

Towards a flexible harmonised 5G air interface with multi-service, multi-connectivity support

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Abstract—Current 4G air interfaces (AIs), by which we mean existing cellular standards and their evolution, including inter-networking with other technologies such as WLAN, lack the flexibility required for support of multiple and diverse services envisaged for 5G, such as Massive Machine-Type Communications – mMTC, Ultra-reliable Machine-Type Communications – uMTC, and Extreme Mobile Broadband – xMBB, with their diverging and sometimes conflicting requirements. Evolutions of 4G AIs may meet some of the KPIs of individual 5G services, but not the key 5G requirement to natively integrate multi-service support. The evolutionary alternative would hence result in the deployment of multiple 4G AI evolutions, leading to a very heterogeneous system – a mix of different RATs (Radio Access Technologies).

With ambitious 5G goals for support of services with different (and often diverging) requirements, a highly flexible 5G air interface design will be required to answer this demand. One way to solve these issues is to harmonize the air interface variants with the goal to find an optimal compromise between potentially highly specialized solutions for specific services, and the broader goal to only have one air interface supporting multiple services.

This paper will describe the approach adopted by EU H2020 / 5G-PPP project “METIS-II” for a harmonized 5G AI and its impact on protocol stack level. In particular, we will:

- Show how AIs in currently deployed networks do not meet many of the 5G performance requirements, such as multi-connectivity, support for a wide range of frequencies, and multi-service support;
- Elaborate the concept of harmonisation of different AIs towards a common user plane design and capture our key design principles;
- Present the most promising set of AI variants with respect to identified KPIs and identify potential AI variants to be integrated in the 5G system; and
- Perform an initial analysis of harmonisation possibilities.

Keywords—air interface design, multi-connectivity, multi-service support, cellular protocol stack, 5G waveforms, user plane design

I. INTRODUCTION AND BACKGROUND

Beyond 2020, 5G shall support multiple heterogeneous services; among these and of special importance are extreme Mobile Broadband (xMBB), ultra-reliable Machine Type Communication (uMTC), and massive Machine Type Communication (mMTC) with their evolved requirements and more ambitious Key Performance Indicators (KPIs) than 4G is able to meet today [1], [2]. The KPIs to be used for

benchmarking novel solutions for the 5G system have been identified in [2].

While LTE and LTE-A are well suited for MBB, since this is the service they have been originally developed for, and their further evolution may go some way towards meeting the more demanding requirements of xMBB, they are currently limited in their support for the diverse requirements of uMTC and mMTC. For the above referenced KPIs, insufficient support by LTE and LTE-A can be noted for the following reasons:

- LTE is not well suited for MTC traffic comprising short data packets and transmitted in quick bursts. It is noted, though, that 3GPP has initiated activities (LTE-M) to improve 4G with respect to the support of MTC traffic efficiently, see [3].
- Achieving high spectral efficiency becomes a challenge in scenarios where different services with diverse requirements share the spectrum, which current LTE is not capable of meeting.
- For new applications requiring lower latencies (in many cases 1ms or lower) like industrial control and traffic safety and efficiency (Vehicular-to-Everything /V2X use cases), the static LTE structures designed for MBB are not well suited.
- LTE operates on the principle that consecutive retransmissions based on HARQ process can compensate for information losses and finally achieve the desired reliability by extending the transmissions over time. For 5G systems, services are envisaged that require an ultra-high reliability within a comparatively short time frame.
- To enable the availability and retainability required for ultra-reliable 5G services like those from the V2X arena, the LTE requirement to always be connected and served by a Base Station (BS) need to be relaxed, facilitating the use of alternative connection types such as Device to Device (D2D), for example. It is nonetheless noted that 3GPP has initiated activities to improve 4G with respect to the support of D2D [4].
- In particular for machine type devices generating only sporadically small amounts of traffic, the energy efficiency based on LTE is comparatively poor. This is due to the fact that the overall time a device needs to be in active mode will be large compared to the

comparatively small amount of time it takes to transmit the user data.

- The LTE Air Interface (AI) was designed having mobile phones or even more complex devices in mind, where the cost of the transceiver was not considered the most relevant KPI. In contrast to this, 5G should also support sensors or other low cost devices. Note that 3GPP started a work item to reduce complexity in MTC devices e.g. by not using control channels (e.g. PCFICH, PDCCH) for MTC devices in LTE, see [3].

With ambitious goals set for 5G, as outlined at the beginning of this section, of supporting services with different (and often diverging) requirements, a highly flexible 5G AI design will be required to answer this demand. We have just shown how the LTE interface (with its well-established resource grid and frame structure suited for a limited set of frequency bands and geared mainly towards MBB support) does not meet many of the 5G performance requirements, including multi-service support. It additionally does not support the wide range of frequencies where 5G is expected to operate. Further evolutions of 4G AIs (by which we mean existing cellular standards and their evolution, including inter-networking with other technologies such as WLAN) might meet the KPIs of individual 5G services, but not the key 5G requirement to natively integrate multi-service support. The “evolutionary” alternative would hence result in the deployment of multiple 4G AI evolutions, potentially leading to a very heterogeneous system – a mix of different Radio Access Technologies (RATs).¹

One way to solve this issue is to harmonize the AI Variants (AIVs) with the goal to find an optimal compromise between potentially highly specialized optimization for specific services, and the broader goal to only have one AI supporting multiple services. Within this context, the METIS-II project [5] has developed key design principles for a 5G AI:

1. Flexibility by design: 5G AI needs to be adaptable and flexible in order to provide the required flexibility for multi service and non-traditional applications (such as tactile internet and V2X services).
2. 5G AI should be forward-compatible.
3. 5G AI should offer easy interworking with evolution of LTE.
4. Design of 5G AI should be lean, minimizing signaling overhead and unnecessary transmissions.
5. 5G AI design should take into account the latest information on bands available (or to be made available shortly) to mobile; in all likelihood 5G

systems will operate across a wide range of mm-wave and cm-wave frequencies.

6. 5G AI design should take into account terminal complexity as well as network/infrastructure complexity.
7. 5G AI design should enable APIs to higher layers so as to facilitate the implementation of network slicing [1].

Based on these principles, and key 5G KPIs, a set of AIVs has been selected, including legacy technologies, which seem the most promising candidate components of 5G AI design. The key design question to now be answered by METIS-II is the protocol stack level(s) on which multiple AIVs should be aggregated, and the mechanics of this aggregation and its impact on implementation complexity and system performance.

This paper reports on the initial findings captured in METIS-II internal report [6] and is structured in the following way: in Section II we present key concepts used in METIS-II AI work; Section III provides the motivation for our work, focusing on the key concepts of AI harmonization and aggregation; Section IV then details selected AIVs; Section V presents a preliminary AI analysis, including initial observations on harmonization possibilities; Section VI will provide key takeaways.

II. AIR INTERFACE AND RELATED CONCEPTS

An AI comprises all the functionalities of OSI layers 1 and 2 between the infrastructure and the mobile terminals (or between two terminals as in the case of D2D). In other words, an AI comprises the entire protocol stack that is common in the communicating nodes. According to this definition, a 5G AI is the complete Radio Access Network (RAN) protocol stack (i.e. PHY/MAC/RLC/PDCP/RRC or 5G equivalents) and all related functionalities describing the interaction between infrastructure and device and covering all services, bands, cell types etc. that are expected to characterize the overall 5G system [7]. A 5G AIV is the RAN protocol stack and all related functionalities as described above covering a subset of services, bands, cell types etc. that are expected to characterize the overall 5G system. A 5G AI can, hence, be defined as the integration of multiple AIVs.

METIS-II considers the overall 5G AI to be comprised of multiple AIVs, which may for instance be characterized by tailored features for certain frequency ranges, services, cell types, etc. As an example, an AIV tailored towards lower carrier frequencies, large cell sizes and high velocity, will likely be based on a PHY designed to be most robust towards delay spread and Doppler spread, whereas an AIV tailored towards mmWave frequencies and used for short-distance communication with limited mobility may rather require robustness towards other impairments such as phase noise. Further, in order to support applications requiring very low latencies (in the order of 1ms) and/or very high data rates, some new 5G AIVs are expected to use new time-domain structure(s) based on shorter Transmission Time Intervals

¹ In this paper the term RAT is used in a similar way as the term AI, as it is a widely-recognised term, particularly in the expressions such as inter-RAT handover, and in the context of HetNets. Still, there are subtle differences – RAT does comprise the underlying physical connection method (same as AI) but also extends to include the access network, with some definitions using it almost interchangeably with RAN.

(TTIs) and a wider bandwidth for radio resource blocks compared to the one specified for LTE, [8], [9]. As another example, an AIV tailored towards a specific service may foresee a specific parametrization of HARQ, or a specific form of PDCP functionality.

As can be seen from these examples, variants could differ from one another by a subset of specific features / functionalities or parametrization only applicable to the particular carrier frequency, service or cell type. For instance, two AIVs based on OFDM may differ only in the subcarrier width and symbol length. In particular, the subcarrier width in the cmWave band is most likely of the order of dozens of kHz, whereas the bandwidth available in the mmWave band allows the use of much wider subcarriers and, hence, shorter symbol lengths. In addition to this, the same OFDM-based variant may support different subcarrier widths e.g. if they are of the same order. Therefore, an exact distinction of different parametrizations of an AI into separate AI variants depends on a number of factors and is not straightforward; this will be tackled as part of METIS-II research.

Fig.1 illustrates the AI and AIV concepts with different degrees of integration and harmonization. An individual AIV is shown in Fig.1(a) – this is, as already explained, a parameterization of an AI based on device capabilities, carrier frequency, or service. Fig.1(b) shows two variants integrated at the PDCP and RRC layers. In this case, the RLC layer over the two PHY/MAC variants is the same but either requires a different parametrization – we refer to this as harmonization, elaborated further in Section III – or the two PHY/MAC/RLC layers reside in non-co-located network entities. Fig.1(c) shows an AI in which the MAC to RRC layers are completely integrated and the same parametrization can be used for the two PHY variants.

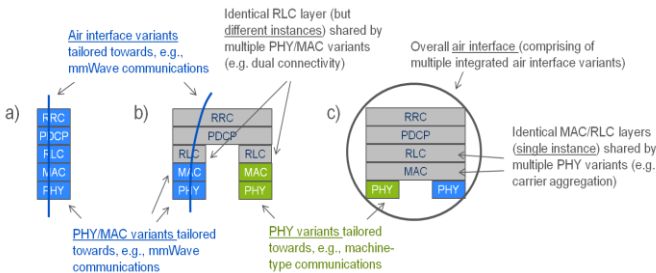


Fig. 1. Illustration of the relationship between air interface and air interface variant, based on the LTE control plane protocol stack but applicable to the user plane, which is our focus as already explained.

It needs to be pointed out [7] that it is unclear at this stage whether different PHY / MAC layers, or parameterized variants of the same PHY / MAC layer, or layers which are subsets of the same overall set of PHY / MAC functions, will eventually comprise a single 5G AI. Answering this question is one of the key priorities for METIS-II – and the present paper will contribute to this AI harmonization and integration philosophy, in which evolved LTE will play an important role.

But from a purely technical (and hence more tangible) point of view, the key focus of our work is to determine whether multiple lower layer variants (e.g. PHY, or PHY / MAC variants, which will be presented in Section IV) could use identical higher protocol stack layers (i.e. the same message formats and procedures) – or, put in another way, to design a single 5G AI akin to cases b) and / or c) in Fig.1 above.

III. CONCEPTS OF HARMONISATION AND AGGREGATION

On the one hand we would like to optimize performance for each of the individual envisioned services; on the other hand we want to avoid using several different AIVs at the same time as this would lead to a lot of complexity, handover delay, specification impact, and so on. As an illustration, when a single user has device(s) supporting multiple services, the different service data flows diverge at a very high level of the protocol stack, resulting in the need to rely on inter-RAT handover. This increases latency, implementation complexity and signalling load in the network, and results in potential loss of coordination and efficiency.

One way to solve these issues is to harmonize the AIVs with the goal to find an optimal compromise between potentially highly specialized optimization for specific service and the broader goal to only have one AI supporting multiple services.

The harmonization approach in METIS-II goes beyond other approaches used in existing systems. METIS-II tries to harmonize the air interface from the very beginning, i.e. considering the harmonization aspect already when combining the different variants into one AI. The goal is to fulfil all requirement sets with the least number of overlapping functionalities.

Similar problems are already addressed in current systems like LTE/LTE-A, but the approach and the constraints are quite different. The concept of dual connectivity (DC) currently enables to combine 3GPP based radio access network technologies, meaning to combine radio resources from at least two different network nodes of same or different existing RATs [10]. Based on this a terminal can be served by two base stations where one base station is serving as a master. DC basically manages the use of different AIs, whereas METIS-II tries to integrate different AIVs into one flexible AI. We have the freedom to design the different layers having the harmonization of different variants in mind from the beginning. This promises to enable a more efficient system design and implementation. Consequently, DC is only a partial solution whereas the harmonization METIS-II aims for will be more general, but probably also covering DC as a special case. Unlike 3GPP who, due to understandable constraints of dealing with a mature system, are limited to co-ordination of different RATs, in our work we have the freedom to integrate the benefits of individual RATs into a harmonized AI.

Another related functionality already implemented between GSM, UMTS and LTE is the inter-RAT handover, which basically switches between different AIs depending on their

suitability and availability. This does not provide the same benefits as a harmonization either, as in this case the whole information flow is switched from one protocol stack implementation to another one, which, besides other issues, usually causes a significant delay. Therefore, inter-RAT handover is not well suited for flexibility in short time scale like fast switching between RATs and still requires the implementation of the two or more complete AIs. Another major issue with this switching is the inability to guarantee an agreed QoS (Quality of Service).

Multi-RAT integration is also treated in the NGMN white papers in different ways [1]. For example, connectivity transparency is one of their proposed Enhanced Services Requirements where it is said that inter-RAT mobility service interruption time shall be unnoticeable by the user. Enhanced Multi-RAT coordination is also one of the design principles for the RAN and is described as a technology building block. Therein, multi-connectivity and multi-transmission is part of the story as it improves network resource / operation efficiency and user experience, hence a solution relying on a common protocol layer as aimed by the harmonization approach in METIS-II can be a response to these requirements without relying on a new network element. While NGMN emphasizes the relevance of enhanced multi-RAT coordination, the harmonization approach in METIS-II will work towards a general framework and to provide concrete ideas how to achieve this.

The key benefits of harmonization can hence be summarized as:

- Better utilization of available resources due to the flexibility even in short time scales, e.g.,
 - Multiple services being provided using the same frequency
 - Potential of utilizing multiple bands for the same service in a very flexible manner
- Reduced complexity in the access nodes and the end devices, as less functionalities may need to be implemented
- Lower delay in case of switching between air interface variants, as this can happen on a rather low protocol layer
- Less standardization and implementation effort, as less functionalities have to be specified and tested, and
- Simpler upgrading of an existing system by implementing additional air interface variants.

An AI is harmonized if it is a combination of AIVs in which some or all of the protocol stack functionalities are identical, but the individual parameters' values may be different. This is indicated through the same grey color of layers in Fig.2(b). In the special case of exactly the same values of parameters of the variants (or at least parts of them) the two protocol stacks can be aggregated and a single instance of this function can be used for multiple AIVs on and above a certain protocol layer as illustrated in Fig.2(c). In this case, the layers of different AIVs are said to be aggregated and appear as

a single protocol stack to the layers above, offering a single set of Service Access Points (SAPs). Two protocol stack instances aggregated on a certain layer will have one joint instance of each protocol stack layer on and above this layer. If certain functionalities or their parametrization are not exactly the same, but have some similarity, a trade-off should be aimed for between the harmonization or even aggregation of these functions leading to a more simple AI and the price to be paid for this compromise in terms of, e.g. performance.

The harmonization will most probably start from the higher layers (corresponding to PDCP or RLC in LTE), whereas for the PHY layer it may be difficult to harmonize all variants as they may be targeting different carrier frequencies or different scenarios. More specifically, the individual PHY blocks of modulation, channel coding, waveform mapping and so on would ideally be easily interchangeable through parameterization or (de-) activation of certain features. In other words, there would be a physical or logical implementation that supports easy switching between different variants, and even their multiplexing in time, frequency and/or space. However, due to conflicting requirements of AIV candidates presented in the next section, it is likely that physically separate baseband processing chains (with potentially different / parallel transmission circuitries) would be required. For this reason, it is assumed that a full harmonization of novel 5G AIVs on PHY layer may not be feasible, but the aim should be to strive for harmonization on MAC layer and above, in the sense of having one single standards specification for these layers, but with the possibility to parametrize or (de-)activate functionalities in each layer to cater for different services, bands or cell types etc. This approach of harmonizing the layers from the top down to the PHY as much as possible as illustrated in Fig.2(c). However, even if it is not beneficial or possible to harmonize all functionalities in, e.g., the RLC layer, it may still be possible and beneficial to harmonize certain, e.g., MAC layer functions. Although it is not clear yet what the benefits would be, it is included here and illustrated in Fig.2(d) in order to not exclude this option at this early stage of the harmonization work.

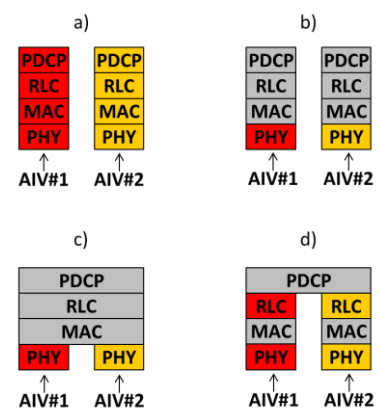


Fig. 2. Different options for two AIVs: a) Separated stacks, b) Harmonized PDCP, RLC and MAC, c) Aggregation by using a single instance of PDCP, RLC and MAC, d) Usage of different RLC but with harmonized MAC.

It should be noted that common functionalities support aggregation from the implementation point of view. The higher the degree of commonality, the more straightforward aggregation is, and the lower performance impact compared to having two separate specialized protocol stacks. However, there will be cases (as indicated above) when even if all the functionalities are common and have exactly the same parameters, we may still want to have individual instances of a layer, e.g. if network entities on which these layers are run are not co-located. On the opposite end of the spectrum, we may wish to integrate protocol stack instances that have comparatively few common functionalities, potentially even with different parameters. The answer to the question of whether to aggregate is not straightforward. As an illustration, this paper will highlight some of the complexities that underpin the issue by providing an initial analysis of selected AIV candidates in Sections IV and V.

IV. SELECTED AI VARIANTS

METIS-II has selected a comprehensive set of AIVs which help meet one or more 5G KPIs, and conform to one or more 5G AI design principles presented earlier in this paper. These AIVs and their underlying technologies are presented in Table 1. It should be pointed out that at this stage a number of issues remain open including the detailed design of the 5G user plane; therefore it was not always possible to provide uniformity across individual AIV description, most notably how high up the protocol stack a description should extend. The descriptions are therefore focused on the PHY layer. These individual AIVs comprise a certain degree of component overlap, but also conflict each other in some design requirements. The following section will then provide initial observations on harmonisation possibilities of selected AIVs.

V. INITIAL OBSERVATIONS ON HARMONISATION POSSIBILITIES OF SELECTED AIVS

Some convergence of views concerning the possibilities of harmonization of these AIV candidates is already emerging in METIS-II:

1. The co-existence of different waveforms (e.g. OFDM / FBMC based solutions) in the same band is a key element of many AIV proposals under consideration.
2. It is further noted that in some cases certain aspects of proposed AIVs could work with both OFDM and FBMC based solutions.
3. Implementation complexity / performance trade-offs play an important role in proposal selection and will be made further challenging by the desire to harmonize functionalities.
4. Not all AIVs are applicable for all bands of interest to METIS-II, as shown in the “Frequency band” column in the Table above.
5. Widespread use of QAM is noted, except in certain very special cases (CRS and CNCR).

6. Use of LTE-like resource grid is noted but with heterogeneous numerology.

On the topic of selected AIV candidates, it should additionally be noted that other 5G-PPP projects may design new AIVs not captured by our current survey, but which will be considered in our future work.

VI. CONCLUSIONS

This paper (based on a METIS-II internal report) provided the motivation for our 5G AI work through a brief gap analysis, explaining why existing AIs (the “evolutionary” approach) do not meet many of the 5G requirements, and outlined our key 5G AI design goals.

These design principles were then further elaborated, focusing on the key concepts of AI harmonization and aggregation. Furthermore, we discussed benefits of harmonization and how it differs from other co-existence techniques.

The selected AIVs which meet some or many of the 5G requirements and contribute to our overall AI design goals were then introduced. We then presented initial observations on harmonization possibilities of these AIVs. This work has laid the foundation for the future work which should determine which novel AIVs are expected to be introduced in the 5G context, which forms of AI aggregation are foreseen for 5G, and on which protocol level novel AIs should ideally be integrated among each other and with legacy technologies such as LTE-A and its evolution.

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Name	Motivation	Waveform details	Frame structure	Main features	Frequency bands	Other PHY details
<i>OQAM/FBMC</i>	Low OOB emissions, flexible sub-band configurations, better spectral efficiency, higher robustness to time/freq. distortions	Filtering per subcarrier, time/freq. localized filter design, no Cyclic Prefix (CP), OQAM: real-field orthogonality	Scalable frame design, enabling service-specific adaptations. OQAM poses constraints	Supports async. transmission; efficient spectrum sharing	Original design for <6 GHz. Applicability for above 6 GHz.	Due to OQAM modulation, adaptations are necessary for some MIMO schemes.
<i>QAM/FBMC</i>	Low OOB emissions, flexible sub-band configurations, better spectral efficiency, OFDM compatible	Separate filters for even- and odd-numbered sub-carrier symbols, no CP, QAM: complex-field orthogonality	Supports multiple numerology sets	Supports async. FDMA transm., efficient spectrum sharing	Original design for <6 GHz. Applicability for above 6 GHz.	All MIMO schemes supported. QAM modul., LDPC coding preferred over turbo.
<i>P-OFDM (pulse shaped OFDM)</i>	Low OOB emissions, flexible sub-band configurations, higher robustness to time/freq. distortions, OFDM compatible	Filtering per subcarrier, time/freq. localized filter design, QAM: complex-field orthogonality	Scalable frame design, enabling service-specific adaptations	Supports async. transmission, efficient spectrum sharing, robust to phase noise	Original design for <6 GHz. Applicability for above 6 GHz.	All MIMO schemes supported. Modul. & coding like in LTE
<i>F-OFDM / UF-OFDM based user-centric multi-service air interface</i>	Low OOB emissions, flexible sub-band configurations, OFDM compatible	Filtering per sub-band (aggregation of M subcarriers) with steep roll-off	Scalable frame design, enabling service-specific adaptations	Supports async. FDMA transm., efficient spectrum sharing	Original design for <6 GHz. Applicability for above 6 GHz.	All MIMO schemes supported. Modul. & coding like in LTE
<i>CP-OFDM for xMBB in mm-wave bands</i>	Support mm-wave transmission & adaptive beamforming for hotspots targeting high data rates and short E2E delay	CP-OFDM for ease of implementation and backward compatibility with LTE/LTE-A	Follows the LTE resource grid, frame length & symbol duration significantly shortened	Beam scheduling	Above 6GHz with focus on mm-wave.	Both short and long CP supported; QAM modul. & LDPC (preferred over turbo), MIMO support
<i>CP-OFDM for Cell-edge/Energy Efficient Application</i>	Increasing cell-edge rate, reducing PAPR	FQAM based on OFDM (other WF also possible)	Follows the LTE resource grid	Tailored for cell edge users and energy constrained services	Mainly for below 6GHz.	QAM & LDPC (preferred over turbo), MIMO support
<i>Harmonized OFDM enhancements</i>	Harmonized CP-OFDM with scalable numerology for different operating frequencies, low OOB emissions	CP-OFDM for DL/UL/D2D, SC-FDMA for UL, zero-tail SC-FDMA and OFDM for D2D, F-OFDM optionally	Support for flexible TDD with scalable and flexible numerology, dynamic TTI sizes, short subframes (~0.2 ms)	Multiple numerology sets for scaling in time & freq., multiplexing of different services using flexible spectrum sharing	Both above & below 6GHz; Multiple carrier frequencies with target bandwidths of 5 MHz to 2 GHz	LTE-like modul. up to 256 QAM; new DL & UL control channels embedded within a subframe, MIMO support
<i>Communication with Relaxed Synchronism (CRS)</i>	D2D with relaxed synchronism requirements and MTC with low power budget	FBMC, UFMC or F-OFDM	Any frame structure with a low quantity of sync. signals	Tailored for D2D and MTC with high data rate	Any, scalable bandwidth	MCS-agnostic, MIMO support
<i>Communication with Non-Coherent Reception (CNCR)</i>	Pilot signal overhead can be drastically reduced for non-coherent reception	Any WF that provides negligible ISI	Any frame structure with a low quantity of pilot signals	Tailored for V2V and massive MIMO in high-mobility scenarios	Any, scalable bandwidth	Modulation: DUSTM [11] and Grassmannian [12] constellations, MIMO support

Table 1: Key features of chosen AIVs.

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