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Synchronization Techniques in "Device to Device- and Vehicle to Vehicle-Enabled" Cellular Networks: A survey[☆]

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ABSTRACT

Device-to-Device (D2D) communication is introduced for cellular networks allowing User Equipments (UEs) to communicate directly in close physical proximity. In traditional cellular networks, time synchronization is performed by the network infrastructure equipment to address the challenges of coordinating independent clocks and tasks of UEs to communicate with each other. These challenges are more critical in D2D as the network has no central point to coordinate UEs. The aim of this paper is twofold: (i) reviewing synchronization standards and techniques for D2D-enabled cellular networks and (ii) discussing different scenarios and contemporary cellular network generations. We review the main signals, channels, and entities used by D2D-enabled cellular networks for synchronization procedures in different scenarios. Moreover, we focus on the synchronization in Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X). Finally, we conduct a literature study on effective proposed synchronization techniques in D2D and vehicular communications to highlight recent advances and provide future directions.

1. Introduction

Cellular networks are increasingly set to become the principal network infrastructure for different network applications like the Internet of Things [1] or vehicular networks [2] to connect billions of devices worldwide. The fourth generation of cellular networks (4G) or Long-Term Evaluation (LTE) is the latest fully implemented cellular networks that can transfer voice and data simultaneously at high speed based on the Internet Protocol (IP). In addition, upcoming 5G and recently 6th generation (6G) are the new emerging generations of cellular networks that address previous generations' problems by improving the efficiency, speed, and network throughput. Specifically, 5G is going to answer these three use cases; enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), and ultra Reliable Low Latency Communications (uRLLC). The 5G cellular system deployment is still on-going, and continuously new features are added to this generation. However, some drawbacks exist in the fundamentals of the 5G architecture. Consequently, the development of 5G and 6G attracts researchers' attention to address the challenges of these upcoming generations [3]. Currently, there are no fundamental architecture and performance components for 6G. In contrast to previous generations of cellular systems, 6G will not only utilize a broader spectrum at higher-frequency bands. Still, the critical point to the feasibility of 6G is the convergence of forthcoming technological trends driven by core service classes [4] based on radar technologies and collective Artificial Intelligence (AI).

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The available cellular networks are undergoing a revolution in standards/ protocols resulting from new applications and technologies, e.g., Internet of Things (IoT) and Vehicular networks. These technologies are basically not designed to work on top of cellular networks. There are increasing concerns regarding their performance, basically due to the lack of comprehensive standards and slow pace of standardization concerning different scenarios and techniques [5]. As an emerging concern, device communication protocols are disputed issues in cellular networks to improve the performance of massive scale and Ultra Dense Networks (UDNs). Traditional cellular networks utilize a hierarchical network infrastructure to connect devices based on central points, called base stations, Access Points (APs), and Evolved Node Bs (eNBs). In such infrastructure-dependent networks, devices are essentially needed to connect through the central points. Although using the central points has several advantages, there are many scenarios where direct communication among devices in close proximity is more efficient than central points. Concerning different issues like delay, resource consumption and interference, cellular networks are enabled to allow User Equipments (UEs) to communicate directly, called D2D. D2D can improve the resource consumption and network agility along with reducing delay and interference as crucial issues of different time-sensitive and resource-constraint applications [6]. As a new technology that is not harmonized with the principles of traditional cellular networks, there are many efforts to adapt D2D with implemented cellular networks. Technically, in cellular networks, it is impossible to connect devices directly as in a connection different synchronization and communication techniques are performed by central points to start and maintain the communication session. The integration of D2D communication technology in the cellular networks opens up opportunities to enhance the current proximity-based services and brings new use-cases like direct communication in social and commercial services, public safety, V2V communication, and traffic safety. However, the incorporation of D2D capabilities into cellular networks leads to new technical challenges such as mode selection, spectrum management, and synchronization [5].

According to a definition proposed by ITU Telecommunication Standardization Sector (ITU-T), synchronization in a computer network aims at delivering a common clock reference to nodes in the network within specific accuracy and stability [7]. The synchronized clock can be used in different operations, basically for UEs communications. Similar to infrastructure-dependent networks, synchronization among D2D-enabled UEs is a prerequisite to establish and maintain a connection to avoid collision, interference and giving the ability to UEs to communicate directly. In contrast to the traditional cellular communication that is fundamentally based on a global reference clock, D2D communication is a local Peer-to-Peer (P2P) communication without any global reference clock. Thus, the synchronization procedure in a D2D communication system is more complicated than the traditional cellular network, because there are multiple Synchronization Referencess (SRs) with different levels of priority In D2D communication, synchronization is essential to recognize the frame/sub-frame boundaries (i.e., coarse synchronization) and adjusting the clock drifts for decoding and transmitting D2D control data and traffic data (i.e., fine synchronization). Although D2D communication can be performed asynchronously [1], synchronized D2D communication can offer decisive advantages including the decline of power consumption, efficient network resource management, reducing interference and improving channel utilization. This paper focuses on synchronization techniques that are used in D2D and V2V communication in cellular networks. The main contributions of the paper are summarized as follow:

- Discussing different scenarios of synchronization in D2D- and Vehicle-to-Vehicle (V2V)-enabled cellular networks and procedures to synchronize the direct communication between UEs.
- Studying the main synchronization standards and techniques that have been introduced to use in D2D-enabled cellular networks.
- Comparing D2D with V2V and Vehicle-to-Everything (V2X) synchronization techniques along with explanation of their differences.
- Reviewing literature of proposed synchronization techniques in D2D-enabled contemporary and emerging generations of cellular networks identifies their key factors and proposes future directions.

To the best of our knowledge, no survey paper exclusively focuses on synchronization standards and techniques in D2D- and V2V-enabled cellular networks. Only a few papers have focused on other aspects of D2D- and V2V-enabled cellular networks or considered synchronization in these networks sufficiently e.g., Kar et al. [8] have overviewed D2D communication in cellular networks, considered D2D synchronization as a challenge and briefly investigated it.

1.1. Review methodology

We follow a basic plan to select and refine the existing literature on D2D synchronization to conduct this review. We apply a combination of search approaches to ensure complete coverage of the relevant literature across well-known scientific databases, including IEEE, ScienceDirect, Springer, Wiley, ACM, Taylor & Francis, and international conferences. We use and combine multiple keywords such as “D2D”, “D2D AND Synchronization”, “Device-to-Device AND Synchronization” to filter possibly related papers. We examined each of the selected papers titles, abstracts, and keywords closely to double-check whether an article is precisely related to our paper goals. Also, we try to select papers with the highest citations. Moreover, we use the *snowballing* technique to identify the additional papers in the references of the final selected papers. Fig. 1 shows the procedure of selecting the related literature. The rest of this paper is structured as follows. In Section 2, D2D communication, synchronization and different scenarios and techniques are reviewed. In Section 3 synchronization techniques in V2V and V2X are reviewed, which provides an overview of advances of synchronization techniques in these paradigms. In Section 4, new effective developments of synchronization techniques are reviewed. Finally, Section 6 concludes the paper.

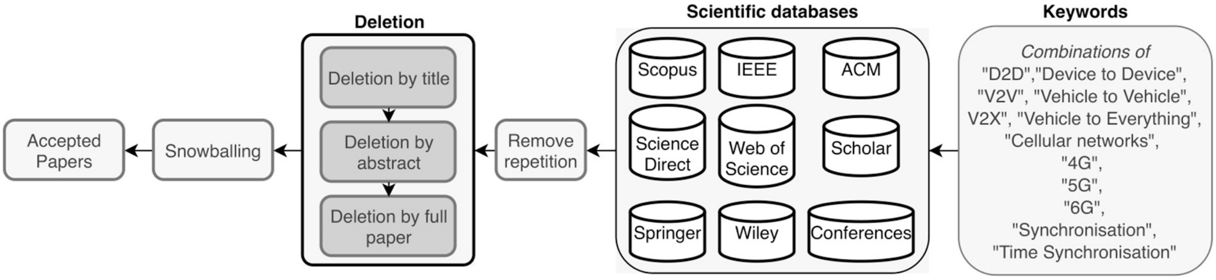

Fig. 1. Procedure of selecting the related literature.

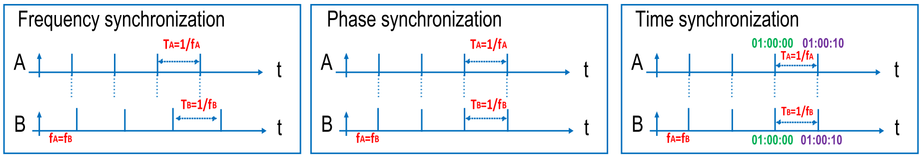

Fig. 2. Frequency, phase and time synchronizations.

2. Overview of D2D communication and synchronization

To understand the synchronization techniques, we need to review possible scenarios of D2D to comprehend the synchronization techniques and standards.

2.1. Fundamentals of D2D synchronization

From a historical perspective, synchronization challenges have received considerable attention in different scientific fields. As one of the main applications, synchronization in digital networks points to the following procedures:

Frequency synchronization: It means that devices A and B receive the leading edge of the signal at the same pace, but not at the identical moment . Frequency synchronization is a precision manner to synchronize the clock frequency of digital entities in a widely deployed system in almost every communication system. Some systems such as synchronous Ethernet only need frequency synchronization as the main synchronization technique.

Phase synchronization: It means that devices A and B receive the leading edge of the signal at the identical moment. One can refer to a wide diversity of the phase synchronization applications in computer networks, electronic, mechanic, electromechanics, etc. For instance, in multiprocessor clusters, phase synchronization has been widely used to control distributed systems of clock generators.

Time synchronization: It means devices A and B receive the leading edge of the signal at the identical moment and identical time. In the context of computer networks, there are two main types of time synchronization, called internal and external synchronization. In the former, the network devices are synchronized with each other, without an external source. The latter refers to the case in which the network devices use an external source such as the Global Positioning System (GPS) to synchronize the UEs. Fig. 2 shows different types of synchronization techniques.

In traditional cellular communications, UEs do not need to know whether they are communicating in synchronous or asynchronous serving cells since all UE to UE operations are with the assistance of the pairing eNBs. However, in case of direct communication among UEs, synchronization, and timing techniques need to be performed by communication participants. Nevertheless, in the synchronous transmission where the transmissions are only at the beginning of periodic time intervals, channel utilization can be increased roughly twofold.

From a technical point of view, there are two major timing synchronization approaches in D2D-enabled networks: centralized and distributed. In the centralized approach, a D2D-enabled UE takes the role of coordinator in a cluster of UEs (also called Cluster Head (CH)) in order to deliver reference timer within its transmission range to other D2D-enabled UEs as cluster members. Also, in the distributed approach, a D2D-enabled UE provides a timing reference for other D2D-enabled UEs within its transmission range. However after that, all D2D-enabled UEs that have acquired the recommended reference timer will become involved in initiating and keeping reference timer within their transmission ranges. The centralized approach suffers from several drawbacks compared to the distributed approach. One of the main disadvantages is the heavy dependency upon the CH for delivering the timing reference. If the CH is detached from the cluster, a re-selection procedure is needed for selecting a new synchronization

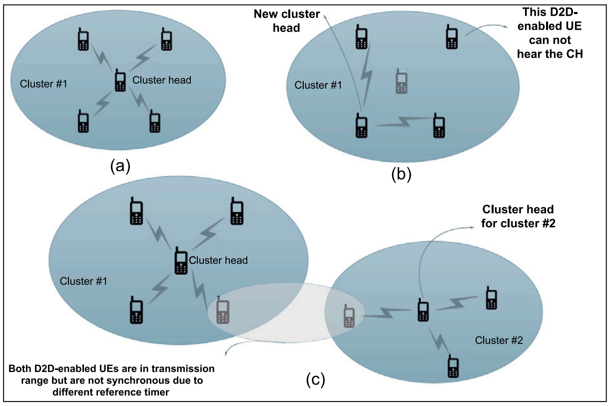

Fig. 3. Possible challenges in the centralized synchronization approach.

source, and all communication in the cluster may be suspended. Also, after selecting a new CH, it may be challenging to guarantee that the whole cluster can hear the new CH because of transmission range limitations. Therefore, there is a necessity to introduce a mechanism to relay or transmit the reference timer beyond the CH's transmission range, as shown in Fig. 3.b. The third drawback is that the inter-cluster communication becomes more difficult as all D2D-enabled UEs within a cluster may receive synchronization signal not only from its CH, but also from neighboring CHs as shown in Fig. 3. Hence, one should provide a mechanism for nearby independently founded clusters to get a single reference timer from itself and recognize nearby unwanted reference timer signals and remove them.

2.2. Scenarios and basic architecture of synchronization in cellular networks

D2D, also known as Proximity Service (ProSe), is introduced in Release 12 of the 3GPP, 4G standards to enable D2D in cellular networks. In ProSe, D2D communication is mainly restricted to two basic operations: direct communication (public safety applications) to communicate and proximity discovery (commercial applications) to discover close UEs. D2D synchronization is a compulsory procedure for both operations. Prior to starting the operations, the D2D-enabled UE transmitter sends a synchronization signal to the D2D UE receiver(s) in its communication range to align itself with the transmitter. In case of network coverage and D2D communication, three different network coverage conditions have been considered for UEs, as shown in Fig. 4 and explained here:

In-coverage scenario: In this case, all the UEs are covered by the eNB, possibly in two different modes IDLE or serving cell (CONNECTED). This scenario is the simplest case, as network equipment is available and UEs in a connection can deliver the duty of synchronization management to the equipment, e.g., eNB, even in case of direct communication establishment.

Partial-coverage Scenario: In this scenario, some UEs camp on a cell, while other UEs are out of the coverage of the cell. In this case, synchronizing communications has many challenges, e.g., expanding the network's coverage area and improving energy consumption.

Out-of-coverage Scenario: This scenario refers to the situation where the participating UEs in a connection cannot connect to an eNB. For an out-of-coverage scenario, the UE's resources are pre-configured through the mobile devices or in the Universal Subscriber Identity Module (USIM). This scenario is critical for applications in areas that are not under the coverage of cellular networks or network infrastructure outage causing by natural disasters as D2D is the primary method to connect UEs. In this case, UEs themselves are responsible for synchronizing communications.

These scenarios can be employed for all D2D communication cases in cellular networks. So, they should be considered in 4G and in the next-generation network infrastructures that should perform synchronization.

2.3. 3GPP ProSe reference network architecture

Some entities and interfaces have been introduced to enable 4G network infrastructure to use D2D. Fig. 5 shows the non-roaming basic architecture of the 3GPP ProSe. Besides the conventional radio interface between an eNB and a UE (also known as LTE-Uu), and interface between eNB and Customer Premises Equipment (CPE) (also known as LTE S1), the architecture introduces new interfaces and reference points as follows:

ProSe App Server: In the non-roaming architecture, the ProSe App server is responsible for implementing the capability of the proximity service. This entity can active a proximity service, e.g., discovery for a specific use case.

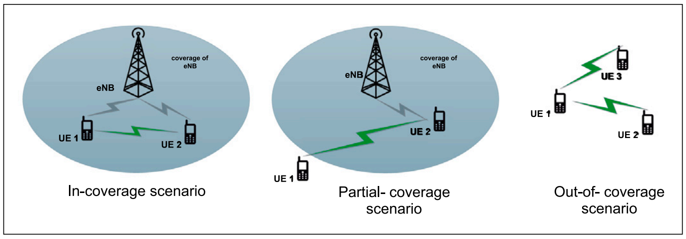

Fig. 4. Coverage scenarios in D2D communication introduced by 3GPP.

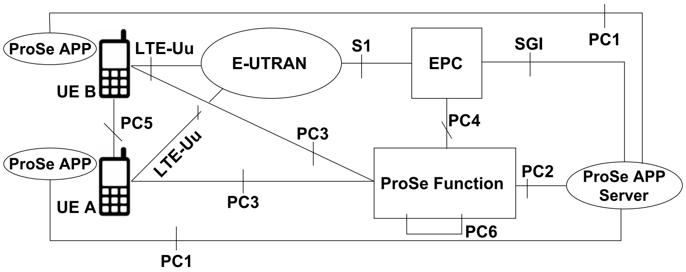

Fig. 5. Non-Roaming reference architecture.

ProSe App: By using this entity, a range of operations such as communication and discovery can be performed by UEs based on PC5 interface.

ProSe Function: The entity meets the requirements of ProSe communication and discovery, and also discovery at Evolved Packet Core (EPC) level.

PC1: It is a reference point between UEs ProSe Apps and ProSe App Server. It is also used to support requirements of application-level data exchange.

PC2: The interaction between the ProSe App Server and the ProSe function, provided by the 3GPP Evolved Packet System (EPS), is supported via PC2, e.g., data used by the ProSe App server to perform name translation.

PC3: A UE needs to identify the existence of other UEs in close proximity. PC3 is used as a reference point between the UE and the ProSe Function to authorize and configure proximity discovery (in both Public/non-Public Safety use cases) and communication (only in Public Safety use cases).

PC4: The interaction between EPC and ProSe functions has been defined through the PC4 reference point. It can be used to configure a one-to-many communication path between UEs or real-time authorization of ProSe services for mobility/management.

PC5: It is also known as Side-link at the physical layer. Two D2D-enabled UEs use it to control and interaction user plans for discovery, communication and broadcasting, i.e., relay and one-to-one communication.

PC6: This is the interface between many ProSe functions of different Public Land Mobile Networks (PLMNs). PC6 can be used for proximity discovery operations between UEs in different PLMNs.

PC7: It is the reference point between the ProSe functions in the Visited PLMN (VPLMN) and the Home PLMN (HPLMN). The PC7 reference point can be used for HPLMN control of service authorization of ProSe services.

PC8: It acts as the reference point between a roaming UE and the HPLMN. The ProSe Function in the HPLMN may be used for configuration of UEs.

SGi: The application data and application-level control information between the EPC and the ProSe App server exchange via this reference point.

2.4. D2D synchronization signals, channels, and entities

As mentioned, D2D synchronization is a precondition for new functionalities, i.e., direct communication and proximity discovery. To support these functions, the following D2D synchronization signals, channels, and entities are introduced:

- *Physical Sidelink Broadcast Channel (PSBCH):* This channel can carry information like frame number, bandwidth, and Time Division Duplexs (TDDs) Uplink/Downlink configuration.
- *Primary Sidelink Synchronization Signal (PSSS):* The signal is used for an initial synchronization to have one or few common synchronization signals to facilitate the initial timing and the frame/sub-frame boundary estimation. With this intention, PSSS signals are designed to simplify the detection of in- and out-of-coverage synchronization sources. The PSSS signals include the synchronization source type (i.e., eNB or independent UE) and hop count.
- *Secondary Sidelink Synchronization Signals (SSSS):* A combination of SSSS with PSSS is employed for fine-tuning of the reference timer and recognition of Synchronization Source Identification (SSID). The SSSS can optimize the performance of frequency offset estimation.
- *D2D Synchronization Signal (D2DSS):* A D2DSS is composed of the pair of PSSS/PSSS signals. The D2DSS is provided for receiving D2D communication capable UEs to derive time and frequency synchronization. The receiver uses the earlier obtained D2DSS for the detection of the corresponding communication/discovery signal.
- *Master Information Block Sidelink (MIB-SL):* The MIB-SL contains some fundamental and most frequently transmitted parameters that are necessary to get other information form the serving cell, for example, whether the transmitter is in coverage of a cell and TDD configuration. The MIB-SL is transmitted over the SL Broadcast Control Channel (SBCCH).
- *Physical Device-To-Device Synchronization Channel (PD2DSCH):* The PD2DSCH is used to exchange some information associated with the synchronization or resource allocation. This information may be advantageous to synchronization procedures or D2D signal transmission and receiving. It is worth mentioning that for the UEs with different network coverage levels and synchronization conditions (i.e., in-, out-, partial- coverage), the provided information would be different. The D2DSS may carry the information, including resource allocation information of the serving cell, current frame or sub-frame index for synchronization, identification information, current hop level, and system bandwidth.
- *SBCCH:* This channel is defined for carrying synchronization signaling information used for the out-of-coverage and partial-coverage scenario, or for synchronization procedure between two D2D-enabled UEs camped in different cells.
- *Synchronization Reference UE (SR-UE):* This is a timing reference different from the eNB. SR-UE does not gain its synchronization signal from synchronization references, which are UEs. In other words, an SR-UE transmits its local timer beyond network coverage or transmits eNB timer at the edge of the network coverage.

2.5. D2D synchronization procedure

D2D synchronization procedure aims to enable the receiver to derive a reference timer for frame/sub-frame level tracking and obtain an oscillator lock for demodulation of D2D control and traffic data. Resource pools define physical resources in time and frequency that carries D2D control and traffic data. These resource pools, are key to understanding how ProSe traffic can coexist with legacy LTE traffic, especially in the out-of-coverage scenario to decline the D2D-enabled UE energy consumption. The general D2D synchronization procedure is shown in Fig. 6.

1. After powering up a D2D-enabled UE, the D2D-enabled UE scans for the synchronization source (signal).
2. If no synchronization signal is detected, the D2D-enabled UE may become an Independent Synchronization Source (ISS) and transmit D2D synchronization signals using its own clock.
3. If a suitable synchronization signal from an eNB is found, the D2D-enabled UE synchronizes itself to the eNB. In this case, the D2D-enabled UE will relay D2D synchronization signals, configured by the eNB.
4. If the D2D-enabled UE detects the eNB but synchronization signals are not available, the UE adopts its timer towards the source with the highest priority. The priorities of synchronization sources are eNBs followed by UEs in coverage of the network.

There are four types of synchronization sources, including eNB (eNB-SS), CH, D2D-enabled UE (UE-SS) and Synchronization Relay (R-SS). A D2D-enabled UE can become an R-SS by relaying the Synchronization Signal (SS) from another synchronization source. These synchronization sources correlate with different synchronization coverage range and applications. For example, as for eNB-SS, synchronization signals can cover the LTE cell area or at the network level. Since this type of synchronization source can stably handle a large area, it is appropriate for public safety, business service, and personal communication. In CH's case, each D2D-enabled UE in CH's proximity can derive synchronization signals from the CH. The CH uses higher transmission power and has a fairly accurate internal timer and longer battery lifetime than a regular D2D-enabled UE. Moreover, the CH's synchronization signals cover a local area that nodes are mobile. Therefore, this type of SS is suitable for public safety and temporal personal communication. In UE-SS case, since the synchronization procedure is on a temporary basis and for a local range, it can be employed for accident alarm and temporal personal communication use cases. These synchronization sources are associated with different signal ranges and use cases. Therefore, D2D-enabled UE shall detect the type of synchronization source when it goes through the synchronization procedure.

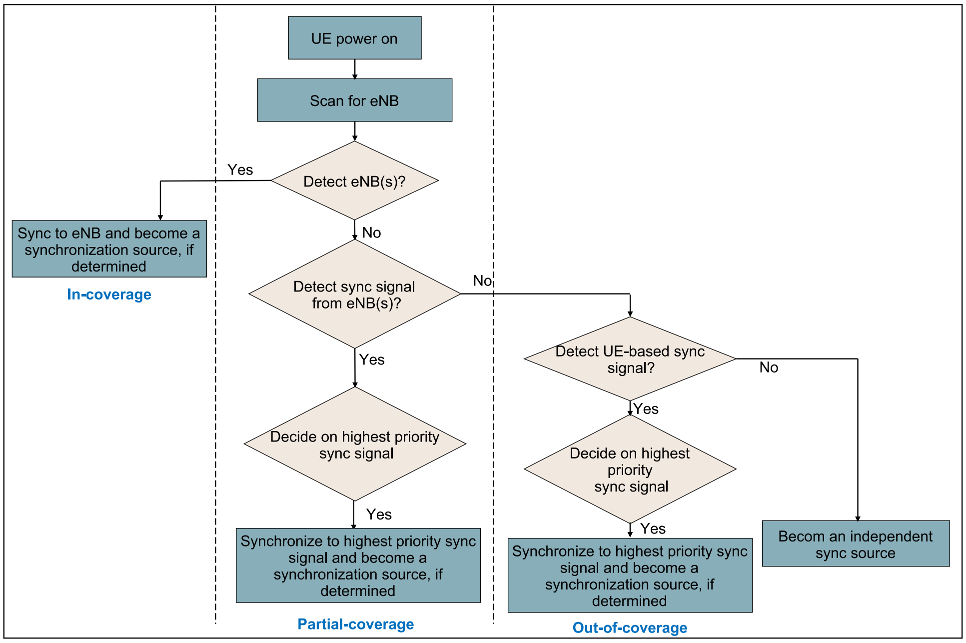

Fig. 6. Overall D2D synchronization procedure.

2.5.1. *In-coverage synchronization procedure*

As we noted earlier, eNB-SS has a higher priority than other synchronization sources. So in this scenario, all D2D-enabled UEs will derive their synchronization information from potentially multiple serving eNBs via PSSS/SSS. The selection of serving eNB involves regular mobility operation. A more complicated case is when a D2D-enabled UE is placed at the edge of the cell and identifies more than one eNB-SS in the overlapping area with neighboring cells (Fig. 7.a). In this case, a simple approach is that the D2D-enabled UE gives the top priority to an eNB with the strongest synchronization signal and synchronizes itself with it. However, if two D2D-enabled UEs camp in different asynchronous cells and try to communicate with each other, they must synchronize with the desired D2D-enabled UE in close proximity before communicating directly. As depicted in Fig. 7.a, UE2 and UE3 have been connected to eNB1 and eNB2, respectively. If eNB1 and eNB2 use two different reference timers, the transmitted discovery signal/direct communication information from UE2 will not be detected by UE3, and vice versa. In this situation, UE2 needs to transmit a synchronization signal to notify UE3, before it transmits the information. When UE3 tries to communicate with UE2, it shall follow this approach. The ability to maintain at least two different reference timers by D2D-enabled UEs (i.e., cellular and D2D communications reference timer) is the precondition for developing this approach. As an observation, the complexity, cost, and design of D2D communications will rise due to an asynchronous network.

2.5.2. *Partial-coverage synchronization procedure*

In the partial-coverage scenario, it is expected that the synchronization procedure adds some complexity, because alongside the existence of eNB-SS, a D2D-enabled UE may acts as a relay and forwards synchronization signal to the D2D-enabled UEs in the out of network coverage, based on its serving cell timing reference (See Fig. 7.b). Here, UE2 and UE3 are the first hop synchronization relays that forward the synchronization signal obtained from the serving eNB to UE4, which is out of the network coverage. UE6 acts as a CH, which is able to provide the synchronization signal for the D2D-enabled UEs in out of network coverage and in close proximity. One observation is that UE4 may detect synchronization signals from different sources, including R-SSs (UE2, UE3, and UE5) and the CH (UE6). Let us assume that UE2 propagates the strongest synchronization signal, and UE4 gets its timing reference from UE2 for D2D operations. But if UE4 decides to communicate with UE5 or UE6, there are two choices between maintaining another reference timer and switching between two different sets of reference timer to communicate with these UEs. When a D2D-enabled UE switches between different sets of reference timer to form a communication with other D2D-enabled UEs, after ending the communication, the D2D-enabled UE shall choose the synchronization source with the highest priority as a source, since it may be more stable and can cover a larger area.

As discussed, in the partial-coverage scenario, some D2D-enabled UEs are determined to relay synchronization signal. We believe that this approach is more beneficial than the condition that all D2D-enabled UEs relay synchronization signals. The main reasons behind such an approach include the fact that it reduces power consumption and interference as the number of relays is much lower. Besides, it avoids wasting resources, and there is no issue with detection.

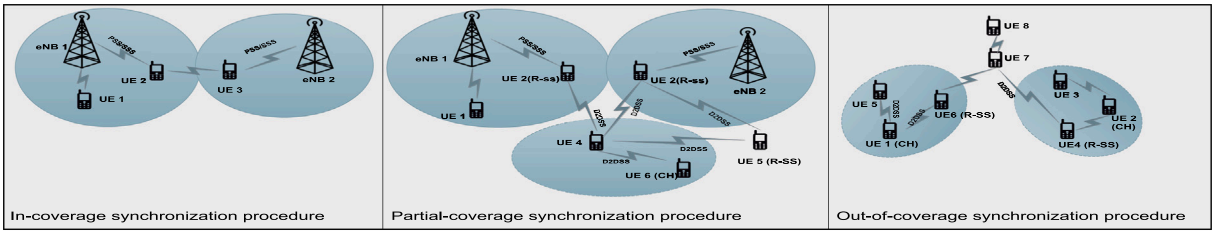

Fig. 7. Synchronization procedure in different scenarios.

2.5.3. Out-of-coverage synchronization procedure

In this case, CH is used as the synchronization source by D2D-enabled UEs. All D2D-enabled UEs that receive a synchronization signal from the same CH can establish a group of D2D communications. In this group, each group member is able to communicate with the CH or another member. In this scenario, if a D2D-enabled UE inside a group identifies D2DSS from the non-member UEs in close proximity, this D2D-enabled UE may play the role of R-SS and forwards D2DSS to the outside of the group. This approach is beneficial in the extension of the synchronization range and formation of a stable local area synchronization system. Moreover, it helps that more D2D-enabled UEs communicate with each other by keeping fewer reference timers.

To get detailed insights into the out-of-coverage synchronization, one may refer to Fig. 7.c, in which UE6 derives its reference timer from UE1 (CH) and also it can recognize the synchronization signal from UE7, thus it will forward the reference timer from UE1 (CH) to UE7. Since UE7 recognizes that the synchronization signal has been initiated from the source with higher priority (i.e., UE6), it will synchronize with UE6. In this figure, if UE7 at the same time recognizes two synchronization signals from different sources, which have the same priority, it shall choose the source with the stronger synchronization signal. One must note that, if UE7 decides to get information from UE8, it shall follow the same synchronization procedure.

2.6. The priority of source selection/re-selection for UE-based synchronization

During the synchronization procedure, a D2D-enabled UE may recognize more than one synchronization source. As mentioned above, eNBs and UEs in coverage of the network have priority over other sources. However, selection and re-selection of synchronization sources are discussed in detail in the following.

In the centralized synchronization approach, one of the critical issues is associated with the management of CHs. In order to investigate and address the issue, here we answer the following questions: Which D2D-enabled UE can be chosen as the CH to transmit the synchronization signal? And what rules should be used in the case of CH selection/re-selection procedures?

In the case of the in-coverage scenario and a public safety application, a D2D-enabled UE will acts as a CH, if no synchronization signal is recognized in the close proximity. In the case of partial-coverage scenario, the D2D-enabled UE within the network coverage can takes CH's lead. This scheme is beneficial to decline the interference between D2D and cellular communications because the in-coverage D2D-enabled UE has the opportunity for deriving accurate synchronization timer from eNB. Besides these possible rules, the criteria related to UE capabilities, such as maximum transmission power, battery lifetime, and stability, can be involved in selecting the CH. For instance, in a public safety use case, it is reasonable to select a firefighter vehicle as the CH, since it has more battery capacity, wider coverage and possibly a more stable connection.

In the partial-coverage scenario, when an in-coverage D2D-enabled UE chooses as the CH, a question needs to be answered that when the CH should start/stop the transmission of the synchronization signal. This question is fundamentally crucial because if there are no out-of-coverage D2D-enabled UEs within the proximity, the transmission of the synchronization signal by the CH is not meaningful. In other words, it just wastes energy and resources, particularly when the allocated resources for signaling takes from cellular resources. Thus, when the CH starts transmitting the synchronization signal and there is no out-of-coverage D2D-enabled UEs nearby, it should ideally stop the transmission.

2.7. Synchronization signal design

In LTE, Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS) are conventionally placed in the 6 central Physical Resource Blocks (PRBs) of a band. A UE may detect several PSS/SSS from different eNBs. Since the number of the detected eNBs is usually not high, various sequences are used for PSS/SSS in order to maintain the good orthogonal property. As a result, a low level of unintended interference between PSS/SSS from different eNBs is predicted in a synchronous network.

In D2D communications, D2DSS fills 4 Single Carrier Frequency Division Multiple Access (SC-FDMA) symbols in the middle 6 PRBs. Therefore, 7 (extended cyclic prefix) or 9 (normal cyclic prefix) SC-FDMA symbols stay in the subframe. Fig. 8 represents PSSS and SSSS mapping in case of normal Cyclic Prefix (CP). One must note that for optimization and simplification of the timing and frequency offset estimation, the position of PSSS and SSSS may be varied. Based on the figure, when D2DSS transmits for proximity discovery operation, there is no need to transmit the PD2DSCH. However, if the desired operation is direct communication, the PD2DSCH will be transmitted. In order to find a UE-SS in the out-of-coverage scenario, a D2D-enabled UE will search all SSIDs and measure the Sidelink Reference Signal Received Power (S-RSRP) for these IDs. The S-RSRP is measured by means of Demodulation

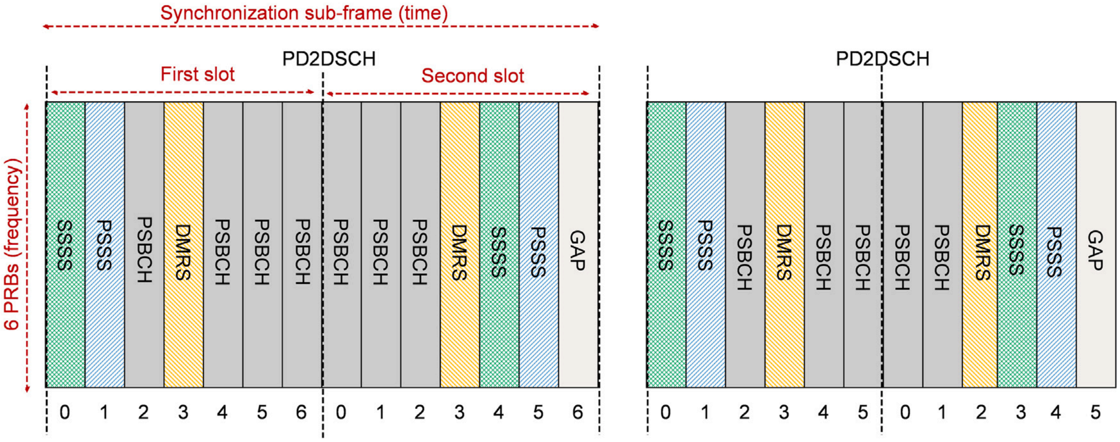

Fig. 8. Example D2DSS for extended and normal CP.

Reference Signals (DMRS). Hence, two SC-FDMA symbols are used for DMRS in the synchronization sub-frame. The seven remaining SC-FDMA symbols are used for actual PD2DSCH data. PD2DSCH will be demodulated using synchronization signals (PSSS and SSSS) transmitted in the same sub-frame.

PSSS/SSSS signals and PD2DSCH channel have the same periodicity and in RAN1 it was fixed to 40 ms for synchronization resource. In other words, one D2DSS sub-frame occurs every 40 ms. For both in-/out-of-coverage scenarios, every PD2DSCH channel transmission is placed in one D2DSS sub-frame. There are two approaches for mapping the PD2DSCH to the D2DSS sub-frames:

- **Approach 1:** The PD2DSCH can map to the all unoccupied SC-FDMA symbols in the entire sub-frame.
- **Approach 2:** the PD2DSCH can map to a set number of SC-FDMA symbols in the sub-frame.

Theoretically, approach 2 seems superior to approach 1 because all the available symbols can be used for transferring another channel. Nevertheless, let us consider 4 SC-FDMA symbols for the PD2DSCH code rate , therefore, only 1 or 3 unused SC-FDMA symbols will remain in approach 2 for extended and normal CP, respectively. It is clear that transmission through another channel with such a limited number of symbols is challenging. As a result, approach 1 is preferable, and all unoccupied SC-FDMA symbols in every D2DSS sub-frame will be used to transmit the PD2DSCH that its decode is based on DMRS. In DMRS-based demodulation, the fourth SC-FDMA symbol (normal CP case) or the third SC-FDMA symbol (extended CP case) is used for transmission of DMRS. In this situation, the number of available SC-FDMA symbols for the PD2DSCH is 7 (normal CP case) or 5 (extended CP case), as depicted in Fig. 8. It is worth noting that if the PD2DSCH does not carry resource pool information, DRMS will be employed for the PD2DSCH channel estimation.

3. Overview of V2V and V2X synchronization techniques

D2D-enabled cellular networks are mainly introduced in release 12 [9] of the 3GPP standards of 4G, called ProSe. Along with enabling D2D, 3GPP introduced an attractive feature in Release 14 [10] that covers applications and essential requirements of vehicular communications, known as V2V communication. V2V communication refers to the transmission of data (e.g., position, speed, and status) among vehicles to perform different tasks like preventing car accidents, monitoring the traffic, and improving traffic efficiency flows. 3GPP conducted that the V2V communications are indistinct from the D2D communications and it is possible to use LTE side-links for the V2V communications, known as PC5 interface V2V communications. However, there are major differences between V2V and D2D communication, e.g., the higher velocity of V2V entities that should be addressed.

Vehicular ad-hoc Networks (VANETs) are used as a key network infrastructure of Intelligent Transportation Systems (ITS) to provide services which improve road safety and entertainment for different paradigms like connected cars. Road services are provided for vehicles based on message propagation through available links among vehicles, vehicles and the infrastructure, and vehicles and things. These communications all need to be synchronized to transmit data, specifically in case of V2V and V2X as they resemble D2D communications.

In addition to 3GPP, IEEE also introduced a new V2X protocol and standardization that is nominated as the IEEE 802.11P standard. Consequently, this technology becomes one of the exciting approaches for V2X communications. This protocol was officially introduced in 2012, but there are still many open issues and use cases that can be solved with that. Zhao et al. studied the performance comparison of LTE-V2X and IEEE 802.11p in [11].

In Release 14 of 3GPP related to V2V, Global Navigation Satellite System (GNSS) is introduced as an extra synchronization source. eNB can configure D2D-enabled UEs within the network coverage to utilize eNB-based (Uu timing) or GNSS-synchronization (PC5 timing). The eNB can indicate D2D-enabled UEs within the network coverage to get a synchronization signal from GNSS if the UEs

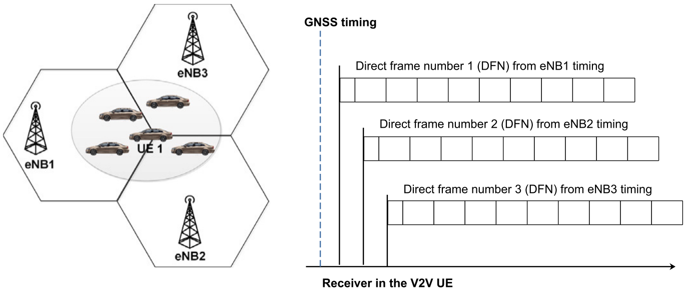

Fig. 9. Multiple reference timers in the V2V.

synchronized to it. Otherwise, the UEs will be synchronized to the eNB. Fig. 9 is a graphical view of three general scenarios which one may imagine in V2V communications, i.e., in-coverage, out-of-coverage, and partial-coverage.

The scenarios are the same in V2V as in D2D. PC5-based V2V communications can use a shared or dedicated frequency band. In the dedicated frequency case, timing can be different from the Uu frequency band and be separated. In the rest of the paper, we call the V2V and V2X UEs as Vehicular Equipments (VEs). If VEs derive the same reference timer that is reasonably accurate, having a global timer for all the VEs is understandable, despite different synchronization sources. When V2V and D2D communications use a shared frequency band, synchronization is more complex. For example, eNB may configure a VE to derive GNSS synchronization signal, although the VE uses a shared frequency band. In this case, GNSS timing can be different from Uu timing. Consequently, the performance of V2V communication will be affected. We can conclude that in the case of in-coverage, a VE has two choices between Uu timing and GNSS timing to derive PC5 timing. The former is preferable as it is the same as D2D, and there is no need for further standards. However, the PC5 timing for in-coverage VEs will be different from the out-of-coverage VEs. Furthermore, when the available eNBs are asynchronous and VEs are distributed among them, V2V communications will suffer from some negative effects like interference and multiple synchronization signals. In the latter case, all the VEs will benefit from the global timing. Nevertheless, this scheme leads to negative effects on the scheduling of cellular and V2V traffic by the eNB because of the difference between PC5 and Uu timing. Regarding the first choice, the major challenge is that some VEs shall keep multiple PC5 timers in an asynchronous network.

As illustrated in Fig. 9, V2V UE1 can get PC5 timing from several proximity cars that camped in different eNBs. Here, it is evident that UE1 has to maintain three different PC5 timings and switches among them. In this situation, UE1 may lose some synchronization signals. Equipping the V2V UE with multiple PC5 receivers is also an alternative approach, but it will raise the receiver's cost. The discussion shows that using a global timing for the in-coverage scenario is advantageous, especially in a shared frequency band.

In the out-of-coverage scenario, VEs may or may not have access to GNSS synchronization signals. The latter case will happen when a vehicle is in a basement or tunnel. For out-of-coverage V2V UEs, it is natural to follow the defined D2D synchronization protocol in Release 12/13 as a baseline. However, carrying out some improvements in the protocol is needed. Since GNSS is fitted as an additional synchronization source in V2V communications, the first improvement is associated with the priority of synchronization sources. More specifically, the priorities should be as follows:

- Priority 1: In-coverage VE with eNB-based timing/in-coverage VEs with GNSS-derived timing.
- Priority 2: GNSS synchronization signal.
- Priority 3: Out-of-Coverage VE directly derive timing from GNSS.
- Priority 4: Out-of-Coverage VE indirectly derive timing from GNSS.
- Priority 5: Out-of-Coverage VE synchronized to in-coverage VEs.

In order to explain the priorities, we assume an out-of-coverage VE called *A*, which can derive a synchronization signal from in-coverage VEs which are connected with the eNB. The eNB may configure its connected VEs to employ the eNB timing, which is different from GNSS timing. Here, if VE *A* employs GNSS timing, it is possible its transmission causes interference with cellular communication. Hence, in-coverage VE should have a higher priority than GNSS/ GNSS-derived timing. Now, consider a distant VEs *B* that cannot derive a synchronization signal from any eNBs or in-coverage VEs. For this VE, it is better to use a GNSS or GNSS-derived synchronization signal because in the majority of cases out-of-coverage VEs either are in coverage of GNSS or place in close proximity of other VEs with GNSS timing. Therefore, it makes sense why GNSS or GNSS-derived synchronization signals should have higher priority than out-of-coverage VEs synchronized to in-coverage VEs. If an out-of-coverage VE receives synchronization signals from different sources with the same priority, the strongest synchronization signal should be used.

VEs within the network coverage that places at the cell edge may have substantial timing offset with GNSS timing due to transmission delay and synchronization error. As depicted in Fig. 10, if VEs with partial coverage (UE3) derive directly GNSS timing or partial-coverage VEs (UE4) derive synchronization signal from out-of-coverage VEs (UE6) which synchronize directly with GNSS, VEs within partial-coverage (i.e., UE3/4) will experience serious interference with the VEs within the network coverage. Hence, to prevent the interference and preserve the cellular communications, the VEs with partial coverage should derive timing from the in-coverage VEs. In other words, the priority of VEs within the network coverage that is synchronized with eNB, should be higher than the out-of-coverage VEs, which derive directly timing from GNSS.

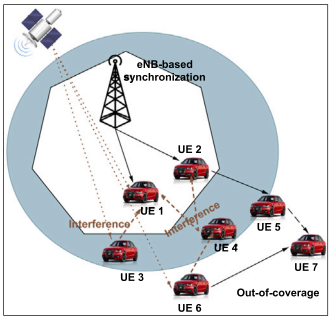

Fig. 10. Example of interference in partial-coverage and in-coverage scenario.

3.1. Synchronization signals and channel enhancement of PC5-based V2V

In the shared frequency case, it requires to distinguish between V2V and D2D traffic. One way is to use PSBCH to distinguish them, e.g., using the number of DMRS symbols. Nevertheless, this task is challenging since for D2D discovery; the synchronization frame will be transmitted without PSBCH. Therefore, PSBCH is not applicable to distinguish D2D and V2V synchronization operations. Another alternative is to use D2DSS because of low complexity and delay. More specifically, when a Signal-to-Noise Ratio (SNR) is low, it requires recognizing multiple D2DSS before the reorganization of PSBCH. It is clear that if PSBCH is used for distinguishing V2V from D2D, it causes further delay because it will occur after D2DSS. Another aspect that should be investigated for V2V communications is the periodicity of PSBCH. In D2D communications, the PSBCH periodicity is 40 ms. With this periodicity, the overhead is nearly high since other D2D channels cannot use the sub-frame. It is beneficial for V2V communications to decrease the overhead as a VE may have to get several PSBCHs. Nevertheless, by extension of the period for PSBCH, the detection time will also increase. Furthermore, since the minimum V2V message periodicity sets to 100 ms, the PSBCH detection and stability time should be coordinated. Based on the 100 ms V2V message periodicity and 40 ms D2D synchronization periodicity, 80 ms and 200 ms PSBCH periodicity are proposed in [12]. The link-level simulation results indicated that in the latter case the synchronization overhead is acceptable (about 0.5%), and performance in the PSBCH detection is satisfactory. Hence, the PSBCH periodicity is fixed to 200 ms.

As mentioned before, information such as side-link system bandwidth and TDD Up-Link (UL)-Down-Link (DL) configuration exist in the D2D PSBCH. Because the shared frequency band is introduced for PC5-based V2V communications, the information in the D2D PSBCH is necessary to keep for V2V PSBCH. Furthermore, additional information is needed for V2V PSBCH, e.g., GNSS (inGNSS) indicator, if the timing derived from GNSS, in TX. InTx indicator to indicate PC5-based V2V is supported and aligned to indicate if PC5-based V2V uses the shared frequency band. InTx and aligned indicators occupy reserved bits in V2V PSBCH and inGNSS indicator uses reserved D2DSS ID(s).

Given that GNSS is supported as a new source of timing, the further enhancements need for PSSS and SSSS. Hence, new PSSS signals for transmission of GNSS timing are introduced for V2V synchronization. Moreover, new 168 sequences are defined for SSSS. The high velocity of VEs necessitates the Layer1 enhancements in order to improve demodulation performance and deal with time-changeable channels in V2V environments. As mentioned earlier, Doppler fading represents a major challenge to the V2V demodulation because of the considerable variation of the channel in the sub-frame. It is clear that the legacy DMRS in D2D communications has no reliable structure to guarantee efficient channel estimation for V2V.

3.2. 5G V2X synchronization

In 5G, NR stands for a New Radio interface and radio access technology for upcoming generation of cellular networks, which is standardized by 3GPP in the 2018 Release 15 and continued in Release 16 in 2020 with more specifications details for implementation. Based on the NR system, NR V2X side-link communication has been discussed to support V2X applications [13]. There are some differences between NR and LTE; for example, the NR system supports multiple numerologies, different frame structures, and beam transmission. Hence, we cannot fully reuse the LTE side-link synchronization procedure for NR V2X. Nevertheless, it would seems that the dissimilarities between side-link synchronization in LTE and NR V2X are not significant. For example, when the transmitter and the receiver camp in two different serving cells or one place in-coverage area while the other places in out of area or even both the transmitter and the receiver are out of the area, the synchronization can be performed by using Sidelink Synchronization Signal (SLSS)/PSBCH transmission. Broadly speaking, some mechanisms in LTE side-link synchronization can be used/reused as a point of reference in NR V2X synchronization in order to avoid unnecessary efforts for standardization.

3.3. 5G V2X synchronization signals/channels

As we mentioned, SLSS and PSBCH are used for side-link synchronization. Synchronization requirements for NR V2X in the 5G network do not change considerably. More specifically, like LTE network, in some cases, e.g., in the out-of-coverage scenario, there

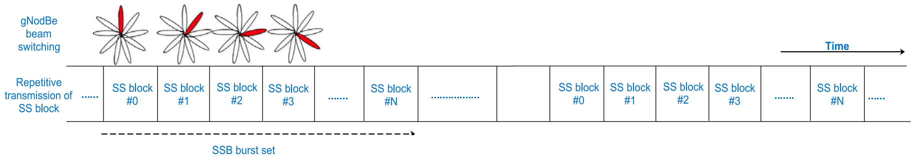

Fig. 11. Repetitive SS transmission.

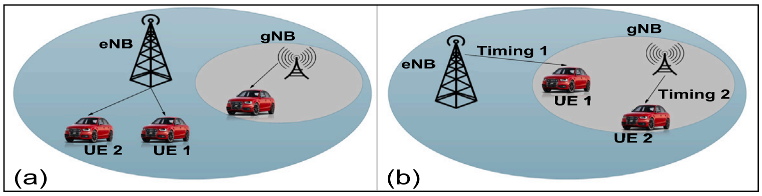

Fig. 12. Example of 5G V2X synchronization.

is still a need to transmit SLSS/PSBCH to achieve side-link synchronization. NR V2X communication employs NR V2X SLSS/PSBCH, (also known as NR-based SLSS/PSBCH) as a resource format, which containing several symbols and PRBs in time and frequency domain, respectively. Like LTE side-link synchronization, NR-based SLSS can be sent through the SLSS/PSBCH resources in a configured/preconfigured fixed period of time. However, attention should be paid here; the quantity and pattern of symbols used by PSSS/SSSS or PSBCH need further investigations.

In NR, a beam sweeping technique is used for the transmission of the synchronization signal. This technique may be considered for the transmission of SLSS/PSBCH. Meanwhile, to save the resources during transmission of NR-based SLSS/PSBCH for frequencies below 6 GHz, beam sweeping technique may be discretionary. Moreover, in the NR system, a new technique for transmission of SS blocks is developed. Based on this technique, in order to handle multi-beam operation, SS blocks should be transmitted in a repetitive manner. Each block contains PSSS, SSSS, and PSBCH, and may act as a next generation eNB (gNB)'s physical beam, as depicted in Fig. 11.

In LTE side-link synchronization, PSBCH is defined to exchange essential information associated with the synchronization, such as bandwidth and coverage indicator. PSBCH in NR V2X can exchange semi-persistent configuration, but not the dynamic indication. Note that the slot format indication in NR consists of semi-persistent configuration and dynamic indication. In general, the new features of the 5G network should be considered during the design of the contents of PSBCH. For example, NR V2X UEs can support both LTE V2V and NR V2X. Hence, co-transmission of NR- and LTE-based SLSS/PSBCH may occur, and coexistence mechanisms should be adopted.

3.4. Synchronization procedure in 5G V2X

Before going to the details of the synchronization procedure, one must note that gNB should also be considered as a synchronization source since an NR V2X UE is capable of supporting NR V2X and LTE V2V. Fig. 12 represents an example of synchronization reference selection, in which it presumes that UE1 and UE2 are NR V2X UEs and are connected to eNB, as they are not under the coverage area of gNB. It is clear from the figure that UE1/UE2 cannot recognize NR-based SLSS/PSBCH from the gNB; however, they can recognize the synchronization signal from the eNB. Consequently, UE1 and UE2 synchronize with eNB and neglect to follow the recognition or re-selection of NR-based SLSS/PSBCH. In other cases, it is possible for NR, UE to be in coverage of NR and LTE network at the same time means that the coexistence of NR V2X and LTE V2V communication is possible. In Fig. 12.B, UE1 is an LTE UE and UE2 is NR UE. UE2 is able to communicate with other NR UEs and UE1 by NR V2X side-link and LTE V2V side-link, respectively. Further investigation for synchronization in this scenario is needed because, as an example, UE2 can synchronize with gNB and eNB for LTE V2V communication.

4. Literature review

Based on our review, there has been a small number of works on the synchronization in direct communications despite the importance of synchronization techniques. In this section, we review literature that improves synchronization techniques in D2D-enabled as well as V2X-enabled cellular networks. Regarding the fact that time synchronization is computationally a demanding task, the authors in [14] focus on designing primary synchronization signal for D2D communication in order to reduce time complexity. To be precise, a significant amount of synchronization complexity in the receiver side is associated with the gate count and chip area. Hence, to reduce the complexity of PSS, a centrally symmetric design for PSS has been proposed to lessen the number of complex-valued multiplications in modulation sequence. The simulation results show 50% improvement in case of synchronization complexity. Abedini et al. have targeted the challenge of distributed time and frequency synchronization for D2D systems in [15].

Indeed, they aim at introducing a distributed synchronization algorithm for D2D communication in LTE with a reasonable level of errors (a few microseconds). Unlike prior arts, this paper considers different impairments factors, such as propagation delay, and the occurred errors when measuring the time and frequency offsets. Two scenarios, including the partial-coverage (anchored case) and the out-of-coverage scenario (non-anchored case), are considered for simulations.

D2D synchronization with respect to the partial-coverage and out-of-coverage scenarios has been investigated in [16] as a challenge of synchronization since there are multiple synchronization sources. More specifically, the authors list the fundamental requirements for both scenarios as well as some significant challenges represented in D2D communication. These requirements are as follows:

1. How one can use local information in the out-of-coverage synchronization case to implement distributed operation for spreading a global clock?
2. How one can spread the reference timer associated with UEs in network coverage among the UEs with the partial-coverage?
3. For a synchronized group of UEs in the out-of-coverage scenario, it is difficult to guarantee that a new arrived UE will not bring critical issues to the group.
4. In partial-coverage scenario, for the UEs which are not connected to a base station, it is challenging to decide on the appropriate type of synchronization approaches.

Accordingly, an approach with a low-complexity algorithm, called ARES, is introduced to meet the challenges. The authors in [17] focus on the problem of distributed synchronization for D2D communication. In the proposed solution, devices only consider Reference Signal Received Power (RSRP) related to D2D synchronization signals as a reference timer for synchronization. In contrast to the conventional methods, in this method, devices choose a reference timer with minor errors. System-level simulations prove this fact that the proposed synchronization method benefits from smaller timing error.

In [18] the issues related to synchronization procedure in the out-of-coverage scenario have been explored. Based on this fact that synchronization in out-of-coverage communications is conducted in a distributed way, this work focuses on issues arising from the simultaneous synchronization execution in this scenario. Detection and convergence issues are referred to two main problems caused by half-duplex constraint and periodic scheduling. They prove that the periodic performing of synchronization and very small time interval, lead to difficulties in the synchronization convergence. Hence, they introduce an algorithm to prevent or meet the issues in a reasonable amount of time V. The UEs go through the process of synchronization reference selection after a random back-off.

The design of a new preamble for D2D synchronization is investigated in [19]. Since in D2D communication, PSS is considered as preambles for D2D synchronization, an effective structure for the preambles is designed to meet tight requirements of time and frequency synchronization in LTE-A D2D communication. In the new design, signals transmit only at odd sub-carriers in order to decline the impacts of inter-carrier interference; so, the required time for time offset estimation reduce, without negative effects on frequency offset estimation.

In [20], a synchronization algorithm, called distributed phase-locked loops (DPLL), has been introduced for decentralized environments. The authors claim that DPLL is a 5G-based algorithm and they consider multiple D2D parameters in their analysis, including multi-path propagation, propagation delays, and the use of SC-FDMA. In addition, to evaluate the performance of the algorithm, new performance indicators have been developed. The implementation constraints associated with PSS have been targeted in [21] and also a detection scheme for PSS has been adopted by the authors. They explain this fact that compared to UEs'power, PSS transmits at lower power. Thus, synchronization signal detection is challenging for D2D-enabled UEs. Regarding this fact, they adopt an effective detection scheme for PSSS. The proposed scheme uses the summing of correlations at peak locations to improve its performance.

Motivated by the importance of synchronization in vehicular communications, Yoon et al. [13] introduce a novel PSSS for V2V. Indeed, the authors express that the basic version of the PSSS signal has a problem with Carrier Frequency Offset (CFO) estimation and side-link ID set detection. Hence, they proposed a modified PSSS to tackle the problem. In the standard LTE D2D synchronization channel, CP symbols add to the PSSS, with the length of N. This design can reduce performance in the presence of large CFO. Hence, the study proposes a modified PSSS, with $2N$ length for CP to improve the performance in the case of a large CFO. The performance evaluation of the modified PSSS in comparison with LTE PSSS shows a small better performance.

In large V2V and V2I networks to maintain lower delay and on the other hand, improve packet rate, it is essential to have a distributed time synchronization approach. Regarding this need, in [2], a distributed time synchronization approach has been proposed to assign time slots in a distributed way. In this mechanism, at the lower layer, each CH handles the process of the time slot distribution among the members. Three different scenarios, called SC1, SC2 and SC3, are implemented for evaluation end to end delay and average throughput in the proposed approach. The simulation results indicate the distributed approach reduces the end to end delay and increases the throughput.

The synchronization requirements in the coexistence of in-band D2D/V2X and cellular transmissions have been studied in [22]. This work offers an interference-aware synchronization mechanism for the coexistence case, in which synchronization among multiple cellular and direct connections is necessary to avoid interference. The proposed mechanism has been claimed to be robust for the coexistence of numerous D2D/V2X transmissions, despite sending at the same frequency band with cellular transmission.

In [23], the author proposes a synchronization protocol to use by mobile devices in public safety applications like natural disasters that the network infrastructure is not available. Their method is able to adapt the dynamic D2D-enabled devices with channel conditions and dynamic network protocol. Their method is based on the signal-to-interference-plus-noise ratio (SINR) to encounter with physical layer reception effect. The proposed method can forward time synchronization signals to enhance the under the covered area. They show that the method can increases the rate of synchronized UEs up to 18% compare to legacy synchronization techniques. However, in this study, the synchronization source in LTE V2X is considered to be based on Global Navigation Satellite System (GNSS). Whenever PC5 and LTE-Uu are operated in the same band and if there is a large difference between PC5 and LTE-Uu timing offset, then UE synchronizes with GNSS directly. It should be mentioned the transmission of UE via PC5 interface cause interference to LTE-Uu uplink transmissions. However, based on this setup, eNB should instruct vehicle UE to specify which one has a right for synchronization; GNSS or eNB. If both GNSS-based and eNB are based on the synchronization mechanism hired, then the global synchronization is achievable to reduce the number of synchronized clusters and guarantee the synchronization accuracy. Enhancements of radio layer design for LTE V2X in 3GPP have been proposed based on the following key aspects; the design of physical layer structure, resource allocation, and synchronization [24].

In [25], the improvement of synchronization procedure in VSimRTI [26] simulator has been investigated. VSimRTI is a simulator for the assessment of new V2X solutions and provides different synchronization mechanisms. Nevertheless, the developers announced that conservative/look-ahead synchronization as one of the most important principles is supported poorly in this simulator. Thus, optimistic synchronization is introduced as a remedy in order to enhance the simulations of V2X communications. Optimistic synchronization provides support for running parallel simulations. In this paper, the Time Warp algorithm has been used for the implementation of optimistic synchronization. V2X simulation results show the applicability of the proposed mechanism.

The authors in [27] propose a novel framework for sequence generation. In the proposed framework, the transmitting user exploits a type of synchronization source, independently from the user obtains this reference signal directly or via another user. In other words, this framework encapsulates all additional information. The rationale behind is that prioritization of information and accordingly assign a different weight of synchronization signals based on the source type, which causes a faster and more reliable synchronization method.

In [28], the authors first highlight the importance of time synchronization for V2X communications, especially for time-division multiple access (TDMA) protocol and safety use cases. Besides, they point to this fact that GPS-based synchronization techniques are prone to the outage in some conditions, e.g., when vehicles are inside tunnels. The authors provide a novel time synchronization mechanism to deal with this issue, namely Self-time Synchronization Protocol for V2X (SSPV), in which the history of previous time offsets has been used to fix the clock drift rising from the GPS signal loss. The simulation results reveal that the proposed mechanism leads to less synchronization error than the time no correction mechanism is used.The work has been conducted in [29], examines the issue of content synchronization in D2D communication. Towards this end, the City Section mobility model as a realistic model for modeling mobility in the city area has been used. Then, two content synchronization techniques, so-called direct contact synchronization and relay-assisted synchronization have been proposed. In the proposed techniques, a relay-assisted synchronization approach has been adopted to improve delay. However, this approach increases the cost to some extent compared to the direct contact synchronization approach. Table 1 compares the literature on synchronization techniques.

5. Motivations and future directions

According to Section 4, we review the future directions of synchronization techniques in D2D- and V2V-enabled cellular networks:

- **Shortage of research in synchronization techniques of 5G:** As shown in Table 1, most of the available literature focus on LTE and LTE-A as the fully implemented generation of cellular networks. In contrast, there are unexpectedly few works on 5G and no works on 6G. As an emerging generation, 5G should be D2D-enabled to support mMTC and different applications like IoT, mMTC and Vehicular networks.
- **Inadaptability of existing solutions with characteristics of 5G and beyond applications:** In 5G applications, several cases are time-sensitive like Internet of Vehicles (IoV) or healthcare, but available synchronization techniques of D2D suffer from time complexity as some of them are based on central points. Although, time complexity is considered as an important challenge in LTE and LTE-A, the challenge would be more critical in 5G and requires more efforts. In addition, having simultaneous and different applications in a common 5G network infrastructure is a possible challenge that makes the network highly heterogeneous in case of requirements. Thus, there is a strong need to improve and adapt the available techniques with different applications and requirements.
- **Different Infrastructures of 5G and beyond:** 5G exploits small cell technology to improve coverage that shows supporting uncovered areas is a big challenge. In case of D2D synchronization, new techniques that can expand the covered areas should be particularly considered to develop to use in 5G. Also, 5G is considered as a type of UDN with multiple Base Stations (BSs). In this case, the priority of SSs would be a challenge as each node would receive several SSs, not only from BSs, but also from different CHs and neighbors camped out of its cell.
- **Difference in the essences of D2D and V2V:** As a particular application, vehicular networks are considered by standardization corporations as the case that can use available D2D-enabled synchronization techniques. But in real world, emerging challenges of the vehicular networks show that the essence of such networks is different from regular D2D-enabled cellular networks in case of time synchronization. Vehicular networks are highly dynamic compared with typical cellular networks. Also, they deal with safety that makes them more complex cases than typical D2D-enabled cellular networks. In this case, delay and reliability are critical metrics to evaluate the related techniques. The synchronization techniques should be highly reliable and time-sensitive to avoid unexpected issues for providing safety in V2V communication. In addition, uncovered areas can be impressively challenging for such networks to provide reliability, so developing the synchronization techniques that can expand the covered area should be considered as a mandatory solution. The high velocity of nodes can also be considered a

Table 1
Comparing literature of synchronization techniques.

Paper	Year	Publisher	Gen.	App.	Type of coverage			Synch. method		Objectives of the study
					In	Partial	Out	Cent.	Dist.	
Kim et al. [19]	2014	IEEE CONF.	LTE-A	D2D	*		*	N/A	N/A	Reducing the time for time offset estimation
Abedini et al. [15]	2015	IEEE TWC	LTE	D2D		*	*		*	Minimizing error of synchronization in D2D LTE
Berggren et al. [14]	2015	IEEE Commun. Lett.	LTE-A	D2D			*	*		Reduce time complexity of synchronization
Bhamri et al. [21]	2015	IEEE CONF.	LTE-A	D2D	*		*	N/A	N/A	Propose an effective detection scheme for PSSS to improve synchronization
Nasrallah et al. [2]	2016	IEEE CONF.	LTE	V2V			*	*	*	Increase End-to-End delay and throughput of synchronization technique
Sun et al. [16]	2016	IEEE TCOM	LTE	D2D		*	*		*	Reducing complexity and error of synchronization
Manolakis et al. [22]	2016	IEEE CONF.	5G	D2D V2X		*	*		*	Robustness for coexistence of numerous D2D/V2X transmissions
Cao et al. [17]	2017	IEEE CONF.	LTE	D2D			*		*	Reduce Timing Error
Manolakis et al. [27]	2017	IEEE CONF.	LTE	D2D		*	*		*	Achieve faster and more reliable synchronization method
Yoon et al. [13]	2017	IEEE CONF.	LTE	V2V			*	N/A	N/A	Propose a modified PSSS to solve the problems with CFO estimation and side-link ID set detection
Tetreault et al. [20]	2017	IEEE CONF.	5G	D2D			*		*	New synchronization technique based on 5G
Li et al. [29]	2017	Computer Networks	LTE	D2D		*	*		*	Investigate content synchronization issue for D2D communication
karatalay et al. [30]	2018	IEEE CONF.	LTE-A	D2D			*		*	Improve synchronization performance
Zhao et al. [11]	2018	IEEE CONF.	LTE	V2X	*		*	*		Comparison of LTE-V2X and IEEE802.11p
Wei et al. [23]	2019	IEEE Access	LTE	D2D		*	*		*	Enhance covered area and support mobility
Elsharief et al. [28]	2020	IEEE ICEIC	5G	V2X		*	*		*	To overcome GPS outages in the synchronization procedure in V2X communication

challenge as it causes high overhead to keep the network updated and connected. So the proposed techniques should reduce the overhead to optimize resource consumption.

- **Lack of research and definitions in 6G:** At the moment, it is hard to define a road-map for synchronization techniques in 6G but, as mentioned in different papers related to the vision of 6G, e.g., [4], the coverage area of the network is still a great challenge. In addition, D2D communication is considered as a critical solution to establish 6G networks specifically in the use-case of vehicular communications [3]. However, 6G is still being developed as an important solution to enable D2D. In 6G, UEs are grouped to clusters to communicate with the network infrastructure [3]. Currently, distributed synchronization techniques have more advantages than centralized techniques, but based on the vision of D2D-enabled 6G, establishing clusters has an important role. In this case, proposing reliable-centralized synchronization techniques would be considered a challenge.

It seems that the attention on D2D synchronization techniques in 5G and beyond is not enough regarding the special cases and applications; So, we strongly believe the synchronization techniques should be developed particularly to be used in different 5G and beyond use-cases and requirements.

6. Conclusion

D2D technology enables UEs of cellular networks to connect other UEs in close physical proximity directly. Synchronization has a specific role in communication establishment in D2D-enabled cellular networks, due to the lack of a central point in a D2D communication. Various scenarios and challenges can be considered in D2D; consequently, synchronization techniques need to be prepared to face these challenges. Vulnerable techniques can cause a lot of negative impacts on different scenarios, which can jeopardize sensitive and high-priority communications. In this paper, we reviewed the synchronization procedures used by D2D-enabled UEs in three main scenarios, i.e., in-coverage, out-of-coverage, and partial-coverage scenarios. We showed the physical-layer aspects of D2D synchronization by introducing the related signals, channels, and entities. Furthermore, we studied the synchronization procedure in the newly introduced technologies, such as 5G, V2V, and V2X. Here, we also looked at the primary sources of synchronization, and these sources' priority in the different scenarios. Moreover, relevant literature related to the synchronization in different technologies, e.g., D2D, V2V, V2X cellular networks, was reviewed.

In summary, we comprehensively reviewed the technical aspects of synchronization techniques in various D2D-enabled networks, but we also surveyed the most important literature in this field. Our review shows that synchronization techniques in 5G and beyond suffer from the lack of considerable efforts to improve the standards introduced by 3GPP and IEEE. Although there is reasonable work to improve LTE's synchronization techniques, 5G and 6G need more efforts to improve the performance of existing synchronization techniques to support various applications.

CRediT authorship contribution statement

Mahmoud Abbasi: Conceptualization, Investigation, Writing - original draft, Writing - review & editing, Resources. **Amin Shahraki:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Data curation, Resources, Supervision, Project administration. **Hamid R. Barzegar:** Writing - review & editing, Visualization, Resources, Validation. **Claus Pahl:** Writing - review & editing, Validation.

Declaration of competing interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.compeleceng.2020.106955.

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