point of view and the current discourse, integrating the fields of research by documenting the technologies which enhance Electric Connected Mobility. But it also recognises that there are practical limitations.

II. CONNECTIVITY ARCHITECTURE FOR MODERN ELECTRIC VEHICLES

A. Evolution of V2X Communication Standards

The development of vehicle communication systems has been slow, but with a clear progression. Previous systems, which also utilised DSRC, were limited in scope and included less time to cater for vehicle compatibility and broadcasting of safety messages throughout the specified distance. This was an effective

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approach for a relatively infrequent experiment, but as studies of large-scale deployment were pursued, their limits were clear [3]. Shifting from V2X to cellular V2X (C-V2X) was another radical change. The fusion of current cellular infrastructure for C-V2X systems opened the door to greater flexibility and scalability. Finally, due to the increased development level of cellular solutions, vehicular communication was further enhanced with the same approach. Even more clear were the advantages that the advent of 5G added, the network offers the potential of a reduced response latency and much higher data rates [5], [7]. That being said, as we move to cellular systems, additional dependencies are added. DSRC is autonomous; C-V2X is network-level, depending on network availability and performance. But that opens a whole new debate about reliability in areas without high reach — but that's an open topic.

B. IoT Integration in EV Battery and Energy Management

Connected EV systems get less attention; however, IoT technologies can help connected EVs. Modern EVs are also surrounded by dozens of sensors that monitor everything from battery health to environmental conditions. This data is not simply captured locally; the vehicle, but is sent to larger systems for analysis and optimisation. In practice, this can extend to predictability, such as predictive maintenance and adaptive charging strategies. Battery performance can be adjusted based on usage patterns, making the battery more efficient and extending its usable lifetime.

But this degree of connection creates new kinds of problems, too. In this kind of networking, particularly where multiple vehicles are located in the same location, continuous data transmissions load the network heavily. This results in a tradeoff between the availability of data and expedited communication; this trade-off needs to be carefully managed.

C. Heterogeneous Network Requirements

No one communication technique can meet every need; in reality, for connected EV systems. Instead, they are multi-network systems, with diverse capabilities of their own. They're used across the coverage of the whole area that would generally use cellular networks; this is a wide-area problem, while short-distance types of technologies provide localised applications. The system is fully extended with satellite communication and edge computing to an edge-endurance level as well. While such a layered architecture increases the overall reliability and complexity of system design, it also adds more dimensions to the overall system design. The interaction of different network components needs to be integrated smoothly with proper matching and resource utilisation management [9].

Table-1. Comparative Characteristics of V2X Communications Technologies

Technology	Coverage	Latency	Reliability	Key Applications
DSRC	Local	Low	Moderate	Safety alerts
C-V2X	Regional	Low	High	Traffic coordination
5G NR-V2X	Wide-area	Ultra-Low	Very High	Autonomous systems

This table illustrates the different characteristics of the various network technologies with their coverage, latency, reliability, reliability and how those inform their applications.

III. 5G ENABLING TECHNOLOGIES FOR CONNECTED EVs

A. Ultra-Reliable Low-Latency Communication (URLLC)

URLLC is a crucial factor in safety-critical vehicular applications. For example, in collision avoidance problems, millisecond-level latency-driven delays can seriously affect the system's critical performance. 5G networks are designed for low latencies but also high reliability. They are perfect for this [1], [4]. Here, the performance management of those varies a lot due to high-mobility conditions and is quite important, considering the dynamic channel state.

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B.Massive Machine-Type Communication (mMTC)

The rapid emergence of connected devices in the automotive market necessitates help in broad-spectrum communication. Therefore, mMTC enables connectivity, serving tens to hundreds of devices in a single network [6], [18]. Within the realm of EV ecosystems, this feature allows for fleet management and monitoring of intelligent infrastructures, as well as facilitating multiple deployments of IoT.

C.Network Slicing

Network slicing facilitates the design of many virtual networks based on the same physical environment. This enables different applications to run separately and to work independently as required by their own performance needs. For example, communication that is critical for safety can be preferred to other slower data streams [2], [8]

```
           Physical Network Infrastructure
 -----------------------------------------------------
      |            |            |                |
 Safety Slice     IoT    Infotainment    Control Slice
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IV. ANALYSIS OF OFDM-BASED V2X COMMUNICATION SYSTEMS

A. Waveform Design in High-Mobility Environments

OFDM is extensively used to overcome multipath propagation and to achieve maximum spectral exploitation, and is therefore the most effective method to mitigate multipath propagation. However, for high-speed vehicle transmission applications, like traffic with high vehicle speeds, Doppler effects also cause frequency changes on the frequency of the subcarriers, which then disrupt subcarrier orthogonality. This is known as Doppler effect. This creates interference (ICI), which leads to lower performance degradation of the system [5]. The signal processing must be handled through improved techniques to aid mechanisms like adaptive subcarrier spacing and channel estimation that have already been developed

B. Interference Mitigation and Resource Allocation

Densely loaded vehicular environments rely heavily on interference management. System improvements are made using optimisation techniques such as adaptive modulation, power consumption, dynamic resource allocation, etc. And, to get such information, such a mechanism needs to be assumed to be the true channel state information, which is difficult to estimate in a dynamic environment.

C. Comparative Analysis: C-V2X vs DSRC

C-V2X systems are usually much more scalable and integrated on current communications networks than those of DSRC. Even though DSRC remains helpful for localised communication to achieve network localisation in practice, in this case, the range and flexibility of DSRC are not suitable for other applications

Figure 2: Reliability vs Distance (Conceptual Comparison)

```
Reliability
  ↑
  |       C-V2X
  |      /
  |     /
  | DSRC /
  |______/__________→ Distance
```

Fig.2 suggests that while DSRC is good for short-range communication, it performs increasingly less well as distance increases. On the other hand, the reliability of C-V2X reduces gradually, implying it is suitable for use in the widespread vehicular sectors. This trend also reinforces the migration of the industry to mobile and cellular-based V2X for high-mobility, high-scalability applications.

V. SECURITY, PRIVACY, AND DATA INTEGRITY

Increasing dependence on communication systems will lead to different threats to CEV networks: as communication systems have become increasingly used for secure communication, CEV networks are expected

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to be subject to multiple security threats. In particular, charging infrastructure (also known as charging networks) is a major concern because it is the linkage of vehicles to external networks and charging infrastructure is the hook [14]. In dynamic environments like these, standard security features might not be enough. A different type of emerging solution (such as blockchain-based architecture) attempts to provide decentralised and tamper-resistant data management [15]. At the same time, security measures should also be implemented from the beginning to ensure system reliability in the long term [17]

VI. THE TRANSITION TO 6G MOBILITY

The transition to 6G mobile infrastructure will greatly improve vehicular signal transmission. This will make use of advanced technologies like terahertz communications, AI-based network optimisation, and integrated space-air-ground systems. It is hoped that these innovative systems will produce ultra-high data rates and enable near-real-time communication—the basis for the creation of advanced applications such as fully autonomous driving or real-time data analytics at a rate hardly possible previously. Global connectivity and intelligent network management are essential in forthcoming vehicle systems, which in particular must be linked up to data (the latest studies point it out [16], [20].

VII. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Despite notable progress, several challenges remain:
•Spectrum scarcity on the back of increased demand.
• Energy management issues associated with high-speed systems [10].
• Absence of global standardisation and interoperability [19].

Solutions to these challenges are going to require more collaboration across communication engineering, energy systems and artificial intelligence.

VIII. CONCLUSION

This paper has presented a comprehensive review of wireless communication technology for connected electric vehicles that are based on 5G, IoT, and OFDM-based V2X systems from different domains. While these technologies brought a significant improvement to its communication capabilities, they nevertheless have mobility, scalability and security restrictions. While limitations for the mobility applications have raised serious doubts, it could be a paradigm shift toward 6G; a few more works still bear fruit in steering clear of any systemic issues, and providing reliable communication features that are fast (efficient) to secure 5G for vehicular systems.

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