

6G COMMUNICATIONS AND MOBILITY

Augmenting Automotive Safety with Joint Communication and Sensing

CONTRIBUTING AUTHORS: Dick Van Den Broeke, Wim Van Houtum, Kees Moerman, Ashish Pandharipande, Wim Rouwet and Mark Tomesen

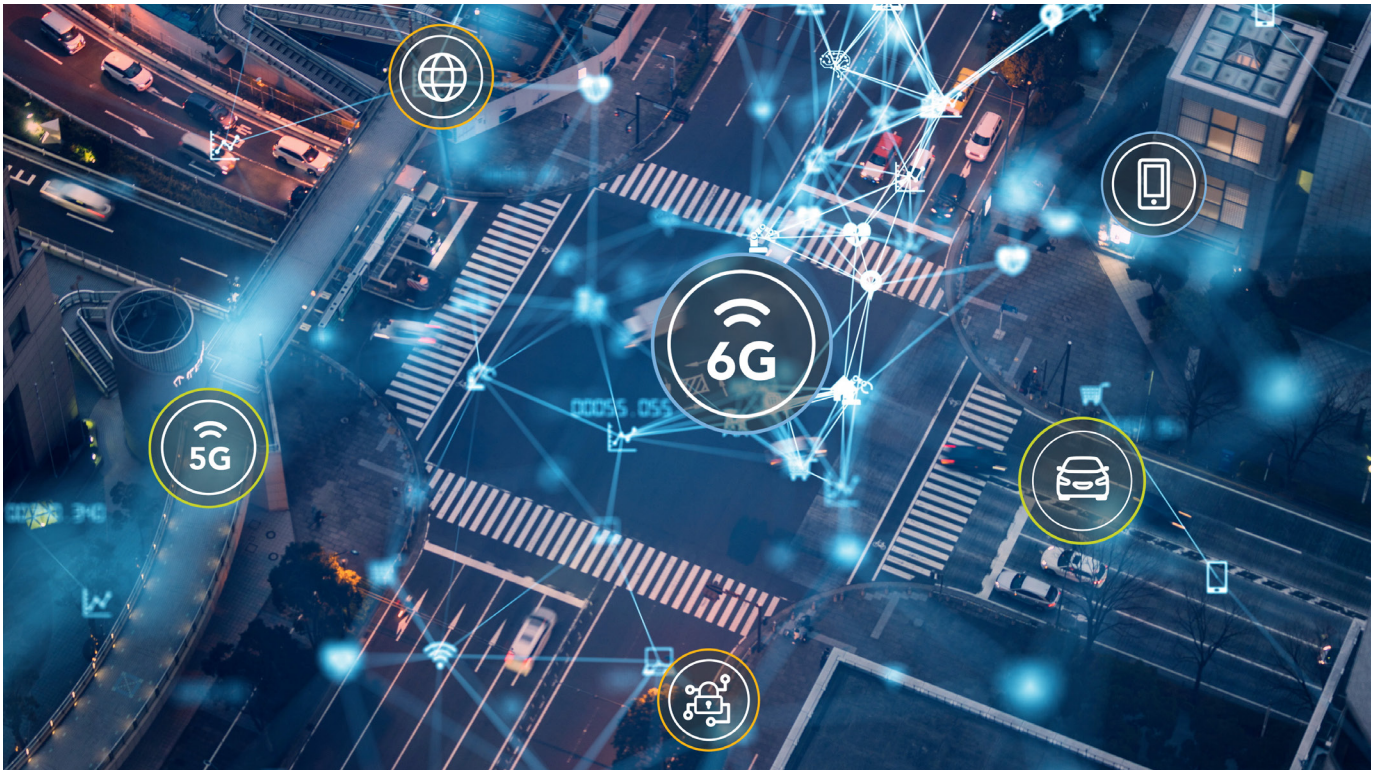


TABLE OF CONTENTS

1. NXP focus on Safe Mobility, Secure Connectivity, and Intelligent Edge
2. Societal Trends and Dynamics around Communications and Mobility
3. Systems Trustworthiness at Focus Application Automotive, Adding Sensing
4. Technical Aspects in Evolution from 5G to 6G
5. Augmenting the Car Safety System
6. Automotive UE and Accurate Localization-info
7. Conclusions
8. References

1. NXP FOCUS ON SAFE MOBILITY, SECURE CONNECTIVITY, AND INTELLIGENT EDGE

NXP Semiconductors N.V.(NXP) is a global company with the mission to enable secure connections for a smarter world, advancing solutions that make lives easier, better and safer. As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the automotive, industrial and IoT, mobile, and communication infrastructure markets.

With more than 60 years of combined experience and expertise, NXP has approximately 31,000 employees worldwide including 11,000 engineers in R&D who have created 9,500 patent families. The company posted revenues of \$11.06 billion in 2021. Based on the company’s expertise in high-performance mixed-signal technology, NXP drives innovation in the automotive, identification and mobile electronics industries as well as in the fields of communication and connected and automated driving (CAD). Core areas of the NXP portfolio include processors and microcontrollers, automotive sensors such as car radar, cyber-security, and wired/wireless communication. Wireless communication is a key field of expertise at NXP, and 5G, beyond 5G (B5G) and 6G are target product areas. The purpose of this paper is to provide a vision for what lies beyond 5G / 6G communications aiming especially at secure connectivity and safe mobility.



Fig. 1: NXP applications overview

Three major automotive system trends are driving the future of the connected car [1]. First, vehicle-to-cloud connectivity and telematics are redefining critical use case domains including vehicle safety and public safety. Second, advances in technology are enhancing car-centric, in-vehicle experiences, smart access and mobility. Third, the rise of vehicle-to-everything (V2X) communications complements other sensor technologies used for advanced driver-assistance systems (ADAS) and autonomous driving. Beyond these automotive connectivity topics, we are developing new ways to enhance automotive system designs by integrating environmental sensing as a feature of the communications network. The NXP blog [2], “[6G Joint Communication and Sensing](#)”, provides several examples of ways to enhance the safety of roadway infrastructure including smart street intersections. A recent blog from Ericsson [3] identifies sensing capabilities as an integral part of future 6G networks. In this NXP white paper, we will elaborate on the wider field of 6G communications and mobility.

2. SOCIETAL TRENDS AND DYNAMICS AROUND COMMUNICATIONS AND MOBILITY

Our daily lives have become increasingly interconnected in a world where “things” observe, perceive and interact

with us in smarter ways. Through advances in engineering, we are adding sensing capabilities to connected devices and provide communications technology and intelligence to create complex systems such as self-driving cars and smart robotics in manufacturing facilities. 6G connectivity will have a profound impact on the future of transportation and manufacturing. 6G technology encompasses signal waveforms, network architecture and topologies, edge compute options, target applications and use cases. This white paper provides NXP’s view on the broader scope of 6G development while focusing on the application 6G in automotive safety.

To set the scene, let’s start by discussing key societal progress drivers relevant for 6G communications and mobility. Then we will delve deeper into a key overarching topic: the element of “trustworthiness” of the system as a whole. Many stakeholders have raised the topic of trustworthiness as an important consideration in 6G development given ever-increasing system complexities and the public’s high desire for systems/data integrity and credibility. Purposeful networking has been part of NXP’s 6G vision [13]. To this end, we see high value in building on the trustworthiness target model as described in [4].

Delving deeper into the matter, we will discuss 6G drivers with a focus on the automotive ecosystem’s high demands

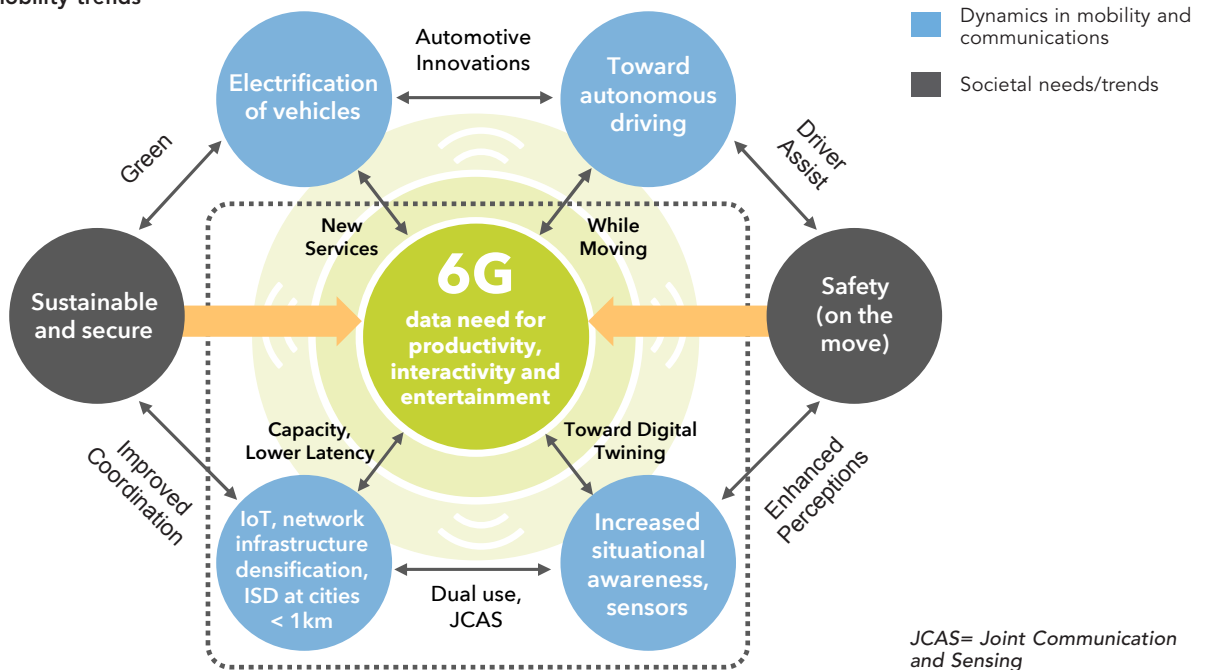
for safety and conclude with examples of potential 6G enhancements in addition to the embedded car safety system with its connected side communications options through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity, leveraging the strength of local available information and local communications channels. The augmentations through 6G are described in Beyond 5G (B5G) / 6G next-generation localization principles, as well as through embedding communications infrastructure capabilities such as Joint Communication and Sensing (JCAS).

Given its leadership position in the automotive semiconductor industry and broad portfolio of hardware and software security technologies, NXP has considerable expertise in automotive safety and security. NXP views trustworthiness as a comprehensive assurance of systems operations, guaranteeing very critical service performance in line with the expectations the industry commonly applies to automotive systems. Figure 2 provides a snapshot of several dynamics in the field of mobility and communications. Over the past decade, the electrification of vehicles has boosted the rate of innovation in automotive technology. However, the car of the future is defined not only by power source (fossil fuels versus electrification) but also by the vehicle’s broader capabilities. For example, electric vehicle (EV) innovation coincides with the increased demands for automotive infotainment, which many drivers and passengers use to bridge waiting times while charging EV batteries. The proliferation of new in-vehicle services drives increased demand for data and communications capabilities. With the trend toward autonomous vehicles, we see even

greater demands for data used by safety systems and V2V/V2I communications. In the case of full autonomous driving, the transportation experience will be converted to a productive time for passengers, which will bring extreme data throughput and data integrity requirements. Wide-area coverage will become essential while automotive passengers are on the move, driving up cellular networking performance demands. This is happening even today as the infotainment and productivity demands of vehicular passengers are driving increased deployment of mobile networks. The top part of Figure 2 illustrates this point, showing the “outside-in” market drivers (sustainability, security and safety) boosting the demand for 6G data for productivity, interactivity and infotainment.

Looking at the wireless communications/mobile network side of the equation, we see a strong dynamic toward network infrastructure densification, driven by network capacity demands. Geographical coverage needs drove the early days of cellular network deployment toward base-station installations with wide-area coverage. This trend is now augmented with dense cellular equipment deployments using reduced inter-site distances (ISD) of below one kilometer to support higher aggregate network throughput. A side effect of bringing the telecommunications equipment to everyone’s doorstep is the potential to further direct the communications systems’ radio techniques to gather relevant local situational information. This information can be used to increase situational awareness of stakeholders through network communication. This approach will enable new use cases

Fig. 2: 6G and mobility trends



such as crowd monitoring and traffic safety. Recent NXP and Ericsson blog references [2,3] provide an example of enhanced perceptions in a street cross section safety use case. These blogs show that effective use of the available infrastructure equipment can be achieved with JCAS technology. The lower part of Figure 2 summarizes these findings and illustrates the described communications network-related dynamics around situational awareness and network densification, which again drive up the demand for 6G network data needed to support a wide variety of use cases.

3. SYSTEM TRUSTWORTHINESS IN SENSING-FOCUSED AUTOMOTIVE APPLICATIONS

Intelligent systems benefit from providing combined communications and sensing capabilities. Beyond focusing on communications, evolutionary 5G standards are adding sensing capabilities on top of communications platforms to combine both functions. An obvious communication-related benefit is how sensing can help make communications more effective. For example, beam path selection can be based on knowledge of certain obstructions and/or movement in the environment and therefore can be chosen more effectively.

Let's look into complex automotive systems like ADAS and explore how B5G/6G can play a role in improving its performance. As part of the ADAS architecture we believe that an independent, vehicle-mounted, time-critical

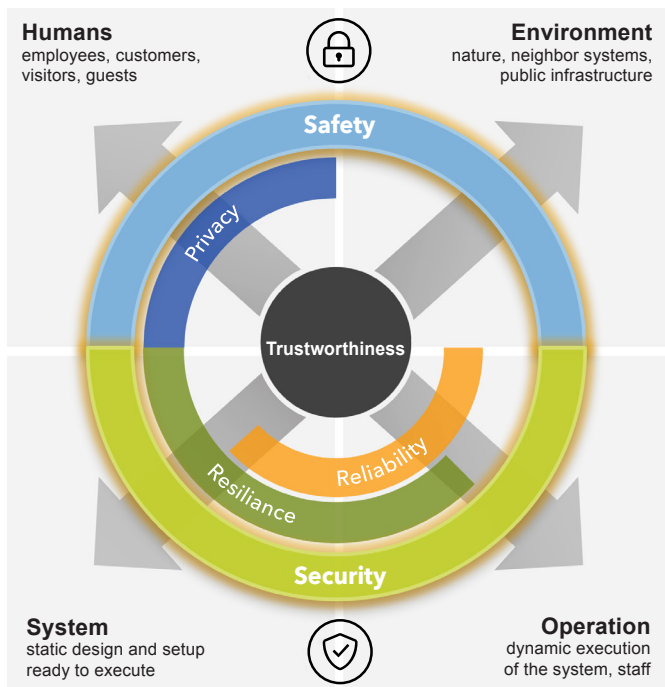
compute engine will continue to be used for mission-critical assignments to assist safe driving, parking and other maneuvers. In this case, a 6G network can be used for perception enhancement.

For any system capability enhancement, migrating from 5G to 6G or from today's to tomorrow's ADAS technology, it is essential to provide adequate safety and security measures. To understand this requirement, we will take a closer look at trustworthiness concepts.

Many of the elements described in the trustworthiness model can be understood intuitively. The top half of the model (Figure 3) shows the field of safety, linking trustworthiness aspects from the perspective of humans and their surrounding environment. The lower half of the model shows the field of security, as related to systems and operations. Returning to the mobility model (Figure 2), the optional use of network sensing information to an automotive system introduces strong alignment needs related to safety and security.

Let's look at a safety-centric technical example of distributed sensing designed to enhance perception targeting mobility safety at a traffic intersection. Various mobile devices such as cars and stationary facilities such as traffic lights all can use 6G JCAS to provide vehicle occupants with enhanced perception of traffic users and an elaborate view of the traffic situation. Time-critical use cases must be handled by local mechanisms through V2I and V2V communications

Fig. 3: Trustworthiness target model



The IIoT Trustworthiness Framework Foundations document (4) defines trustworthiness as a combination of security, safety, reliability, resilience and privacy. It also looks at the tradeoffs made amongst these factors in the face of environmental disturbances, human errors, system faults and attacks. Fig 3 demonstrates the trustworthiness target model. Quoting from the document: "Trustworthiness is the degree of confidence one has that a system performs as expected. It requires an understanding of the system, including interactions and emergent properties". "In the digital world, trust and trustworthiness are achieved by understanding and addressing concerns related to the trustworthiness characteristics appropriately for the context of the entire system. Providing evidence of this can give others confidence".

Courtesy: The Industrial Internet of Things Trustworthiness Framework Foundations. Version V1.00 -2021-07-15

using dedicated short-range communications (DSRC) and/or cellular vehicle-to-everything (C-V2X) technology. However, none of these devices will be able to reconstruct a complete picture on their own: collaboration is needed. To work collaboratively, sensed data streams are first communicated to the base station and then to the edge cloud (a geographically close cloud compute platform) for further processing. In addition, non-time-critical system/training aspects from the automotive system can be further offloaded for cloud processing (at edge or remote). At individual stages, data is further processed and aggregated to create a more complete view to support decisions of the safety system that are less time-sensitive.

Security, along with safety, is an important consideration in automotive systems. Privacy-sensitive data, described in the street cross section use case [2,3], flows through disaggregated services. Privacy-sensitive information includes location and device identity (such as smartphones) of nearby pedestrians. This data must be processed by a trustworthy compute platform and protected by this platform against a variety of threats and adversaries. Multiple data flows processed simultaneously must be sufficiently isolated to avoid data leakage. This is a key requirement when developing 6G to include enhanced perception applications. JCAS use cases are an important topic that is expected to be addressed by various consortia such as the 6G Smart Networks and Services Industry Association (6G-IA) [5].

While 6G-based solutions present high societal value, this does not mean that the revenue models are immediately clear for network operators, infrastructure owners and public authorities, which all have a stake and own part of the solutions puzzle. 6G development requires increased effort throughout the industry to actively seek alignment on solutions that will enable safe automotive systems of the future.

4. TECHNICAL ASPECTS IN THE EVOLUTION FROM 5G TO 6G

The evolution from 5G to 6G connectivity will bring more network capacity and intelligence to end users. Intelligence will come from adding extensive sensing among many other capabilities, combined with massive edge cloud computing. We'll start by addressing the basic capacity and sensing elements of these systems. This section will focus on the following topics:

- Orthogonal frequency division multiple access (OFDMA) technology
- Spatial diversity
- Network densification with a reduced basic cell area

- New frequency band options and technologies
- Joint communication and sensing (JCAS) technology

6G is expected to build on OFDMA modulation schemes in currently used frequency bands including 2/3/4/5G sub-6 GHz and millimeter wave (mmWave). At these frequency bands, the technology has proven to provide data throughput close to the theoretical Shannon limit (the channel capacity of a communication channel) while also providing flexibility to allocate time slots and frequency bands with data for individual users. Ongoing research into waveform evolution for use in higher frequency bands intends to make modem implementations more efficient, with many proposals emerging from the wireless community. Evolved forward error correction (FEC) and low peak-to-average-power ratio (PAPR) waveforms are all part of these proposals.

A second ingredient, which boosts network throughput and is already used in 5G today, is spatial diversity. According to this concept, multiple independent signals can be transmitted and received simultaneously and in the same bandwidth, provided that multiple spatial tracks from transmitter to receiver are available. For example, a 5G base station can send multiple narrow beams (all carrying different data) in the same frequency band toward multiple users simultaneously. In another example using a single-user multiple input/multiple output (MIMO) architecture, a single user receives multiple beams from the same base station, all through different reflection tracks. If a user receives four such beams, in theory the data throughput to that user can be boosted by a factor of 4x even if the beams cover the same frequency range.

Further capacity increases come with the trend of reducing the network's basic cell area and keeping signals more local. The highest data rates typically are required only over relatively a short range in densely populated areas, such as railway stations, stadiums or shopping malls. However, shorter ranges and network densification require more physical base stations, each with high installation and maintenance costs.

As 3GPP networks evolved over time, operating frequencies have increased, culminating with 6G standardization driving up frequency bands possibly up to 7 GHz or even up to 24 GHz to extend the low bands [6] and further up to terahertz frequencies at 100 GHz and beyond to extend the high bands [7]. Higher operating frequency generally comes with higher channel bandwidth, thus increasing data rate. The shorter wavelength also helps minimize the physical size of the antenna and its associated cost. While path losses may increase, given cell site densification, acceptable system capacity can still be achieved.

6G Radio needs

Frequency versus technology for base station infra
 Expecting higher bandwidth availability especially at Terahertz frequencies

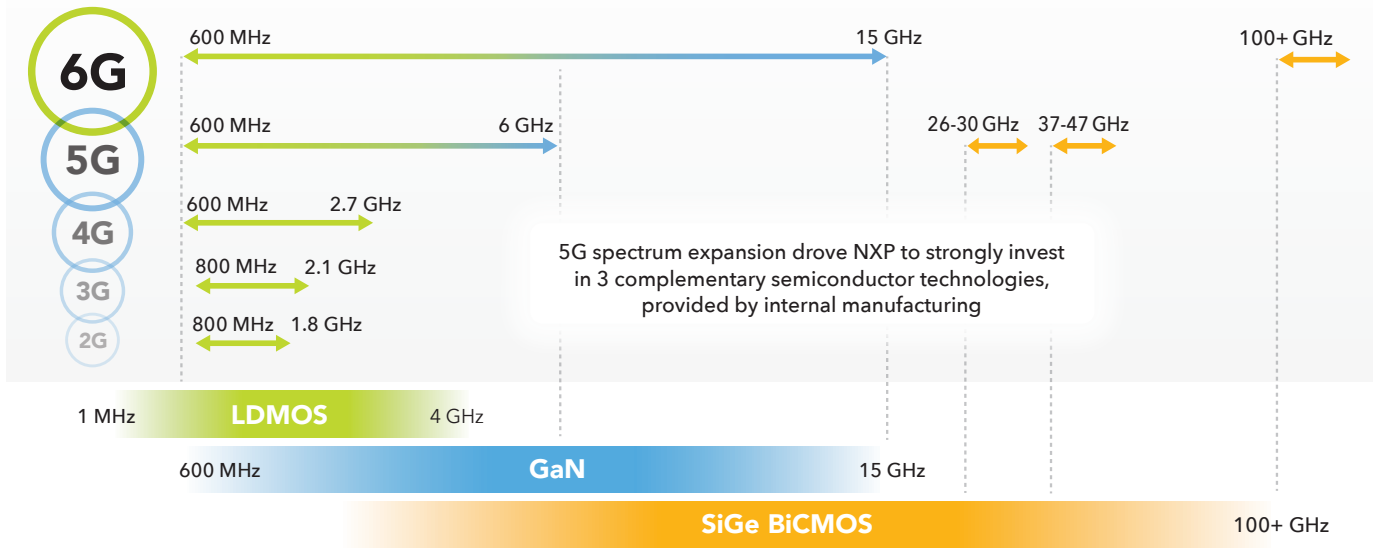


Fig. 4: Overview of potential 6G frequency expansion bands

Figure 4 illustrates potential new 6G frequency bands. A key element in the overall solution is the RF radio where NXP has invested in optimal manufacturing technologies to support the increasing range of frequencies. Figure 4 further shows that LDMOS and GaN are well established technologies for lower frequencies, and moving up in frequency foresees the increased use of silicon technologies, such as Si-Ge BiCMOS. A new and innovative feature emerging from 6G is massive radar sensing capabilities. The 6G physical interface lends itself to support sensing, given the bandwidth of the OFDM signals involved, which is sufficient for high-resolution radar sensing. For example, 5 GHz RF bandwidth already brings 3 cm spatial resolution. The beamforming/MIMO capabilities provide angular selectivity. Thanks to the benefits of seamless connectivity and massive edge computing (enabled by the CMOS roadmap following Moore’s law), aggregation of sensing information can be enabled from different observation points into a full 3D map. We will consider an example of localization based on a single base station and moving user equipment (UE) later in this paper.

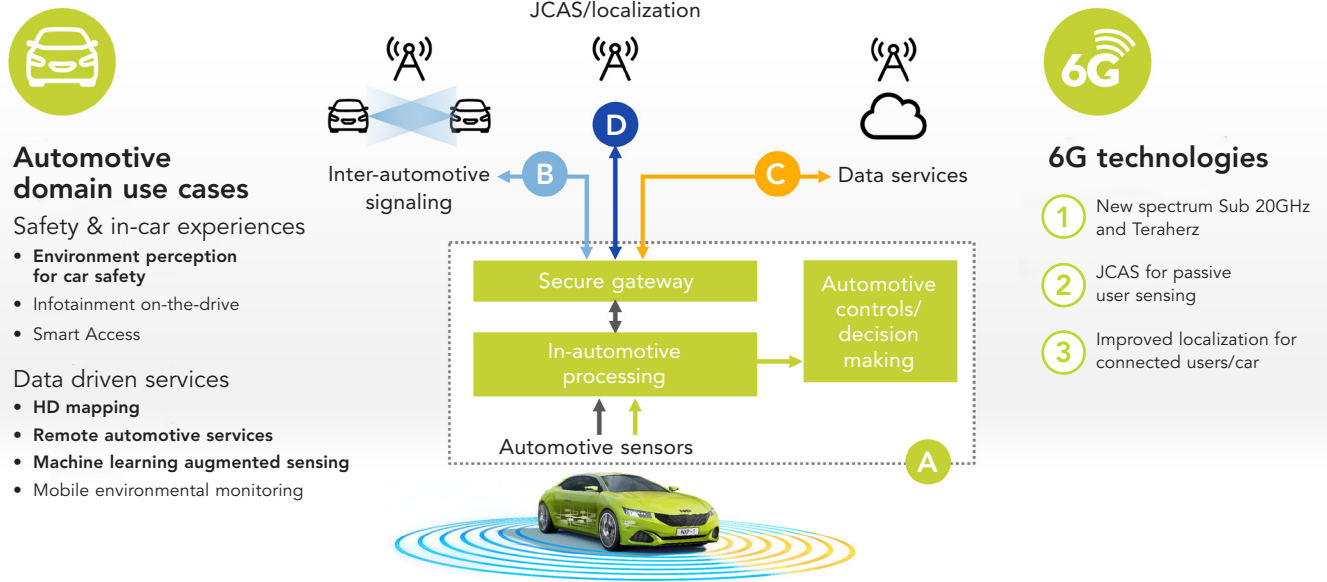
Industry interest in new integrated sensing and communications techniques is rising. As a clear signal of this trend, the IEEE Communications Society recently established a committee on “Integrated Communication and Sensing” to explore new research directions and standardization opportunities [12]. There are multiple incentives for using JCAS technology in 6G development:

Network operators can improve the effectiveness of their network; in particular, beam control becomes more effective if the base station can adapt intelligently to the environment. Second, automation (think robotics) requires both communications and sensing, and there are cost benefits in integrating both functions in a single hardware unit, sharing both antenna and radio hardware.

Most importantly, no solution will be accepted by end users and service providers without a sufficient level of trustworthiness. Many stakeholders play a role in this ecosystem, with multiple ongoing research and standardization initiatives. For example, the 6G Smart Networks and Services Industry Association (6G-IA) is looking into key system aspects of trustworthiness [5]. Next to encryption, security techniques such as hardware fingerprinting and focusing beams only toward trusted receivers will likely be explored.

Research and development at NXP and among many ecosystem partners is underway to craft an architecture and design a 6G base station and UE capable of operating in possible new frequency allocations such as 5-24 GHz and 100 GHz Terahertz bands. For future Terahertz systems, challenges are related to the required accuracy of the beamforming and many implementation constraints such as very narrow antenna spacing (down to 1.5 mm per patch), significant path losses linked to the frequency of operation and concentrated power dissipation.

Purposeful networking: The automotive safety – security case



The future of automotive connectivity, white paper NXP / ABI research

Fig. 5: Connected vehicle highlighting the car safety system

5. AUGMENTING THE CAR SAFETY SYSTEM

In considering diverse automotive use cases, let's explore the role future connectivity functionalities can play in automotive perception and safety. Figure 5 shows a conceptual setup of a car sensing system, along with automotive use cases (the bold marked cases highlight the focus on safety) and 6G opportunities related to car safety. We first elaborate on the general role of connectivity in vehicles and sensing systems. mmWave radar is a core sensing technology for automotive perception in ADAS for enhancing comfort, safety and security. NXP provides a scalable portfolio of highly integrated products for automotive radar applications supporting car safety performance programs such as the European New Car Assessment Program (Euro NCAP).

Multiple levels of autonomy for ADAS have been described by the automotive community. At autonomous Level 3 (L3), a driver in an "eyes and hands off" driving mode must continue to be alert and assume control of the vehicle when faced with specific challenging situations. With high levels of autonomous driving, the interaction between the driver and vehicle will be further reduced. These higher autonomous driving levels come with new system redundancy requirements as the vehicle becomes responsible for a larger number of driving functions. One design approach is to equip the vehicle with a redundant sensor configuration that includes sensors such as cameras and radars.

In this sensor configuration, automotive connectivity provides an additional means to enhance redundancy as well as extend sensing performance to support ADAS functions. Connectivity can extend the perception capabilities of a vehicle to beyond its on-board sensors' detection range and provide awareness farther down the road. Wireless connectivity also enables the data collected on-board to be shared with other vehicles in the vicinity, neighboring infrastructures and remote backend systems, enhancing applications and opening new data-driven services.

The dashed box marked (A) in Figure 5 shows the on-board car automation system supporting safety-critical driving and consists of sensors for environmental perception, an in-automotive processing unit, and the automotive controls and decision unit. V2I or V2X connectivity, indicated as [B] in Figure 5, can support inter-automotive signaling. Connectivity supported by V2I and V2X enables various warning signaling such as traffic speeding and local road condition updates, as well as diverse collision avoidance safety use cases once such automotive connectivity deployments become denser.

Higher rates of connectivity can enable advanced applications such as high-definition (HD) mapping, which is expected to be a part of future autonomous driving solutions. This mapping technology provides a wide range of attributes including traffic signs, speed limits,

road curvatures, pedestrian crossings and barriers with sub-meter-level accuracy. The maps complement in-car automotive sensing by providing perception capabilities under difficult scenarios such as inclement weather conditions and occluded sensing views. For instance, the map can provide information on relevant road elements that aid the automotive sensors in enhancing their detection capabilities and provide a higher level of safety in autonomous decision-making. Given the safety-critical nature of the autonomous driving application, it is vital to assure the integrity and currency of the map data. A high-rate wireless connection from the vehicle to the backend mapping infrastructure allows crowd-sourced collection of sensor data that aids in HD mapping as well as ensures timely updating. Furthermore, ultra-low latency communications enables navigation aids to be provided in real-time to enhance the driving experience. HD map enablement with automotive localization and local sensing provides a powerful combination toward safer driving.

Automotive wireless connectivity enables collection of data that is generated by the large number of on-board sensors, controllers and devices, opening new data-driven applications and services based on advanced analytics and machine learning, as depicted by [C] in Figure 5. These data services may be offered either by a remote cloud, infrastructure edge cloud or a combination of these technologies. Remote services supported by data monitoring can ensure that various components and sub-systems are functioning in conformance and any performance anomalies are detected in a timely manner.

Advanced diagnostics and reactive/predictive maintenance services can be offered to ensure that vehicle performance and safety is assured on the road. A host of vehicle features can be offered to end users through over-the-air (OTA) updates in a flexible manner over the lifecycle ownership of the vehicle. High-rate connectivity supports collection of large amounts of data for training machine learning models and their suitable deployment and updating, further augmenting on-board sensing and enhancing safety in automotive decision-making.

Connected vehicles can be viewed as mobile sensors that can support diverse applications ranging from environmental perception and driving pattern analytics to traffic management and environmental pollution monitoring.

As described previously, new spectrum bands are expected to become available with the next generation of 6G connectivity. Specifically, the spectrum in the mmWave bands fits with a denser infrastructure, resulting from

the radio wave propagation characteristics. Increasing deployment of mmWave connectivity also brings the potential of integrating radar sensing functionality within roadway infrastructure. These twin 6G spectrum characteristics open up new capabilities at 6G base stations in the form of JCAS technology and highly accurate UE localization. These new functionalities, marked by [D] in Figure 5, can be used to further augment automotive sensing capabilities. In the next section, we will elaborate on localization and JCAS technologies and their potential for automotive UEs.

6. AUTOMOTIVE UE AND ACCURATE LOCALIZATION INFORMATION

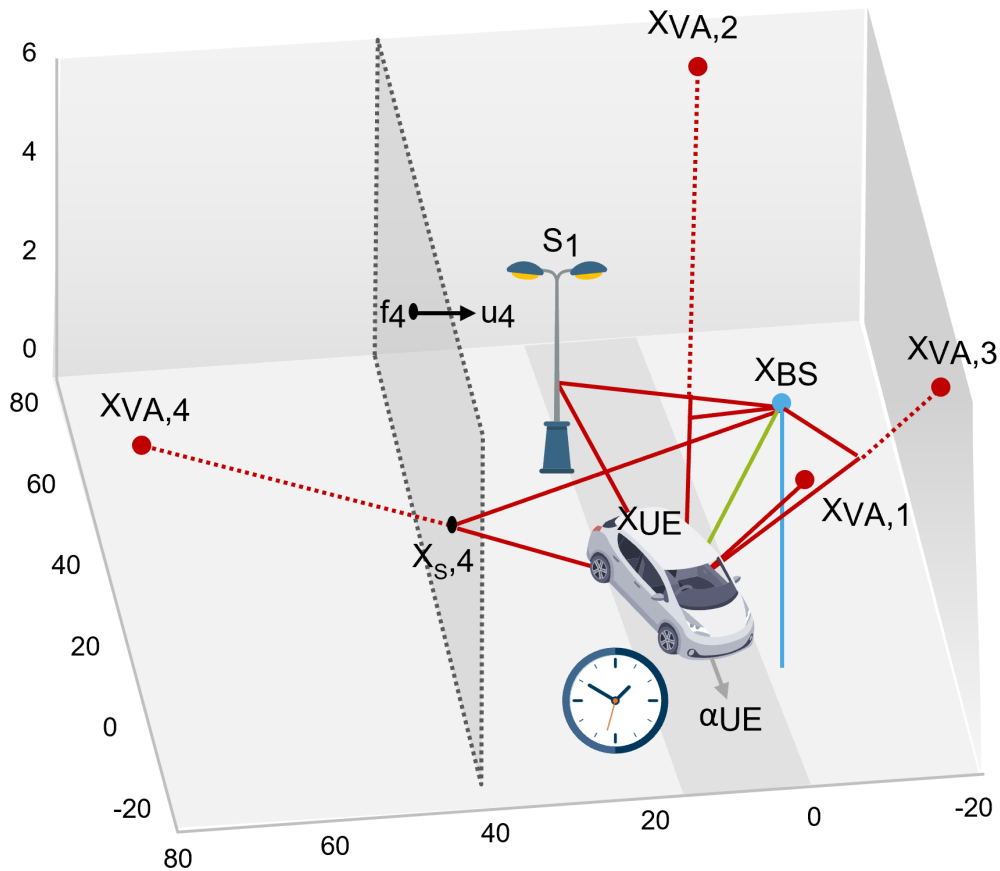
An automotive UE can obtain accurate localization information as an extension to its radar capabilities, as described in references [8] and [9]. Before delving into localization for 6G mobile systems and beyond, it's helpful to explain some key terminology. Radio localization or positioning refers to determining "state," which is the position and orientation of a connected device. In addition, radio sensing refers to the determination of the state of a passive object or phenomenon, e.g. something that is not connected to the network. Finally, radar refers to a specific type of sensing.

5G supports radio localization through a primary technology known as time difference of arrival (TDOA). TDOA-based localization requires several synchronized base stations to perform the computation to determine accurate device positioning (3 nanoseconds inaccuracy equates to 1 meter localization inaccuracy). This requirement is different from the core communication function where one base station is sufficient to provide communication coverage. This introduces the question whether it is possible to perform sensing in the context of a signal received from a single base station in an unknown propagation environment. In this scenario, the following two objectives are relevant to enhancing a safety system:

- 1) We want to determine the user's position.
- 2) We want to know the user's direction of movement.

To address these two objectives, it is important to realize that the user time stamp must be known since the user position/movement and the base station clocks are not synchronized.

The concept behind obtaining the position and movement information begins by building a map of the propagation environment. Fulfillment of objectives 1) and 2) appear to be possible through multipath exploration. This can be achieved even when the line-of-sight (LOS) path is blocked.



Courtesy: Wymeersch – Joint Communication and Sensing

Fig. 6: Bi-static scenario: In 3D each object gives 2 angle-of-departures (AODs), 2 angle-of-arrivals (AOAs), 1 time-of-arrival (TOA) for 3 unknowns (x,y,z). Courtesy of reference [8].

A simple form of multipath exploration occurs when a base station is transmitting a signal to a user device (bi-static scenario), and the user receives a superposition of different propagation paths. In a mono-static scenario, the radar transmitter and receiver are at the same location. In a bi-static scenario the transmitter and receiver are at different locations. In a bi-static scenario, each 3D object reflection provides two angle-of-departures (AODs), two angle-of-arrivals (AOAs), one time-of-arrival (TOA). This information is adequate to estimate the three “unknowns”, being the position coordinates (x,y,z).

If the bandwidth and/or the number of antennas are sufficiently large, these multipath components can be resolved, and the delays give angle information. The resolution of the multipaths is possible if there is a certain amount of multipaths as shown by the red lines in Figure 6. The multipaths represent bounces from small

objects such as a light-pole (S_1) with specific AOAs and AODs, and large objects such as walls where reflection points are represented by “virtual-anchors” ($[X_{VA,1}, \dots, X_{VA,4}]$). Moreover, the base station position (X_{BS}) represented by the blue line in Figure 6 has a line-of-sight (LOS), represented by the green-line, with the vehicle UE at position X_{UE} and direction α_{UE} . The clock image symbolically represents time requirements.

It is now possible to localize user positioning and map the propagation environment even with a single base station. See reference [8] for details.

This scenario aligns with the 6G vision according to the Hexa-X project [9], as well as the views presented in this white paper. The vision for 6G localization and sensing requires extreme positioning performance and a tight integration with communication.

Let's consider an instructive example of an option to enhance automotive safety through network support, which enables precise localization. It is well known that so-called "urban canyons" (dense corridors in large cities with high-rise buildings) impact GNSS/GPS reception. Only a few satellites are visible, and of those visible, it is not uncommon to see their reflection in a nearby building with a stronger signal than the direct path (Figure 7). This situation can cause a significant positional error, sometimes even projecting the car's position inside buildings at the location of the reflection. This positioning error can significantly impact the safety and trustworthiness of ADAS and autonomous driving systems.

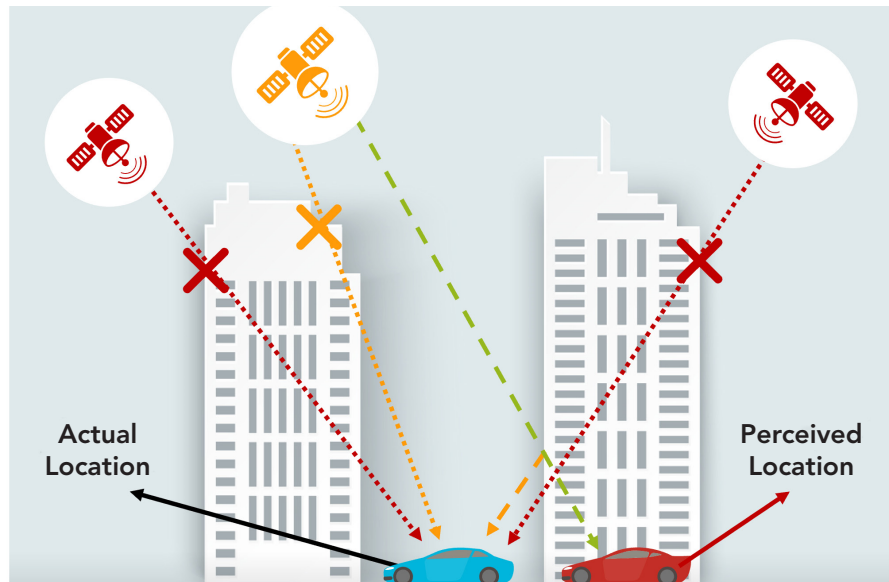


Fig. 7: Mirror image due to reflected GNSS signals in urban canyons

As a next step in 6G and beyond, JRC2LS (an acronym for "Joint Radar Communication, Computation, Localization and Sensing" envisions an extension of the more conventional joint radar communication concept [9]. This means that radar and communication will not only be integrated, it also must be combined in a broader sense with edge computing, localization and sensing. The JRC2LS approach aligns with NXP's long-term view on edge computing. Achieving this vision still requires fulfillment of technical challenges in the field of THz-signals, new waveforms, new infrastructure offloading, reconfigurable-intelligent-surface (RIS), highly directional beamforming and model-based/data-driven algorithms. An important aspect is to understand the mutual strengthening effects. Thanks to highly directional beamforming, there should be more synergy between sensing and communication. Better localization through a coordinated approach rather than conventional trade-offs will lead to a better communication and vice versa.

NXP believes that 6G systems and beyond will be driven by extreme use cases for communication, localization and sensing, which cannot be supported by 5G. These capabilities go hand-in-hand with NXP's portfolio of communication systems and automotive radar-systems. Moreover, NXP has the deep hardware experience to address one of the most important challenges: RF hardware development for 6G and beyond. As 6G covers various frequency bands up to the upper mmWave and terahertz bands there are many challenges on RF/radio technology and design in order to overcome the harsh propagation channel characteristics in order to establish high quality communication links. At the same time there are concerns about energy consumption which brings an additional constraint on the total solution.

The automotive eco-system has a strong need for enhanced perception in cities which can be addressed using the dense networks emerging with the rise of 6G. In urban areas, in-car sensors have issues in perception due to high-rise buildings and dense traffic blocking line-of-sight sensors such as cameras, radar and lidar. Extending perception with 6G enhanced data will be crucial to further increase traffic safety, monitoring and management.

6G communications and sensing can support situational awareness in several ways. First, JCAS can be added to the fixed 6G infrastructure to enhance automotive perception capabilities. Using existing communication antenna arrays for sensing, the system can perform comparable to radar. The data can be processed at the edge, combining the information from multiple antennas shared over a base station. JCAS will enhance in-car perception as the infrastructure implementation is able to see beyond the capabilities of in-car sensors due to longer (potentially multi-cell) distance coverage and observing areas blocked from sight from the perspective of the car. Examples include "looking around a corner" at intersections with tall buildings, and looking at traffic (from the car's perspective) obscured by large objects such as trucks. These capabilities add valuable information to the in-vehicle line-of-sight sensors (camera, lidar, radar).

Trustworthiness can be significantly enhanced using the localization capabilities of 6G – especially JCAS-equipped base stations. Enhanced positional information can be shared by the infrastructure using a secure 6G or V2I link (see Figure 5 link to [D]), and anomalies in the GNSS position can thereby be detected and potentially corrected by the vehicle system, resulting in more reliable and lane-accurate position information.

Using secure and low-latency [14] communication, the resulting position information can also be shared in real time with vehicles in the nearby environment, again using V2I or 6G cellular communication (for example, by using a Cooperative Perception Service as currently being standardized by ETSI). Sharing information increases in-car situational awareness, complementing the real-time in-car data as well as the more static data available from the cloud, such as known traffic congestions, planned roadworks, etc., while adding a level of redundancy to the observations made by the car.

A recent NXP blog, “Joint Communication and Sensing in 6G Networks,” [2] presents a relevant use case: intersection safety. Other use cases include merge assist at right turn traffic lights (with view blocked by buildings), real-time obstacle detection not visible from the line of sight from the vehicle, and vulnerable road user (VRU) warnings. Many use cases are already defined, and more can be envisioned [11 a,b,c].

The gathered data can also be used by the city road infrastructure. Having detailed, real-time traffic data as computed in the 6G secure edge [15] adds significantly to the available information, complementing other data sensors and sources. According to research by IoT Analytics, “Traffic Monitoring and Management” comes second in the top-10 smart city use cases, only after “Connected Public Transport” [10]. It is helpful to realize there is an extensive ecosystem for automotive safety, offering business potential not only to equipment manufacturers but also to multiple organizations in the traffic management chain. For example, the network operator is able to monetize the gathered additional data. The road infrastructure operator can use the data to implement advanced traffic management and safety use cases, while reducing costs as expensive-to-maintain static traffic sensors like wire loops are replaced by more flexible technology. Local municipalities may see a reduction in accidents and improved traffic flow. And vehicle owners with a subscription to this data or with access to the warnings issued by road operators will appreciate the increased safety and reduced travel time.



Fig. 8: JCAS-enhanced intersection

7. CONCLUSIONS

Beyond 5G / 6G encompasses a broad field of topics such as signal waveforms, network architecture and topologies, edge compute options, and myriad applications and use cases. In the field of 6G and mobility, we see the following key opportunities:

- 6G network densification with smaller cells combined with new frequency bands with higher bandwidth can bring convergence of connectivity with environmental awareness through sensing and localization.
- The large bandwidth of 6G technology provides high-data-rate connectivity, enabling data and ML-driven applications. These new 6G features will open new opportunities for augmenting car safety, as well as new automotive services.
- NXP, along with other key players in the connected automotive ecosystem, is well positioned to deliver this vision. NXP has key radio technology available to address the challenges in targeted new frequency domains.

REFERENCES:

1. The future of automotive connectivity. NXP/ABI research White paper by Andrew Zignani, Research Director.
2. Joint communication and sensing in 6G networks, by Kees Moerman. 5 November 2021, <https://www.nxp.com/company/blog/joint-communication-and-sensing-in-6g-networks:BL-SENSING-IN-6G-NETWORKS>
3. Joint communication and sensing 6G networks, by Håkan Andersson. 25 October 2021, <https://www.ericsson.com/en/blog/2021/10/joint-sensing-and-communication-6g>
4. The Industrial Internet of things Trustworthiness framework Foundations, v1.00-2021-07-15. https://www.iiconsortium.org/pdf/Trustworthiness_Framework_Foundations.pdf
5. The 6G Smart Networks and Services Association (6G-IA): <https://6g-ia.eu/>
6. Study item on feasibility of NR operation in 7.125-24.250 GHz bands. 3GPP TR 38.820
7. Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond, IEEE access 2019, by THEODORE S. RAPPAPORT (Fellow, IEEE), YUNCHOU XING, OJAS KANHERE, SHIHAO JU, ARJUNA MADANAYAKE (Member, IEEE), SOUMYAJIT MANDAL (Senior Member, IEEE), AHMED A.
8. 2020 INCOMING winter school, "Radio Localization: Basics and state of the art". 2020, Lecturer, H.Wymeersch, Video: <https://youtu.be/O5rtcCclINc>
9. IEEE PIMRC 2021, WS6 – "Integrated communication, localization and sensing in 6G era", Hexa-X dissemination, <https://pimrc2021.ieee-pimrc.org/integrated-communication-localization-and-sensing-in-6g-era/>
Video: <https://youtu.be/zGOGzbHz0SA>
10. "The top 10 Smart City use cases that are being prioritized now"; IoT Analytics, September 2020
- 11a "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions"; ETSI TR 102 638, https://www.etsi.org/deliver/etsi_tr/102600_102699/102638/01.01.01_60/tr_102638v010101p.pdf
- 11b List of use cases, "On-Board System Requirements for V2V Safety Communications", SAE Surface Vehicle Standard J2945/1, section 4
- 11c Day 1 use cases, "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility", European Commission COM(2016) 766 final, 30.11.2016, <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0766&from=EN>
12. <https://isac.committees.comsoc.org/>
13. 6G Symposium 2021: <https://www.youtube.com/watch?v=qSip2kjPitE>
14. Acc. to the US DoT/NHTSA, several automotive use cases have latency requirements ≤ 20 ms; not guaranteed by e.g. LTE PC5 direct V2X communication. See final CAMP report, <https://rosap.ntl.bts.gov/view/dot/3925> (e.g. pre-crash sensing, page 29)
15. NXP secure edge products. <https://www.nxp.com/applications/enabling-technologies/security:SECURITY-TECHNOLOGY>

HOW TO REACH US

Home Page: www.nxp.com

Web Support: www.nxp.com/support

USA/Europe or Locations Not Listed:

NXP Semiconductors USA, Inc.
Technical Information Center, EL516
2100 East Elliot Road
Tempe, Arizona 85284
+1-800-521-6274 or +1-480-768-2130
www.nxp.com/support

Europe, Middle East, and Africa:

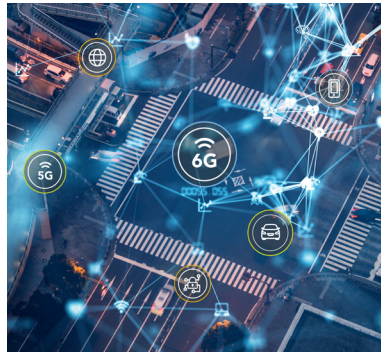
NXP Semiconductors Germany GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
www.nxp.com/support

Japan:

NXP Japan Ltd.
Yebisu Garden Place Tower 24F,
4-20-3, Ebisu, Shibuya-ku,
Tokyo 150-6024, Japan
0120 950 032 (Domestic Toll Free)
www.nxp.com/jp/support/

Asia/Pacific:

NXP Semiconductors Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@nxp.com



CONTRIBUTING AUTHORS

Dick Van Den Broeke, Wim Van Houtum, Kees Moerman,
Ashish Pandharipande, Wim Rouwet and Mark Tomesen

www.nxp.com

NXP, the NXP logo and NXP SECURE CONNECTIONS FOR A SMARTER WORLD are trademarks of NXP B.V.
All other product or service names are the property of their respective owners. © 2022 NXP B.V.

Document Number: 6GWP REV 0