

C-V2X

# Implementation Considerations



# Introduction: Adding safety connectivity to vehicles

C-V2X combines two different communication links:

- > Direct link, used for Vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication. This link operates in the unlicensed 5.9GHz band, using the PC5 interface.
- > Network link, used for Vehicle-to-node (V2N) communication, operating in the licensed spectrum, using the Uu interface.

The two links are fundamentally different. Direct link is used for real-time, safety, short-range communication, while the network link serves Telematics and Infotainment. In the future, 5G might be used for teleoperated driving through the network, but that would require an additional dedicated communication device, on top of today's Telematics Control Units (TCU).

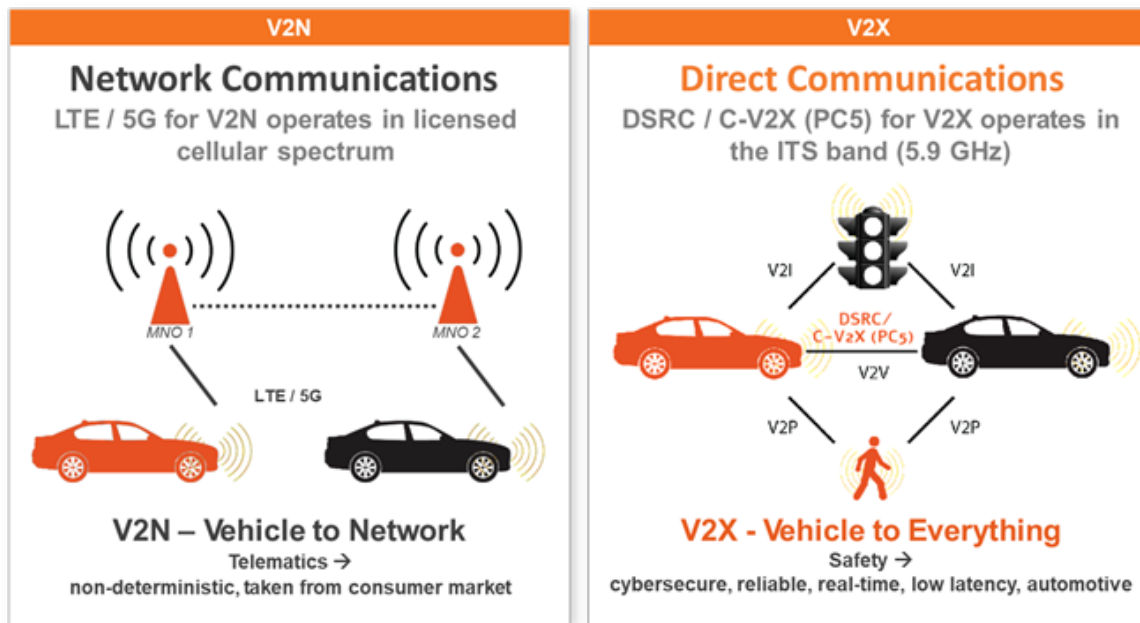


Figure 1 – Vehicle communication types

The term C-V2X is commonly used to represent only the direct link. In this document, any mention of C-V2X or V2X refers only to the direct link.

## Interaction between direct and cellular communication links

### A > Possible vehicle architectures

There are two options of how to add V2X to vehicles: Dedicated ECU, containing only V2X functionality, or TCU, which contains V2X in addition to all other communication links.

Some OEMs strategically prefer dedicated V2X ECU based on some or all of the arguments below:

- > Placement: V2X system is more cost-efficient when placed closer to the roof, which is possible with a dedicated ECU, but more challenging for the entire Telematics unit due to the increased temperature range that needs to be supported in this location
- > Security: Placing V2X in a dedicated ECU assures higher security due to the isolation between safety and non-safety domains, which is generally harder to achieve in TCUs
- > Flexibility: Ability to introduce V2X without a “forced” introduction of a new TCU

Other OEMs favor V2X integration in the TCU, which typically lowers the overall added V2X cost compared with dedicated V2X ECU.

### B > Hybrid communication

Hybrid communication utilizes both V2X and cellular, whichever fits the use-case best. In most cases, the selection is obvious. Safety data is sent through V2X. Non-safety data, such as map and firmware updates, are done over the cellular network. In some cases, both links are used. For example, a broken vehicle would benefit from spreading the alert locally, through V2X, and globally, via the cellular network.

Hybrid communication is technology agnostic. Any cellular technology, LTE (4G) or NR (5G), can work with any V2X technology, DSRC or C-V2X, or their successors. For example. DSRC can be paired with 4G and C-V2X Rel. 14 can be paired with 5G. Data communication through each link is completely independent, disregarding the other link.

A TCU schematically includes two modems, one for the V2V direct link and second for cellular. The host controller controls the communication through the modems. There is no connection between the V2V and cellular modems.

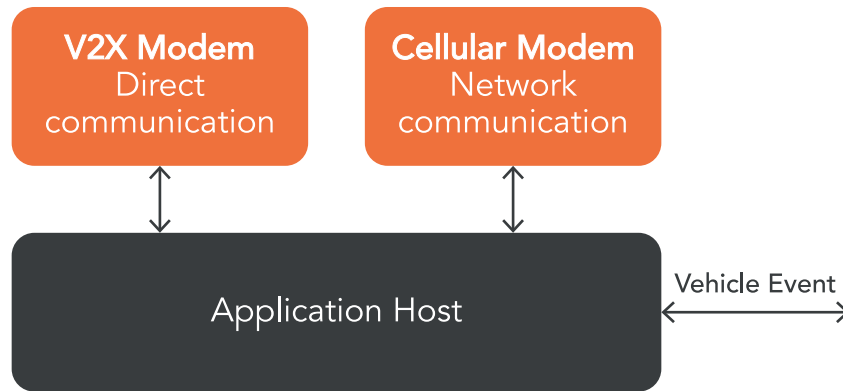


Figure 2 – Hybrid communication system

## C > C-V2X control

The C-V2X direct communication link specification includes control methods through the Uu interface.

### i. Mode 3

C-V2X transmissions are performed in allocated resources. Each resource is defined as a specific time and subchannel.

C-V2X supports two methods for resource allocation. Mode 3, in which the resources are configured in a centralized server, and Mode 4, in which self-resource selection is performed by each vehicle, without using the cellular link. Mode 4 is applying Semi-Persistent Scheduling (SPS), thus selecting the resource that is the least occupied

The effective communication range is decreased if neighboring vehicles are occupying the same resource. Only a single vehicle can be received per resource. An extreme example, just for the sake of illustration, is if the two cars with the red dots, in the picture below, use the same resource, all other vehicles will fail to receive data. In a typical scenario, the two cars with the green dots will share a resource to maximize range.

When the number of vehicles in a given area is higher than the number of resources, suboptimal allocations are made. For example, a car with a green dot will share a resource with a car with a red dot, effectively lowering the communication range.



Figure 3 – Image of highway to explain resource allocation

Resource allocation should be constantly adjusted, as vehicles move in and out of communication range. If two vehicles using the same resource come into range, then the resource of one of the vehicles should be replaced. This can create a chain reaction causing the replacement of other vehicles' resources. The best analogy is the musical chair game. In the game, as with mode 3, there is an attempt to guide competitors to take hold of a chair as the number of people is less than the number of chairs. The game is much simpler than mode 3 scheduler operation, where more vehicles coming from all directions are joining the search for an empty resource.



Figure 4 – Musical chairs game

Communication range changes dynamically influenced by the number of vehicles on the road, the number of connected vehicles in the area, the obstructing vehicles on the road and static obstructions, like buildings, trees, curves, bridges, and more. It is impossible to determine the range without a map with accurate 3D modeling.

A Mode 3 scheduler does not have information about which vehicles are received in which resource. This is in contrast to a Mode 4 scheduler, which bases its decisions on that exact information.

A robust Mode 3 scheduler, working in any road and any traffic load, is extremely complex. In fact, it was never presented or published. Testing of such algorithm will require a tremendous effort.

In comparison, Mode 4 is mature and well tested. The performance exceeds the requirement by far. The usage of mandatory HARQ hides most of the potential scheduling pitfalls since every packet is transmitted twice, and even if one transmission is not scheduled optimally, the second transmission improves the success probability. The technical justification to replace Mode 4 is low to none.

The biggest challenge of Mode 3 is not even the technical feasibility, but the business justification. Each vehicle should constantly receive scheduling messages. Those are calculated in a centralized server. Short-latency communication infrastructure, spanning multiple cellular operators, is required to make this a reality. But who will pay for all of this? For the purchase of infrastructure and usage of the communication bandwidth and servers? The driver does not care about scheduling performance, and wouldn't agree to pay. Safety should be provided for free for the lifetime of the vehicle. The OEMs are cost sensitive, and gain nothing from Mode 3. The cellular operators want to make money, and not to spend it. Mode 3 costs a lot of money and does not generate income to any party.

Mode 3 is not getting closer to deployment. The GCF certification plan, which is aligned with 5GAA, does not include Mode 3, not even as a roadmap item.

Some portray Mode 3 as the future of C-V2X, but that future is very far away and most probably will never be reached. For all practical reasons, Mode 4 should be the only target mode of operation in C-V2X deployments. Same conclusion was reached by ConVeX project<sup>1</sup>.

## ii. SIB21

C-V2X devices are pre-configured based on SAE J3161 in the US or its Chinese equivalent YD/T 3756-2020.

Remote configuration could be broadcasted using System Information Block 21 (SIB21).

```
SystemInformationBlockType21-r14 ::= SEQUENCE {
    sl-V2X-ConfigCommon-r14          SL-V2X-ConfigCommon-r14          OPTIONAL, -- Need OR
    lateNonCriticalExtension          OCTET STRING                     OPTIONAL,
    ...
}

SL-V2X-ConfigCommon-r14 ::= SEQUENCE {
    v2x-CommRxPool-r14               SL-CommRxPoolListV2X-r14          OPTIONAL, -- Need OR
    v2x-CommTxPoolNormalCommon-r14   SL-CommTxPoolListV2X-r14          OPTIONAL, -- Need OR
    p2x-CommTxPoolNormalCommon-r14   SL-CommTxPoolListV2X-r14          OPTIONAL, -- Need OR
    v2x-CommTxPoolExceptional-r14     SL-CommResourcePoolV2X-r14        OPTIONAL, -- Need OR
    v2x-SyncConfig-r14               SL-SyncConfigListV2X-r14          OPTIONAL, -- Need OR
    v2x-InterFreqInfoList-r14        SL-InterFreqInfoListV2X-r14      OPTIONAL, -- Need OR
    v2x-ResourceSelectionConfig-r14   SL-CommTxPoolSensingConfig-r14   OPTIONAL, -- Need OR
    zoneConfig-r14                   SL-ZoneConfig-r14                 OPTIONAL, -- Need OR
    typeTxSync-r14                   SL-TypeTxSync-r14                 OPTIONAL, -- Need OR
    thresSL-TxPrioritization-r14      SL-Priority-r13                 OPTIONAL, -- Need OR
    anchorCarrierFreqList-r14         SL-AnchorCarrierFreqList-V2X-r14  OPTIONAL, -- Need OR
    offsetDFN-r14                     INTEGER (0..1000)                 OPTIONAL, -- Need OR
    cbr-CommonTxConfigList-r14        SL-CBR-CommonTxConfigList-r14   OPTIONAL, -- Need OR
}

-- ASN1STOP
```

Figure 5 – SIB21 content (taken from <http://spectracells.com/2018/09/07/cv2x/>)

The idea behind SIB21 is appealing. Remote configurations of a network always seem useful. But the reality is different.

- > Misconfiguration: SIB21 can be viewed as a giant off-switch that can shut-down the entire C-V2X operation, intentionally or accidentally. For that reason, it is explicitly prohibited in the US (see ahead).
- > Unexpected operation: A safety network is not an environment for trial-and-error. The C-V2X profile is well tested and robust. Vehicles are tested extensively for operating within the profile. Changing the profile might lead to failures due to deployed vehicles with V2X units operating outside their specification.

<sup>1</sup> [https://convex-project.de/onewebmedia/D3.2\\_Radio\\_Performance.pdf](https://convex-project.de/onewebmedia/D3.2_Radio_Performance.pdf)



> Inconsistent configuration: Might prevent vehicle communication. For example, notice the three vehicles marked in the picture below. The first is receiving new SIB21 from the base-station in the picture. The second is connected to another cellular operator, which is not sending SIB21 messages. The third has yet to establish a cellular link. The configuration of the first vehicle is probably different than those of the second and third vehicles.



Figure 6 – Image of vehicles in a parking lot

### iii. C-V2X operation profile

#### 1 - US

C-V2X operation in the US is defined by the SAE J3161/1 profile “On-Board System Requirements for LTE-V2X V2V Safety Communications”. The profile explicitly states that C-V2X cannot use any information from Uu: “A Universal Subscriber Identity Module (USIM) and Radio Access Network (RAN) infrastructure are not required to implement the functionality specified in this document.”. The OBU block diagram reaffirms this by excluding the cellular modem:

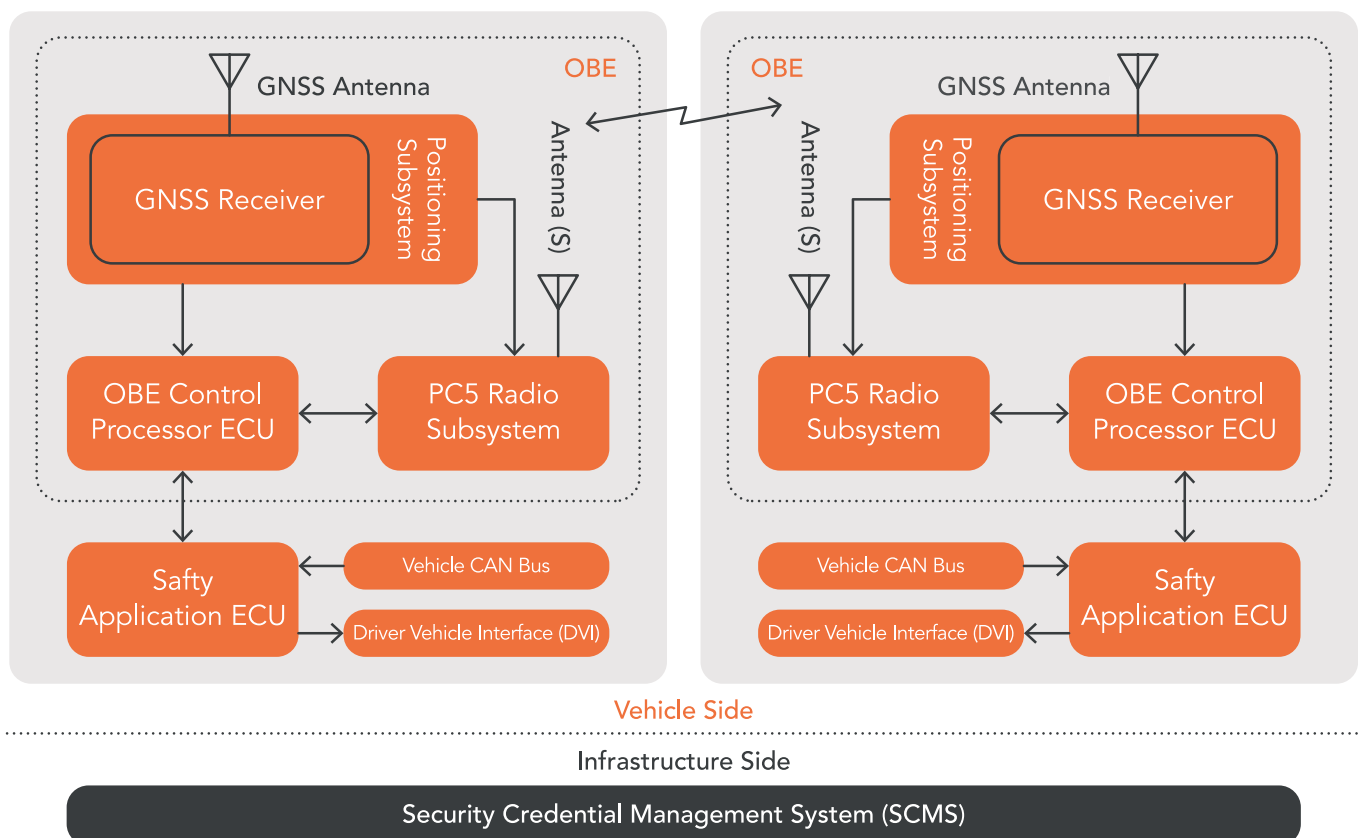


Figure 7 – Onboard V2V system (from SAE J3161/1)

The profile allows only Mode 4 ("UE has no serving cell means the System does not require an infrastructure. Autonomous resource selection using mode 4 is implemented"), and does not allow SIB21 ("only operation without use of infrastructure is supported, i.e. the parameters cannot be updated dynamically").

## 2 - China

The Chinese profile, YD/T-3756-2020, defines four terminal types:

LTE-V2X车载终端根据其支持的通信方式不同，可分为如下类型：

类型A：只支持直通链路（PC5）通信发送模式4；

类型B：支持直通链路（PC5）通信发送模式4和LTE Uu通信，但不支持基站对模式4配置；

类型C：支持直通链路（PC5）通信发送模式4和LTE Uu通信，并支持基站对模式4配置；

类型D：支持直通链路（PC5）通信发送模式4、发送模式3和LTE Uu通信，并支持基站对模式4和模式3的配置。

Figure 8 – Terminal type definition (from "technical requirement of vehicle terminal for LTE-based vehicular communication")

Terminal type	Mode 4	Uu	SIB21	Mode 3
A	√	X	X	X
B	√	√	X	X
C	√	√	√	X
D	√	√	√	√

Table 1 – English translation of Terminal type functionality

Terminal types A and B support only Mode 4, and SIB21 is not included. In the upcoming years, only Types A and B will be considered for deployment.

## D > Summary

A compliant C-V2X system does not require any interaction with cellular modems. Hybrid data communication uses the two links, cellular and V2X, independently. A control interface between the two modems is not required in the upcoming years, and considering the challenges, most likely will never be required. It is very hard to justify any linkage between C-V2X and cellular modems in V2X deployment.



### 3 C-V2X TCU architecture analysis

#### A > Integrated and isolated systems introduction

Two potential C-V2X system implementation models are considered, distinguished by the functionality integrated with the modem.

##### > Integrated C-V2X and cellular solution

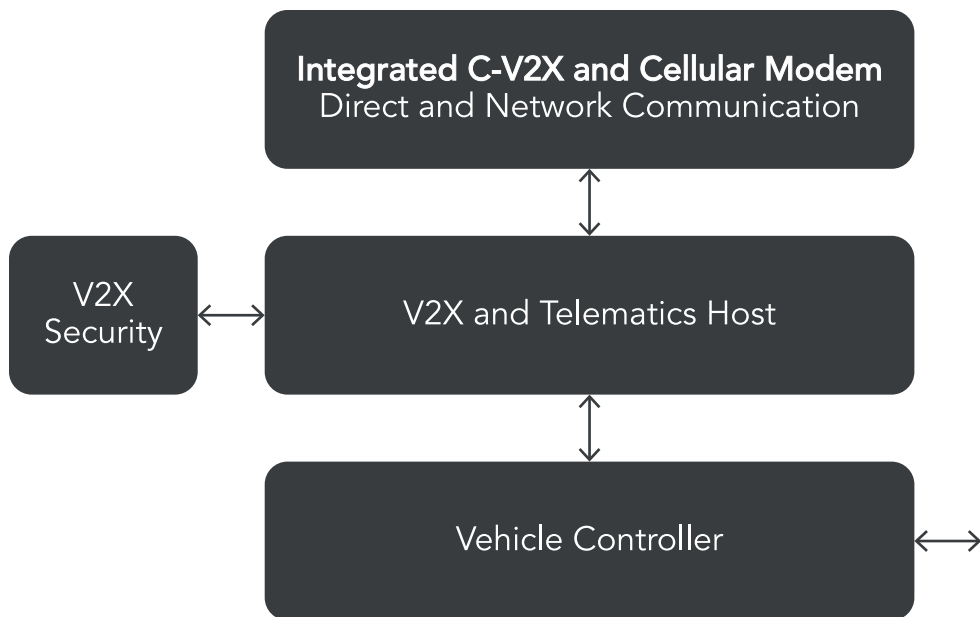


Figure 9 – Block diagram of an integrated C-V2X and cellular solution

##### > Isolated C-V2X and cellular domains

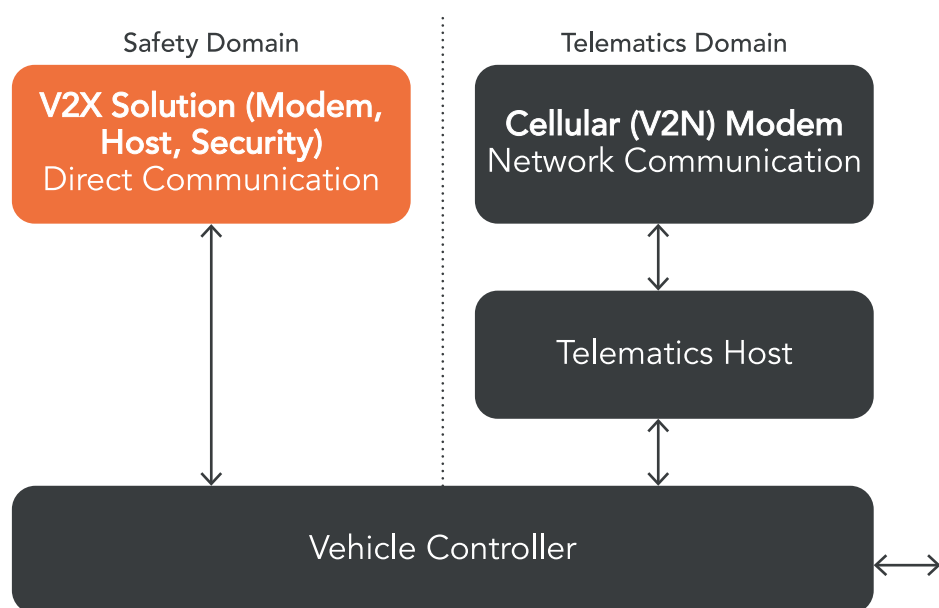


Figure 10 – Block diagram of an isolated C-V2X modem

## B > Analysis of the different concepts

### i. Access to cellular data

An integrated C-V2X modem is tightly coupled with the cellular modem. All cellular modem data and control information is accessible to C-V2X.

There is no technical limitation for an isolated C-V2X modem to access the cellular modem control information.

As explained in the previous section, there is simply no need for a control interface. Both isolated and integrated systems can be compliant.

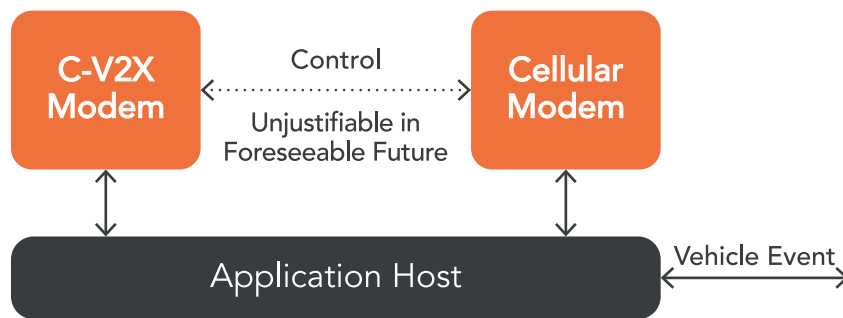


Figure 11 – Block diagram of combining modems of different vendors

### ii. Operating temperature

The introduction of 5G pushes Telematics units closer to the roof. COAX cabling toward the antenna should be shortened because 5G is using higher frequency bands than 4G. Any electronic component placed on a vehicle's roof, or in the headliner, should operate at 105° ambient temperature. Dark roof surfaces, under direct sunlight, can reach 85°, as was shown by research conducted by Lawrence Berkeley National Laboratory<sup>2</sup>. The required operating temperature of the electronic components is higher since the components generate additional heat, without ability to evict it through the enclosure.

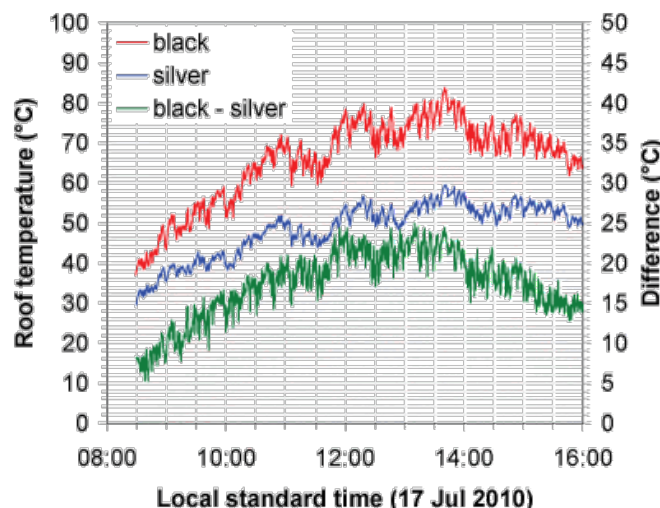


Figure 12 – Roof temperature measurements of Lawrence Berkeley National Laboratory

<sup>2</sup> "Potential benefits of solar reflective car shells: Cooler cabins, fuel savings and emission reductions." Ronnen Levinson, Heng Pan, George Ban-Weiss, Pablo Rosado, Riccardo Paolini, and Hashem Akbari, published in the journal Applied Energy (Volume 88, pp. 4343–4357).

An isolated V2X modem is specifically built for sustaining high operating temperatures.

A cellular modem with Integrated V2X originates from the consumer market. Temperature range is much narrower. A 5G modem includes massive signal processing circuitries leading to high power consumption upon operation. Techniques like shutting down functionality can help reach 85° operating temperature, as implemented for example to support eCall. It would be very challenging to assure continuous V2X operation at 105°.

### iii. Cost

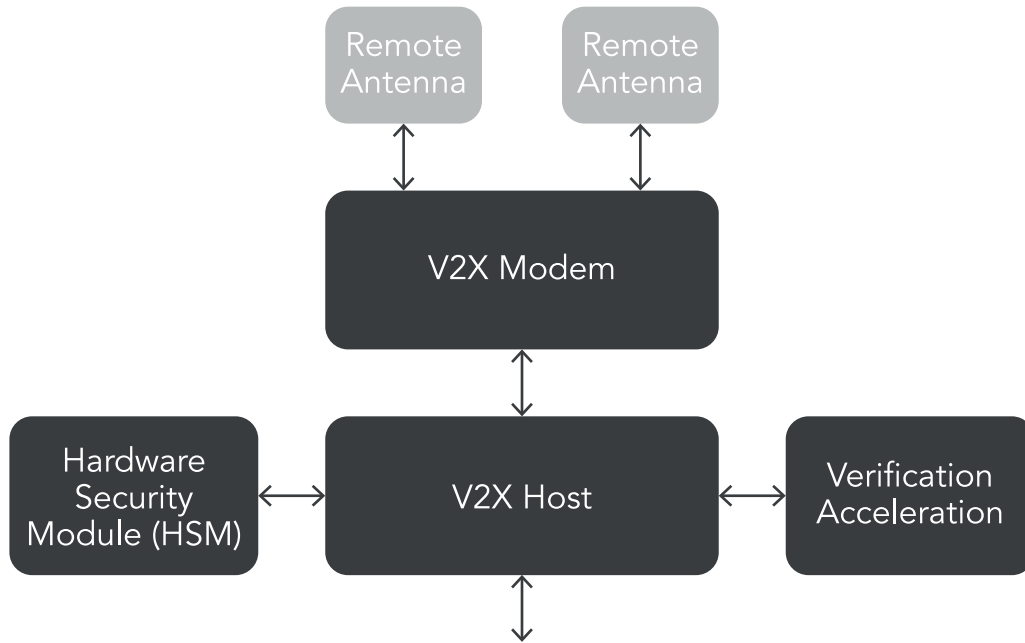


Figure 13 – System building blocks for cost calculation

Silicon integration is common practice to reduce system costs. Integrated C-V2X integrates the C-V2X modem with the cellular modem, while the remaining building blocks are left outside. On the other hand, the isolated V2X solution integrates the C-V2X modem with security functionality and host, while detached from the cellular modem.

Additional system elements can be optimized for cost. Autotalks' whitepaper "Cost efficient C-V2X antenna installation" shows how cost can be reduced by using a single antenna or by eliminating the cable compensator in the front antenna thanks to TX diversity.

Overall, in a competitive market, a solution has no justification if it has a higher cost than its competitor while serving the same exact purpose. Both systems, isolated and integrated, can be used to build a competitive solution. Yet, the integration of the V2X modem with security functionalities provides the best safety / cost-efficiency balance.

#### iv. Flexibility

The Automotive market will adopt 5G modems. The high-end vehicles will be the first, followed by the rest. The adoption pace depends on the cost difference between 4G and 5G and the added value of 5G over 4G. It seems that in the upcoming years, due to the cost difference, 4G will still be used by the majority of the market. On the other hand, safety should be accessible to everyone as quickly as possible; drivers of expensive vehicles as well as the less-expensive. V2X should be made available with 4G, even with low speed categories (Cat), which suits most vehicles. C-V2X integrated solutions commonly implement high speed categories (Cat), and do not efficiently support low-cost, low-speed categories.

OEMs and Tier1s realized that developing a generic platform, which can be tailored with minimal effort to a specific need, is cheaper than developing multiple solutions, each requiring its own development, testing and certification. With integrated C-V2X, the V2X functionality is re-developed, re-tested and re-certified. While isolated C-V2X allows the system to grow, change, use different cellular modem, without unnecessarily repeating the V2X development. This also simplifies management over the vehicle lifetime. Potential upgrades can be executed once using a single platform, rather than multiple times per the number of solutions.

Global platform would require support of two V2X technologies, adding DSRC on top of C-V2X. Isolated C-V2X, with dual-mode DSRC / C-V2X, addresses that target.

#### v. Security

V2X is the first wireless communication capable of alerting the driver and impacting vehicle movement. Secure operation is of the essence.

Using Hardware Secure Module (HSM) to store the private keys and certificates for signing outgoing messages is a global mandatory requirement.

The recent introduction of UNECE WP.29 dramatically increases the certification scope. A car can be sold in Europe, Korea and Japan only if proven to be cybersecure. Threat, Vulnerability and Risk Assessment should be performed for the entire TCU, for V2X and other communication channels.

Vulnerabilities always exist. The Common Vulnerabilities and Exposures (CVE) system provides a reference-method for publicly known information-security vulnerabilities and exposures. The National vulnerabilities database is maintained by NIST<sup>3</sup>. The number of vulnerabilities increases with code size and decreases with code maturity. Cellular and Telematics code size is far higher than that of V2X. Cellular technology is constantly evolving, especially with the major leap toward 5G, as was

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<sup>3</sup> <https://nvd.nist.gov/>

highlighted by a risk assessment report of the European Commission<sup>4</sup>. On the other hand, V2X stack and access layers are relatively stable. Consequently, the number of vulnerabilities in V2X is expected to be orders of magnitude less than the number of vulnerabilities in Telematics.

Today V2X can alert the driver of potential dangers, but in the future V2X will influence automatic vehicle braking. Potentially exploitable V2X vulnerabilities may therefore impose high risk. On the other hand, other communication interfaces, such as cellular network, are not related at all to vehicle braking. For this reason, the risk severity of potentially exploitable Telematics vulnerabilities is much lower than that of V2X.

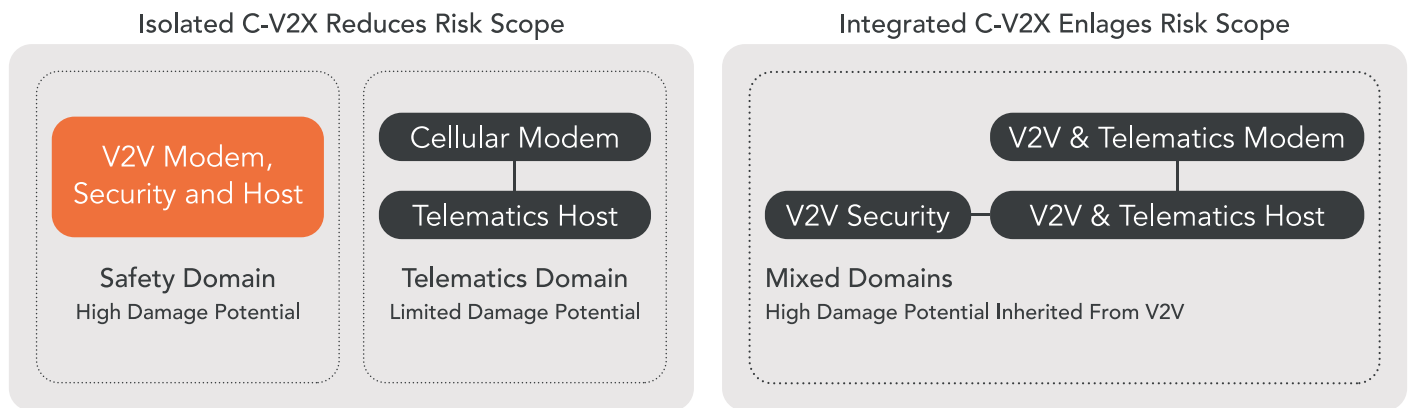


Figure 14 – Vulnerabilities of different systems

Risk analysis of an isolated V2X system can separate V2X threats from Telematics threats. Security Analysis and mitigation are simple.

V2X integration casts all V2X threats on Telematics and vice versa, increasing the span of analysis and imposing more mitigation techniques. Virtualization techniques may be used, but do not match the assurance provided by air gap, as exists in the isolated V2X system.

#### vi. Ability to control the vehicle

The goal of V2X is preventing accidents. As mentioned above, the first V2X use-cases issue alerts to the driver. In the not-too-distant future, vehicle will be able to autonomously slow down in order to prevent an accident based on information coming from the V2X sensor.

Any device capable of influencing vehicle control has to undergo ISO26262 functional safety analysis. V2X is not different. A vehicle using V2X may cause a life-threatening situation if it mistakenly brakes, or if it fails to prevent an accident. Autotalks published a whitepaper concluding that ASIL B is needed for the V2X processing functionality and interfaces with external systems and ASIL A for the remaining V2X functionality once V2X can influence vehicle control.

<sup>4</sup> <https://ec.europa.eu/digital-single-market/en/news/eu-wide-coordinated-risk-assessment-5g-networks-security>

The isolated V2X device, built specifically for safety, can reach the recommended ASIL with careful methodological design.

In comparison, the integrated V2X device is rooted in the consumer market. It is unprecedented for a consumer device to achieve ISO26262 certification, mostly because it is economically unjustified for a mass-market, consumer-based, cost-sensitive product. The challenge for ISO26262 certification of C-V2X integrated with cellular modem is especially high considering the complexity and large scope of 5G and Telematics implementation.

An example of separating functionality from cellular modem is the GNSS receiver, which is commonly integrated in the cellular modem. When positioning is involved in driving decisions, the GNSS receiver should achieved ASIL B. In that case, an external ASIL B GNSS receiver should be added to the TCU, even when an integrated GNSS receiver already exists. It can be expected that V2X would follow the same logic, and ASIL B will be achieved by using an external V2X device.

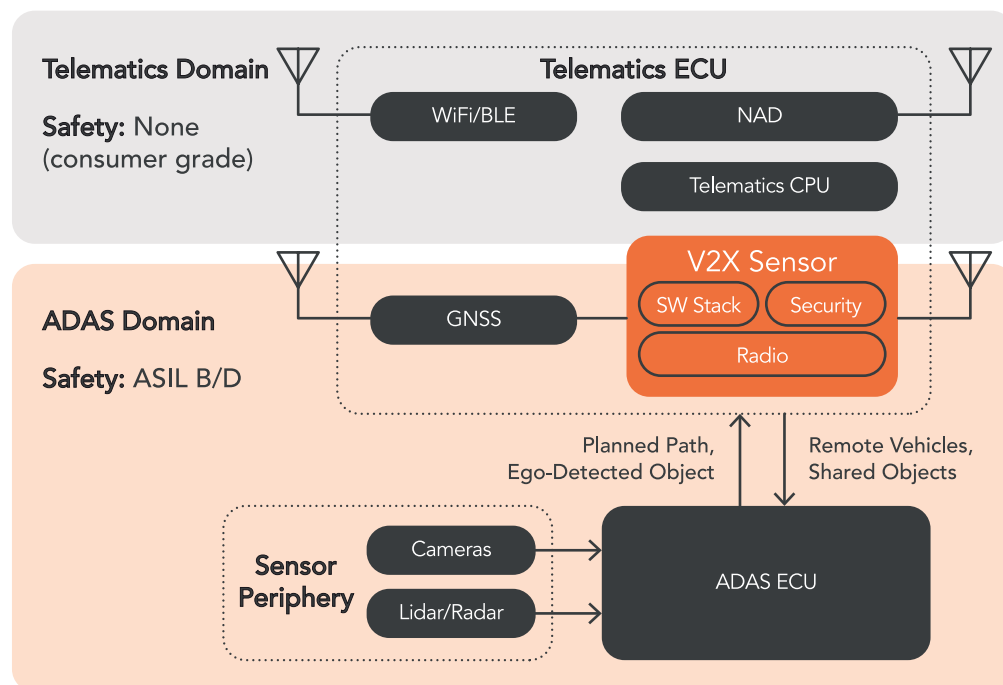


Figure 15 – The V2X sensor as part of the ADAS domain



## C > Summary

Property	Requirement	Integrated C-V2X and cellular modem	Isolated C-V2X and cellular modems
Access to cellular data	Not needed	Assured	Possible
Operating temperature	105° operation	Shutting down functionality to reach 85°	105° operation
Cost	Lowest system cost	Modems integration lowers cost	Security integration lowers cost Antenna installation optimization lowers cost
Flexibility	Single V2X design for all solutions	C-V2X redesign for each flavor	Supporting C-V2X and DSRC
Security	Analyzing and mitigating Threats, Vulnerabilities and Risks	Entire Telematics code, which is evolving and gigantic, should be analyzed and mitigated against safety risks	Clear boundaries of V2X and Telematics simplify analysis and mitigation and enhances security
Ability to control vehicle	ISO26262 ASIL B certification	ISO26262 ASIL B is unprecedented for consumer device	ISO26262 ASIL B is possible with purposely built device

## 4 Conclusion

V2X is a safety technology. A V2X solution should be compliant, cost-efficient, reliable, flexible and secure. The latter requirements are simpler to achieve with an isolated V2X solution.