Evaluating Message Size of the Collective Perception Message in Real Live Settings

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Abstract: The introduction of the Collective Perception Message (CPM) by ETSI offers new possibilities for connected and automated driving by enabling the exchange of object information between several participants. While this is surely beneficial, it also leads to higher load on the communication channel, which poses a problem, especially when considering IEEE 802.11p V2X communication. To overcome this problem, several mitigation strategies were formulated by ETSI. In the literature, several simulation studies regarding the effect on the communication can be found. Goal of this paper is to enrich the discussion with measurements from a real vehicle, showing how many objects might be available for CPM inclusion in the near to mid future.

1 INTRODUCTION

Modern vehicles are equipped with various sensors (e.g., LIDAR, RADAR, cameras), which are used to provide safety (e.g., lane keeping assistant) and comfort (e.g., Adaptive Cruise Control (ACC)) functions. Nonetheless, some objects might be invisible to the existing sensors due to occlusion or insufficient sensor range. Communication offers one possibility to retrieve the missing information, which can be used to improve the situational awareness of a given vehicle. In addition, even older vehicles with unsophisticated or non-existing sensors can profit from such communications. To this end, ETSI published a first draft of the Collective Perception Message (CPM) (ETSI TR 103 562 V2.1.1 (2019-12), 2019), which is used to exchange information about detected objects. These objects are either dynamic (e.g., other vehicles or pedestrians) or static. In the latter case, only objects on the road are of interest.

While the benefit of the CPM is unquestionable, it also has a drawback in form of increased channel load. To minimize the impact, ETSI TR 103 562 V2.1.1 (2019-12) (ETSI TR 103 562 V2.1.1 (2019-12), 2019) proposes an algorithm for the dynamic generation of CPMs as well as several mitigations for decreasing the communication load, which are verified using simulations. A recent study (Delooz et al., 2020) implies that mitigations are not necessary in current scenarios with only a few vehicles equipped, while the authors of the CPM draft show their effectiveness in a very large scale scenario. In addition, Thandavarayan et al. (Thandavarayan et al., 2020) propose a reorganization of contents and the transmission to improve the overall Collective Perception Service (CPS). All of the aforementioned studies concentrate on the communication side of the CPM and consider perfect, possibly even 360°, sensors and do not take into account issues, e.g., of occlusion. On the other hand, Schiegg et al. (Schiegg et al., 2020) consider a sophisticated sensor model in the CPM generation.

While it is true that the upcoming CPS should be able to cope with (near to) 100% equipment rate and future superior sensor setups, we want to enrich the discussion with a short to mid term perspective. In order to do so, test drives in different environments with an experimental vehicle (having a sensor setup superior to most of todays series vehicles) where conducted and the number of objects to be included in the CPM are evaluated following different strategies for inclusion. The test drives were controlled by the testing framework introduced in the ErVast project, which is concerned with how advanced driving technologies, like connected or automated driving, can be tested during the general inspection and how such test scenarios can be derived in the first place.

This paper is organized as follows: The next section gives a short introduction in the Collective Perception Service (CPS) as outlined in (ETSI TR 103

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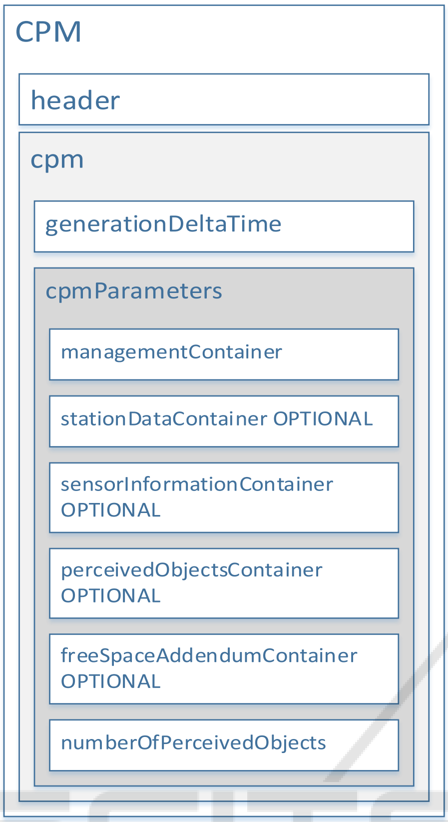

Figure 1: Collective Perception Message (CPM) message format as defined by ETSI (ETSI TR 103 562 V2.1.1 (2019-12), 2019).

562 V2.1.1 (2019-12), 2019) as well as the proposed mitigation strategies. Section 3 describes the experimental setup used in this study, whereas Section 4 presents the results. The paper is concluded in the final section.

2 COLLECTIVE PERCEPTION MESSAGE (CPM)

The CPM as introduced in (ETSI TR 103 562 V2.1.1 (2019-12), 2019) is still in a draft version. Nonetheless, the basic functionality is already defined, with changes only to be expected for some specific data fields, e.g., field sizes or encoding. Figure 1 shows a basic overview over the different containers included in the CPM. It is notable that vehicles as well as infrastructure elements can act as a source. The most significant difference between these two is the way the sensors can be described. In addition, only infrastructure is allowed to collect Cooperative Awareness Message (CAM) of surrounding vehicles and repeat them via CPM. In the following, we will only consider CPMs generated in the experimental vehicle. Please note that the stationDataContainer is mandatory in this case.

Like the CAM, CPMs are to be generated with a frequency between 1 – 10 Hz, where the rules of including a sensed object are similar to the CAM update rules, e.g., including an object if it moved more than 4 meters since it was last included in a CPM. The maximum number of objects, which could be included into one message, are 128, which is the same as for the maximum number of sensors. The proposed message format supports segmentation using a more versatile approach, i.e, having a specific data element for segmentation, than the simple approach used in the Map Extended Message (MAPEM) (ETSI TS 103 301 V1.3.1 (2020-02), 2020).

2.1 CPM and ETSI ITS-G5 Communication

As already mentioned above, the introduction of the CPM will lead to a higher load on the communication system, especially when considering ETSI ITS-G5. While a complete simulation is out of the scope of this paper, we want to give a rough estimate of the impact of the CPM. For this, we rely on the work of Jacob et al. (Jacob et al., 2020), who simulated the Packet Reception Ratio (PRR) vs. communication distance of 300 Byte packets (about the size of a CAM sent from a vehicle) using a highway scenario, IEEE 802.11p and various load conditions. Their setup consists of a sending beacon and several probe vehicles located at defined distances to the beacon as well as different number of additional communicating vehicles. Then

$$PRR(\rho, d) = \frac{N_{recv}(\rho, d)}{N_{total}},$$

where ρ is the density of additional communicating vehicles, d is the distance of the probe vehicle to the beacon, $N_{recv}(\rho, d)$ is the number of message actually received from the beacon at distance d, and N_{total} is the total number of messages sent by the beacon. Typically, $N_{recv}(\rho, d)$ is smaller than N_{total} due to fading effects and multi-user interference. Take, for example, a load of $\rho = 20 \quad vehicles/km/lane$. Then the PRR at $100m$ and $250m$ for Line of Sight (LoS) communication, given by (Jacob et al., 2020), is 68% and 47%, respectively. If one assumes that CPMs are sent as well (with the same frequency of $10Hz$), the number of messages doubles, which is comparable to the simulations using $\rho = 40 \quad vehicles/km/lane$. This reduces the PRR to 25% and 14%, respectively, which can be considered as much worse communication conditions. This simple calculation does not even take into account that CPMs are usually larger than the 300 Bytes used in the study, leading to more multi-user interference and even lower PRR values. Considering this, the segmentation of messages, which can happen easily in ETSI ITS-G5 with its Maximum Transfer Unit (MTU) of just 1,500 Byte, can be seen as problematic as this would lead to even more packets being sent. This gives rise to the mitigation techniques described below, which aim at reducing the amount of CPMs being sent.

2.2 Mitigation Techniques

Although mitigation techniques are not considered in this work, they are introduced here to show how they might impact the amount of objects included in the messages. All mitigation rules rely on the reception of CPMs from other participants, therefore, only little impact is to be expected in short to mid term since equipment rates are expected to be rather low in the foreseeable future. All in all, six different mitigations are proposed in (ETSI TR 103 562 V2.1.1 (2019-12), 2019):

Confidence based: If the object confidene in the ego station is lower than the confidence in one of the received CPMs then the object is excluded.

Distance based: If the object is already included in a CPM by another participant, which is near to the own station, the object is not included again.

Dynamics based: If the dynamic state of the object has not changed by a certain amount since it was last received in a CPM (similar to CAM generation rules) it is not included.

Entropy based: Checks for every communication partner if the inclusion of the object would improve the respective local tracking. If there is improvement for at least one partner, the object is included, otherwise excluded.

Frequency based: Object is excluded if it appeared in more than a given threshold of received CPMs.

Self Announcement: Every participant who sends a CAM is not included as object.

Please note that applying these mitigation rules necessitates to uniquely identify the objects over the several participating stations. This is not a given since one station might, for example, detect the front of a truck whereas the other detects the rear.

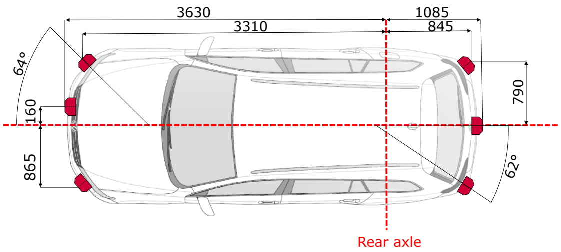

Figure 2: Positioning of the Ibeo Scala sensors on the experimental vehicle.

3 EXPERIMENTAL SETUP

Here, we will introduce our experimental vehicle and describe the test setup used.

3.1 Experimental Vehicle

The test vehicle used in this study is a VW Passat retrofitted with additional sensors. Its series sensors consist of radar sensors in the front and rear, ultra sonic sensors around the whole vehicle, a front facing camera and additional area view cameras in the side mirrors. The newly installed sensors consists of six Ibeo Scala sensors (first generation, see Figure 2 for their location on the vehicle) and two roof mounted Velodyne 16 sensors. This vehicle is a twin to the vehicle introduced in (Auerswald et al., 2019).

3.2 Test Setup

As the goal of the study is to get an impression about the current state, no new sensor fusion algorithms were implemented. Rather, data and algorithms already existing in the automotive domain were used. This excludes using the Velodyne sensors as they only deliver point cloud data and additional processing would be required. Besides, the authors do not see roof mounted sensors in mainstream automotive design, at least for the near future. In contrast, the Ibeo Scala sensors deliver already classified objects. In addition, these sensors are already utilized in series vehicles, e.g., some Audis employ a pair of those. Objects detected by the Scala sensors are queried using the Scala Udp Based Transport Protocol (Henning and Kleiser, 2016), whereas objects from the series sensors are provided via a proprietary CAN connection supplied by the manufacturer of the experimental vehicle. The current position is available via CAN as well. As the generation of the CPM is rather involved (e.g., for static objects it has to be determined whether they are on the road), we opted to count the objects detected by the sensors, with one caveat mentioned below, and do not carry out any steps of fusion or the inclusion algorithm presented by ETSI in Figure D.2 of (ETSI TR 103 562 V2.1.1 (2019-12), 2019). This is done in order to prevent a benchmark of our own implementation instead of the capabilities of the test vehicle. As such, the numbers presented here can be seen as an upper limit to the objects actually included in the CPM. The Scala sensors, in particular, detect a lot of static objects, like curbs or bushes (see also Figure 4). As such items do not belong into the CPM, they have to be detected from the sensor data. This could, in theory, be done using HD maps to determine the objects' absolute positions, but since this would again mean implementing an own algorithm, it was instead chosen to only include objects explicitly classified as road users. For example, out of all the 47 objects shown in Figure 4 only one would be reported (the one detecting a parking vehicle). While this seems very conversative, the authors feel that this is the better approach instead of littering the channel with possibly useless data.

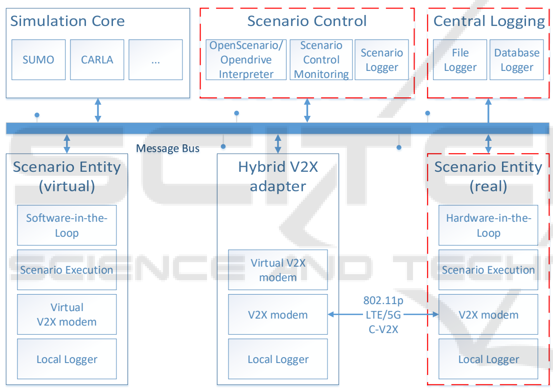

Figure 3: Testing framework developed in the ErVast project. The parts utilized in this study are marked with a red dashed line. Figure adapted from (Klöppel-Gersdorf and Otto, 2020).

The test drives were planned using the ErVast testing framework shown in Figure 3. While the framework also allows to test Vehicle-to-Everything (V2X) communication, here only the scenario planning and especially logging solutions were employed. Nonetheless, the full framework can be employed once the CPM generation is completely set up. The udp data streams from the sensors as well as CAN data were logged in the vehicle (called Scenario Entity (real) in the figure) using a local logger. After finishing the scenario, all data was transmitted to the Central Logging instance for further postprocessing. This approach allows to replay a certain test drive and evaluate additional measures as the full sensor log is available. The postprocessing step mainly consists of evaluating the performance indicators, i.e., in the given case the number of detected objects, but also generates a visual representation of the test drive using streetscape.gl (Uber ATG and VIS.GL, 2020) as seen in Figure 4, which allows an easy monitoring and also facilitates an effective bug fixing.

3.3 Message Size Evaluation

In this part, the storage size requirements of a single object inside a CPM are examined. Two different scenarios are considered (see Table 1 for a detailed statistic): To get an upper bound it is assumed in the first scenario (denoted *complete*) that all optional fields are filled with data. Furthermore, it is assumed that a maximum of four sensors contribute to the detection of one object. This is essential, since the standard allows to specify up to 128 different sensor identifiers, leading to a maximum storage requirement of 128 Bytes for the sensor identifier list alone. For every object up to eight different classifications plus the corresponding confidences can be given. It is assumed that all eight classifications are used in this scenario. In total this leads to a storage requirement of 61.25 Byte or 490 Bits per object. In the second

Table 1: Size of the PerceivedObjectContainer.

	Optional?	Complete	Available
objectId		8 bit	x
sensorIdList	x	32 bit	x
timeOfMeasurement		12 bit	x
objectAge	x	11 bit	x
objectConfidence		7 bit	x
xDistance		25 bit	x
yDistance		25 bit	x
zDistance	x	25 bit	-
xSpeed		23 bit	x
ySpeed		23 bit	x
zSpeed	x	23 bit	-
xAcceleration	x	16 bit	-
yAcceleration	x	16 bit	-
zAcceleration	x	16 bit	-
yawAngle	x	19 bit	x
planarObjectDimension1	x	17 bit	x
planarObjectDimension2	x	17 bit	x
verticalObjectDimension	x	17 bit	-
objectRefPoint		5 bit	x
dynamicStatus	x	2 bit	x
classification	x	120 bit	15 bit
matchedPosition	x	31 bit	-
Total		490 bit	241 bit

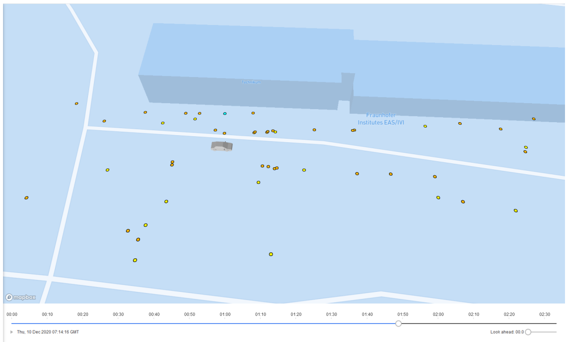

Figure 4: Screenshot of the streetscape.gl (Uber ATG and VIS.GL, 2020) visualization of the parking lot test case. Orange markers denotes object classified as *unknown large* objects, whereas yellow markers denote *unknown small* objects. The single cyan marker directly above the vehicle denotes a correctly detected parking vehicle. Most of the unknown objects either belong to building walls, bushes, trees, or the curb.

scenario (denoted *available*), only the fields actually available in the given test vehicle are considered. As can be seen from Table 1, only some of the optional fields can actually be filled. Also, since the current sensor setup returns only one single object class, the *classification* data field is smaller than in the *complete* case. This results in a storage requirement of 30.125 Byte or 241 bit, less than half the requirement of the *complete* case. Please note, that Unaligned Packed Encoding Rules (UPER) are used, i.e., in addition to the storage requirements for the single fields there is also overhead for handling, e.g., optional fields and sequences. Since this overhead changes depending on the concrete message contents, it was not included in the above numbers.

4 RESULTS

A total of two test drives were conducted. Where the first test drive was mainly for bug fixing and evaluation of the sensor performance, the second test was conducted in real traffic. Figure 5 shows the maximum distance of the detected objects from the vehicle for both test scenarios. Whereas the parking lot scenario is rather confined, with typical distances about 20–30m, the more open layout of the public road network can be seen with typical detection ranges of up to 100m and maximum detection range of over 300m.

4.1 Parking Lot Scenario

The first test drive took place on the 13th of November 2020, 4:30 p.m. in Dresden, Germany, at the parking lot of our institute. As this was the end of the week,

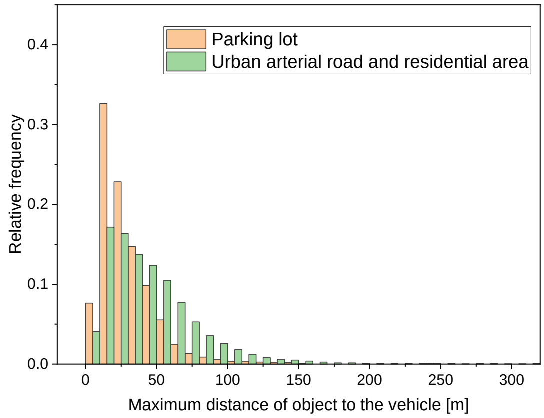

Figure 5: A histogram of the maximum distance between the detected objects and the test vehicles in the two test scenarios, respectively. It is clearly visible that detection ranges are higher in the urban arterial road and residential area case.

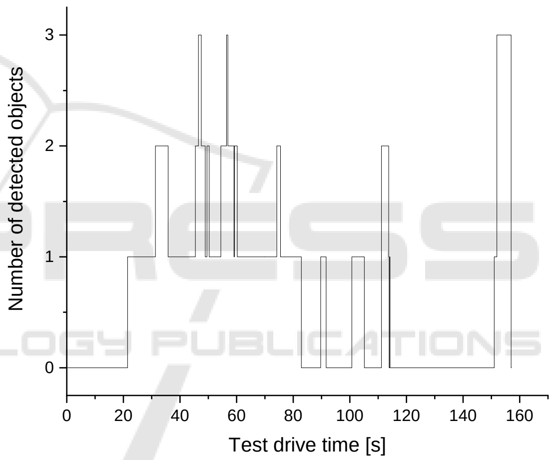

Figure 6: Number of suitable objects detected by the test vehicle during the test drive on the parking lot. Total test duration is 160s, measures were taken for every 0.1s interval.

the occupancy of the parking lot was rather low and there was no dynamic activity by other pedestrians or vehicles. Figure 6 shows the number of objects detected during the 160 seconds of the test drive. As both the series as well as the additional sensors have problems classifying parking vehicles as such, only very few objects were actually detected. With a maximum of only three objects detected a mere 184 Byte would be required in the CPM with a *complete* container and only 91 Byte when considering *available* information, much lower than the MTU of 1500 Bytes in ETSI ITS-G5 communication even when considering the other necessary containers.

Figure 7: Route of the test drive through residential and urban arterial roads. Total trip length was 7.8 km with a total trip duration of 18 min.

4.2 Urban Arterial Road and Residential Area

The second test drive took place on the 18th of December 2020, 4:30 p.m, also in Dresden, Germany. While under normal conditions this would be a time of rush hour, the traffic was massively reduced due to the COVID-19 pandemia. The test drive can roughly be seperated into five parts as is visible from Figure 8. The first 150 seconds are used to get through residental area to the urban arterial roads. The next segment contains a drive along Bergstraße, Zellescher Weg, and Teplitzer Straße (all three of them major urban arterial roads, all with two lanes per direction) till the 500 seconds mark. This is also visible in the number of detected objects, which goes up to 29 maximum during this period. Afterwards, till the mark of 920 seconds, a drive through residential area followed, which in turn was followed by a drive on Bergstraße (same as above) for about 80 seconds. The last segment was the return to the origin, again through residential area. The complete route is shown in Fig. 7.

There is a clear difference between the number of objects detected on the urban arterial roads (maximum of 29 objects detected) in contrast to the more quiet residential areas (maximum of 14 detected objects). Considering the *complete* perceivedObjectContainter case, 14 objects, with a total storage requirement of about 858 Bytes, still fit into one CPM, which is not the case for the 29 detected objects seen on the urban arterial roads. With a storage requirement of about 1777 Bytes, a segmentation of the CPM is definitely necessary. When only considering the *available* object information, storage requirements are 422 Bytes (residential area) or 874 Bytes (urban arterial road), both still fitting into a single CPM.

4.3 Discussion

The results show that the test vehicle can detect up to 29 objects at a single time interval. This means that even for a contemporary vehicle message segmentation might be necessary in the CPM when considering complete object information and if no other measures, like mitigation strategies, are taken. What make things worse is that a need for segmentation appears in a scenario with a lot of potential communica-

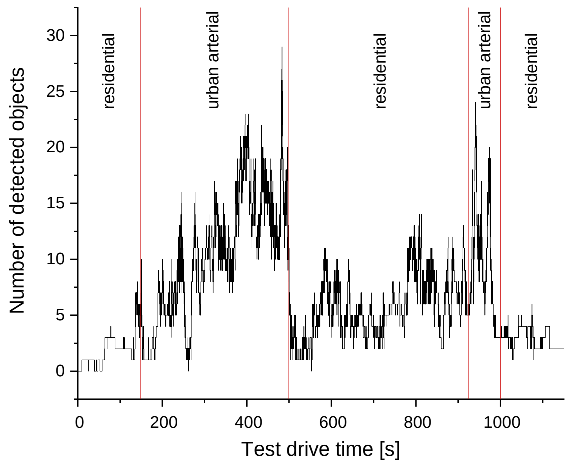

Figure 8: Number of suitable objects detected by the test vehicle during the test drive on urban arterial roads (Bergstraße, Zellescher Weg, Teplitzer Straße in Dresden, Germany) and residential areas. Total test duration is 1150s, measures were taken for every 0.1s interval.

tion partners, which might themselves detect a similar amount of objects. This gives rise to the idea to adapt the CPM generation rules to the current driving environment, e.g., sending information with 10 Hz on residential roads and using mitigation techniques on the larger urban arterial roads as well as on highways. While this proposal is backed by the initial data, much more test drives would be required to determine its actual feasibility. One could also consider if it is useful to use the perceivedObjectContainer to its full extent allowed by the specification. In particular, giving only two classification results instead of the allowed eight would reduce storage requirements in the 29 objects case by 326 Byte alone, although this is still not enough to avoid message segmentation. On the other hand, when only considering information currently available, all 29 objects can be transmitted in a single CPM. On a more general note, inclusion of specific optional information in the CPM could be made dependent on the amount of objects sensed by the vehicle. For instance, even when giving complete information, about 20 objects (depending on the size of the other containers) can be included in the CPM without the need for segmentation. This number increases to 40 objects when considering the information available at the experimental vehicle. Finally, when sending only the required data fields, up to 75 objects can be included.

5 CONCLUSIONS

In this paper, test drives with a real experimental vehicle were conducted to assess the number of objects, which can be detected by a modern car. Sensors were chosen such that the equipment of future vehicles (at least in the near future) could be mimicked. The results show that even under today's conditions a segmentation of the CPM might be required.

Future work includes measurements under different traffic conditions, e.g., different day times and street conditions, and on different streets as well as measurements on highways. Large scale data acquisition, taking into account other probe vehicles with different sensor setups, is necessary to determine if the proposed scheme of making the generation rules dependent on the driving environment is actually feasible. In addition, the derived results can be fed back into communications network simulations to assess the necessity of employing CPM mitigation strategies under the current conditions. This is especially of interest as current research (ETSI TR 103 562 V2.1.1 (2019-12), 2019; Yu, 2020) has shown that the mitigation strategies, while reducing channel load, might also decrease service availability. Finally, the object fusion algorithm as well as the object choosing algorithm provided by ETSI, which were omitted here, can be implemented, allowing to generate and directly evaluate the resulting CPM message size under various conditions.

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