Use Case of Remote Driving and its Network Requirements
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Abstract

   This document illustrates the use case of remote driving that
   leverages the human driver's advanced perceptual and cognitive skills
   to enhance autonomous driving when it is absent or falls short.
   Specifically the document analyzes the end-to-end latency that is
   required in the network to support collision avoidance in remote
   driving. The document also summarizes the other necessary
   requirements that the networking services shall support.

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1. Introduction to Autonomous Vehicles

   Autonomous vehicles (AV) have made great progress in the recent years, which rely on numerous well-placed sensors that continuously detect, observe the location and movement of surrounding vehicles, conditions on the road, pedestrians, traffic lights, etc. Autonomous vehicle can be controlled by its own central computer, which manipulates the steering, accelerator, and brake, achieving self-driving in different levels.

   SAE International's new standard "J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems" defines six LoAs (Level of Automation) [SAEJ3016], including full automation (level 5), high automation (level 4), conditional automation (level 3), partial automation (level 2), driver assistance (level 1), and no automation (level 0).

   Although each vehicle manufacturer has been taking its best effort of making progress in increasing the level of automation, the current automated vehicles by themselves can only fit into the SAE classification 2 or 3. AVs may fail short in unexpected situations. In such cases, it is desirable that humans can operate the vehicle manually to recover from a failure situation through remote driving. Until the autonomous technology becomes mature enough to be level 5, the experts suggest AVs should be backed up by tele-operations.

2. Terms and Abbreviations

   The terms and abbreviations used in this document are listed below.

   * AI: Artificial Intelligence

   * AV: Autonomous Vehicle

   * BE: Best-Effort

   * GPS: Global Positioning System

   The above terminology is defined in greater details in the remainder
   of this document.

3. Remote Driving

   Remote driving is a mechanism in which a human driver operates a
   vehicle from a distance through communication networks. Remote
   driving leverages the human driver's advanced perceptual and
   cognitive skills to further assist the autonomous driving when it
   falls short, and overcomes many complex situations that computer
   vision or artificial intelligence could not foresee or apprehend.
   Such situations and possible failures of autonomous driving include:
   (1) perception failure at night or under challenging weather
   conditions, e.g., low visibility due to fog, lane markers are covered
   by snow; (2) confusing or malfunctioning traffic lights,
   unrecognizable traffic signs due to corrosion or graffiti; (3)
   Confusing detour signs or complex instructions temporarily ordered by
   police officers, which require extra knowledge about the local
   traffic and understanding of the local construction works; (4)
   Complex or confusing parking signs, which might be handwritten and
   hard to be understood by computers. Parking might only be allowed on
   certain dates during the week, or parking lots are only permissible
   for certain types of vehicles. With remote driving being added to
   the AV control loop, passengers could feel safe enough.

   Remotely operated vehicles may also be of interest to personal
   transportation services. Vay, a Berlin-based startup [Vay] plans to
   debut a fleet of taxis controlled by remote teledrivers by 2022. The

concept behind Vay is that when you order a Vay, one of teledrivers
is tasked to navigate one Vay to your pickup location. Then you take
control the Vay. After you reach your destination, the teledriver
takes control of the Vay and deliver it to the next nearby customer.
During the whole transaction, the remote driving takes place for Vay
delivery. This is advertised to happen at the initial roll-out
stage, the Vay might be remotely controlled by teledrivers to drive
the customers around in the future stages when the technologies are
mature enough. Vay's system is promised to be built safer than
conventional driving by controlling the top four causes of fatal
urban accidents, which are driving under the influence, speeding,
distraction, and fatigue.

Remotely operated trunks could possibly eliminate the threats to road
safety, driver/passenger safety that are caused by fleet driver
fatigue during long drives. Remotely operated vehicles are also
particularly useful compared to autonomous trunking [Tusimple] in
situations where it would be hazardous or impossible for humans to
operate in, for example, construction vehicles in remote sites or
emergency service vehicles in areas that are affected by chemical
spills, by active wildfires, or by hurricane conditions.

A remotely controlled vehicle needs to transit necessary data in high
volumes to the remote operation center which might be located in edge
cloud or central cloud. The data includes all the sensory feeds that
the autonomous vehicle itself could collect. Signals from GPS
(Global Positioning System) satellites could be combined with reading
from tachometers, altimeters, and gyroscopes to provide more accurate
positioning of the vehicle. Radar sensors monitor the positions of
other vehicles nearby. Lidar (Light Detection and Ranging) sensors
bounce pulses of light off the surroundings to identify lane markings
and road boundaries. Ultrasonic sensors are used to measure the
position of objects that are very close to the vehicle. Video
cameras consistently take pictures of the surroundings from different
angles. Volumetric data from vehicles are sent from the vehicles to
the remote driving center to provide the remote driver with adequate
perception of the environment. The remote driver can then provide
appropriate instructions to help the autonomous vehicle resolve the
issues.

3.1. Collision Avoidance in Remote Driving

In this section, we use a specific collision avoidance scenario in remote driving as shown in Figure 1 to illustrate that the network and its protocols need to provide the necessary support. There are many similar use cases that have already been specified in [TR22.885] and [TR22.886].

```
    _____                                       [    ]
  /|_||_\`.__                                    [    ]
 (   _    _ _\ <----Collision Avoidance Distance--->[    ]
 =`-(_)--(_)-'                                   [ P  ]
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    .- ~ ~-(       )_ _
   /                   ~ -.
  |         Networks        \
   \                         .'
     ~- . _____ . -~
                 +------+
                 +Remote+
                 +driver+
                 +------+
```
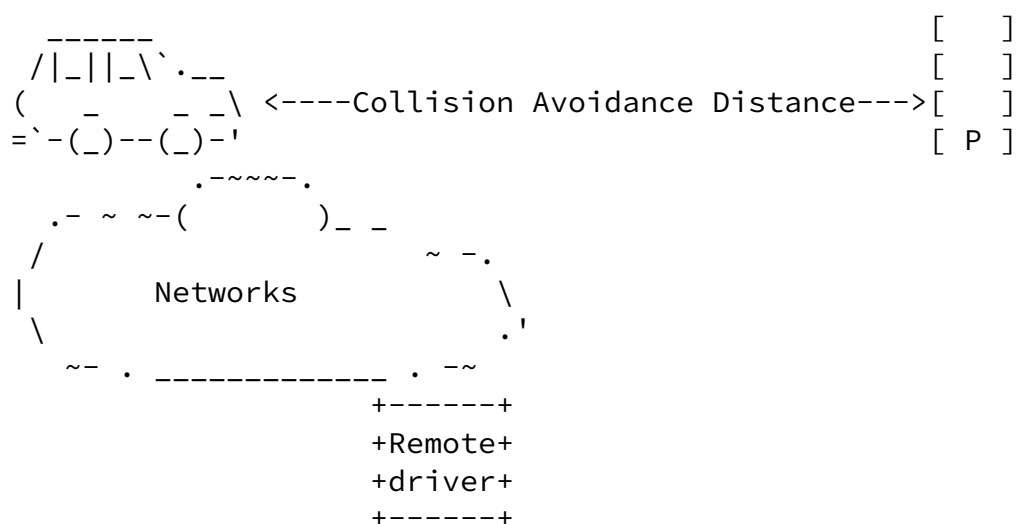
                        Figure 1

Given the current technologies in sensing, encoding and decoding, together with the Best Effort (BE) service provided in the current Internet, the total roundtrip delay between the time when the roadside camera captures picture of pedestrian on the crossroad and the time when the self-driving car receives the signal to brake is

around 250-400 ms. On the other hand, the latency already incurred
by the remote driver's reaction time also adds the total latency,
adding to the distance required for the vehicle to come to a stop.
The detailed breakdown of the total latency is shown as below:

*   Image capture, encoding, decoding and display: 100 ms [Nuvation]
    [Sensoray];

*   Remote driver's reaction time: 100 ms;

*   Total transmission time in the network: 50-200 ms, which includes
    the time for the image data to reach the remote driver as well as
    the time for the command to reach the vehicle [VerizonNetwork]
    [Candela2020]; The image data could be encapsulated in multiple
    packets, depending on the image resolution and size. Thus the
    total transmission time in the network might involve 2 or more
    packets transmission. With the best-effort nature of the current
    Internet, the total transmission time is not determined and
    changes at per packet basis, might for example range between 50ms
    to 200 ms.

*   Total: 250-400 ms.

The collision avoidance distance is proportional to the vehicle
speed. For example, if the car is driving at 60 km/hour, the
collision avoidance distance must be longer than 7 meters, in other

words, the self-driving car must start to brake more than 7 meters
away from the pedestrians. Table 1 shows the calculation of
collision avoidance distance based on the vehicle's speed and the
current total latency.

If the vehicle is driving at higher speed (e.g., 80 km/hour) and for
it to start to brake at shorter distance away from the pedestrians
(e.g., 4 meters), the total round-trip delay needs to be much
shortened (e.g., 4/(80/3600)=180 ms). Assuming with the technologies
advancement, the total time needed for sensory image capture, framing
and encoding, decoding and display is reduced to 60 ms, the total
transmission time in the network cannot be longer than 20 ms
precisely. Within the 20 ms, the captured image or video data, and
other sensory data need to arrive the remote server, the command from
the remote driver needs to reach the vehicle as well.

```
+============================+==============================+
|            Speed           |  Collision Avoidance Distance |
+============================+==============================+
|   5 km/hour = 1.4 m/sec    |      1.4*0.4 = 0.56 m         |
+----------------------------+------------------------------+
|  30 km/hour = 8.4 m/sec    |      8.4*0.4 = 3.36 m         |
+----------------------------+------------------------------+
| 60 km/hour = 16.8 m/sec    |     16.8*0.4 = 6.72 m         |
+----------------------------+------------------------------+
| 80 km/hour = 22.3 m/sec    |     22.3*0.4 = 8.92 m         |
+----------------------------+------------------------------+
| 120 km/hour = 33.4 m/sec   |     33.4*0.4 = 13.36 m        |
+----------------------------+------------------------------+
```

                   Table 1: Collision avoidance distance based on
                                  vehicle's speed

4. Network Requirements

   The following requirements need to be supported by the networks:

   * The networking services shall support multiple concurrent flow
      streams at high data rates and volumetric data transmission from
      vehicles with high mobility.

   * The networks shall deliver services with service level objectives,
      specifically latency objectives. The latency objectives are
      required to be precisely guaranteed and highly reliable, not just
      "optimized" but quantifiable.

   * The network shall be able to identify the packets which carry
      urgent information and treat them in a differentiated manner with
      highest priority

   * The networking services shall reduce and even avoid dropping/re-
      transmission of packets with high significance. Packet loss of
      certain urgent packets are not permissible in the network.

5. IANA Considerations

   This document requires no actions from IANA.

6. Security Considerations

   This document introduces no new security issues.

7. Acknowledgements

8. Informative References

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