CATS WG Interim Meeting

Applicability of Computing-Aware Traffic Steering to Intelligent Transportation Systems
(draft-jeong-cats-its-use-cases-04)

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Update of this Draft

- **Motivation**
  - This draft intends to describe the applicability of CATS to ITS along with Use Cases:
    - https://datatracker.ietf.org/doc/draft-jeong-cats-its-use-cases/04/
- **Four ITS Use Cases in this Draft**
  - Context-Aware Navigation Protocol (CNP)
  - Edge-Assisted Cluster-Based MAC Protocol (ECMAC)
  - Self-Adaptive Interactive Navigation Tool (SAINT)
  - Cloud-Based Drone Navigation (CBDN)
- **Requirements of CATS for Four ITS Use Cases**

Computing-Aware Intelligent Transportation

- Transmission Capacity: Video processing capacity of nodes to reach pedestrian recognition, vehicle recognition, and collision prediction.
- Overcoming non-line-of-sight problem through information sharing between cars and a nearest edge node.
- Handling delay sensitive services by dispatching them to others edge nodes.
- Issues:
  - Steering of various ITS services instances (e.g., car navigation, cooperative driving, infotainment) requires different computing and response demands.
  - How can an ITS edge steer pedestrian-to-car, car-to-car, or car-to-infrastruct ure traffic toward intelligent driving services?

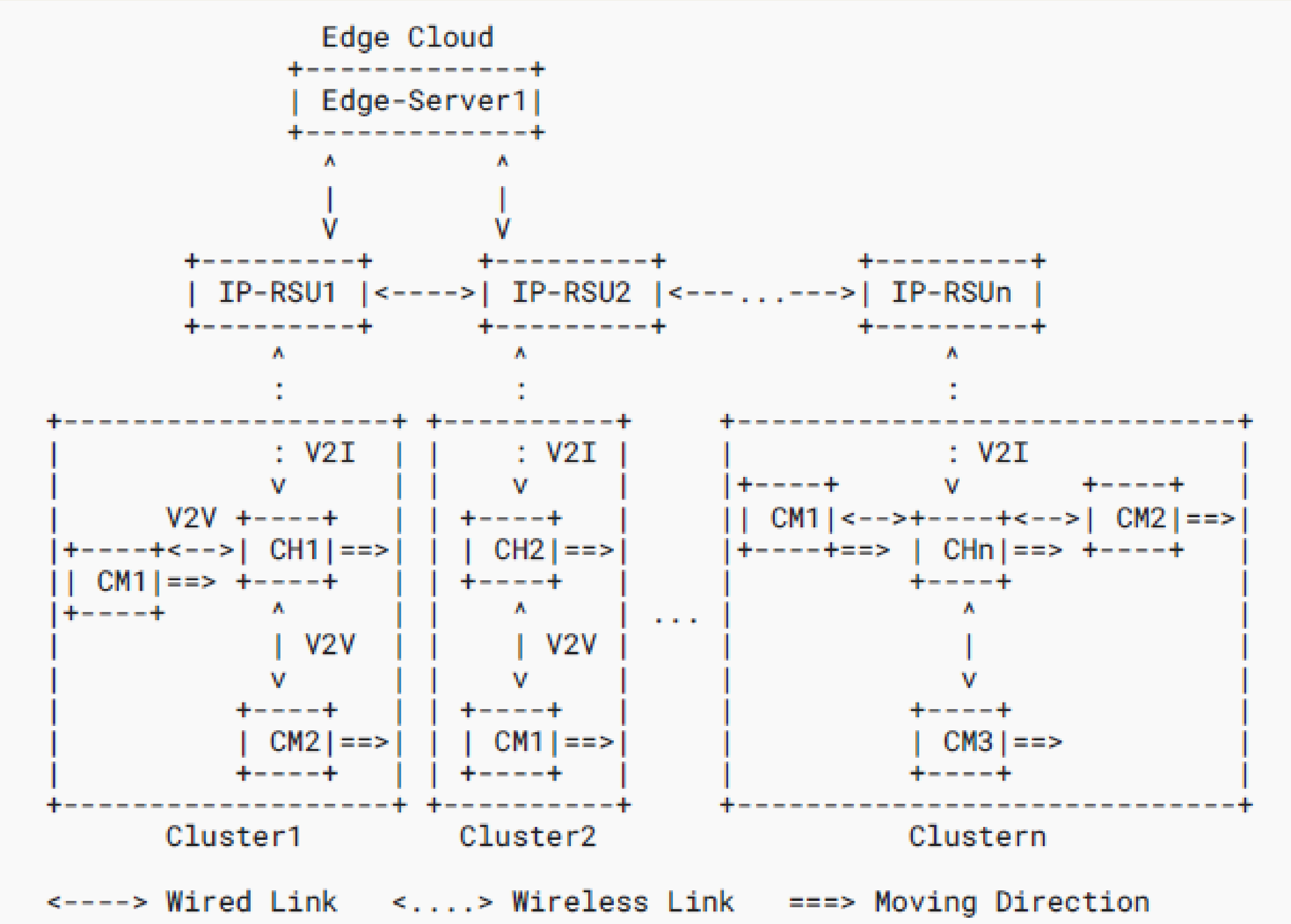
Requirements for CATS ITS Use Cases

1. **Dynamic mapping** between a required service and a service instance.
   - Both network delay and computing delay are considered over time.
2. **Run-time context migration** of vehicles between edge servers (i.e., service instances).
   - Each vehicle's context (e.g., mobility information, communications parameters (e.g., channel, time slot)) is transferred to an appropriate service instance along with its movement over time.
3. **Proactive load balancing** among service instances considering the required QoS/QoE for vehicles.
   - The trajectories of vehicles are considered for such load balancing.

Requirements for CATS ITS Use Cases

4. **Dynamic clustering** of geographically adjacent vehicles.
   - Clusters of vehicles are dynamically reconstructed over time.
5. **Dynamic network configuration** for vehicles and network forwarding entities (e.g., base stations and switches/routers).
   - In wireless networks, network resources (e.g., channel and time slot) per vehicle are dynamically configured by base stations.
   - In wired networks, a network slice from a base station to a service instance are dynamically adjusted for each vehicle.
6. **Differentiated packet scheduling for service types.**
   - Packets of real-time services (e.g., autonomous driving) and packets of non-real-time services (e.g., infotainment) are handled differently.

Use Case 1: Context-Aware Navigation Protocol



- **Context-Aware Navigation Protocol (CNP)**
  - CNP provides vehicles with automatic maneuver control for accident avoidance through Edge Cloud.
  - **Requirements:** R1, R2, R3, R4, R5, R6.

[Source] B. Mugabarigira et al., "Context-Aware Navigation Protocol for Safe Driving in Vehicular Cyber-Physical Systems", IEEE Transactions on Intelligent Transportation Systems, January 2023.

Use Case 2: Edge-Assisted Cluster-Based MAC Protocol

```
                 Vehicular Cloud
         *******************************
       *            Edge Cloud             *
      *    +--------------------------+     *
     *     |       Edge-Server1       |      *
     *     |  +--------------------+  |      *
     *     |  |Cluster Formation,  |  |      *
     *     |  |Channel Assignment, |  |      *
     *     |  |Time Slot Allocation|  |      *
      *    |  +--------------------+  |     *
       *   +--------------------------+    *
         ********************************
                 ^                       ^
                 |                       |
                 V                       V
          +----------+             +----------+
          | IP-RSU1  |<------...------>| IP-RSUm |
          +----------+             +----------+
                ^                        ^
                :                        :
+-------------------+    +------------------------------+
|            : V2I  |    |              : V2I           |
|            v      |    |+----+        v       +----+  |
|      V2V  +----+  |    || CM1|<-->+----+<-->| CM2|==>|
|+----+<-->| CH1|==>|    |+----+==> | CHn|==> +----+    |
|| CM1|==> +----+   |    |          +----+              |
|+----+      ^      | ...|            ^                 |
|            | V2V  |    |            |                 |
|            v      |    |            v                 |
|          +----+   |    |          +----+              |
|          | CM2|==>|    |          | CM3|==>           |
|          +----+   |    |          +----+              |
+-------------------+    +------------------------------+
      Cluster1                      Clustern

<----> Wired Link   <....> Wireless Link   ===> Moving Direction
```

- **Edge-Assisted Cluster-Based MAC Protocol (ECMAC)**
  - ECMAC provides reliable, timely communications to vehicles for safe driving through Edge Cloud.
  - **Requirements:** R1, R2, R3, R4, R5, R6.

[Source] Y. Shen et al., "[ECMAC: Edge-Assisted Cluster-Based MAC Protocol in Software-Defined Vehicular Networks]", IEEE Transactions on Vehicular Technology, September 2024.

Use Case 3: Self-Adaptive Interactive Navigation Tool

```
                    Vehicular Cloud
        **************************************
       *             Edge Cloud               *
      *  +-----------------------------------+  *
     *   |   Edge Server     Edge Emergency  |   *
     *   |                       Center      |   *
     *   | +-------------+ +---------------+ |   *
     *   | |Road Traffic | |Road Emergency | |   *
     *   | |Information  | |Notification   | |   *
      *  | +-------------+ +---------------+ |  *
       * +-----------------------------------+ *
        **************************************
            ^                  ^              ^
            |                  |              |
            V                  V              V
      +----------+       +----------+       +----------+
      | IP-RSU1  |<----->| IP-RSU2  |<------>| IP-RSU3  |
      +----------+       +----------+       +----------+
            ^                   ^                   ^
            :                   :                   :
            :                   :                   :
     +-----------------+ +-----------------+ +-----------------+
     |     : V2I       | |     : V2I       | |     : V2I       |
     |     v           | |     v           | |     v           |
     |   +---------+   | |   +---------+   | |   +---------+   |
     |   |  SDV1   |===>| |   |  SDV2   |===>| |   |  SDV3   |===>|
     |   +---------+<........>+---------+   | |   +---------+   |
     |      ^         V2V       ^          | |      ^          |
     |      : V2V      | |      : V2V      | |      : V2V      |
     |      v          | |      v          | |      v          |
     |  +---------+    | |   +---------+   | |  +---------+    |
     |  |  SDV4   |===> | |   |  SDV5   |===>| |  |  SDV6   |==>|
     |  +---------+    | |   +---------+   | |  +---------+    |
     +-----------------+ +-----------------+ +-----------------+
          Subnet1             Subnet2             Subnet3
         (Prefix1)           (Prefix2)           (Prefix3)

 <----> Wired Link    <....> Wireless Link    ===> Moving Direction
```

- **Self-Adaptive Interactive Navigation Tool (SAINT)**
  - SAINT provides road navigation optimization to vehicles through Edge Cloud.
  - SAINT+ supports emergency vehicle delivery to an accident spot through Edge Cloud.
  - **Requirements:** R1, R2, R3, R4, R5, R6.

[Source] J. Jeong et al., "SAINT: Self-Adaptive Interactive Navigation Tool for Cloud-Based Vehicular Traffic Optimization", IEEE Transactions on Vehicular Technology, June 2016.

Use Case 4: Cloud-Based Drone Navigation

```
                 Vehicular Cloud
          ***********************************
        *              Edge Cloud              *
       *    +---------------------------+     *
      *     |        Edge-Server1       |      *
      *     |  +--------------------+   |      *
      *     |  |                    |   |      *
      *     |  |Drone Route Finding,|   |      *
      *     |  |QCM-Selection Scheme|   |      *
       *    |  +--------------------+   |     *
        *   +---------------------------+    *
          ***********************************
            ^             ^                ^
            |             |                |
            V             V                V
     +----------+    +----------+    +----------+
     | IP-RSU1  |<--->| IP-RSU2  |<--->| IP-RSU3  |
     +----------+    +----------+    +----------+
            ^                 ^                  ^
            :                 :                  :
 +------------------+ +------------------+ +------------------+
 |          : V2I   | |       : V2X      | |      : V2I       |
 |          v       | |       v          | |      v           |
 |   +--------+     | |  +--------+      | |  +--------+      |
 |   |  UAV1  |===> | |  |  UAV2  |===>  | |  |  UAV3  |===>  |
 |   +--------+<.........>+--------+     | |  +--------+      |
 |       ^       V2V  |      ^           | |      ^           |
 |       : V2V      | |      : V2I       | |      : V2I       |
 |       v          | |      v           | |      v           |
 |  +--------+      | |  +--------+      | |  +--------+      |
 |  |  UAV4  |===>  | |  |  QCM1  |      | |  |  QCM2  |      |
 |  +--------+      | |  +--------+      | |  +--------+      |
 +------------------+ +------------------+ +------------------+
      Subnet1              Subnet2              Subnet3
     (Prefix1)            (Prefix2)            (Prefix3)

<----> Wired Link   <....> Wireless Link   ===> Moving Direction
```

- **Cloud-Based Drone Navigation (CBDN)**
  - CBDN provides sky navigation optimization to drones, considering battery charge through Edge Cloud.
  - **Requirements:** R1, R2, R3, R4, R5, R6.

  [Source] J. Kim et al., "CBDN: Cloud-Based Drone Navigation for Efficient Battery Charging in Drone Networks", IEEE Transactions on Intelligent Transportation Systems, November 2019.

Next Steps

- Four ITS Use Cases and their Requirements will be merged to the CATS Problem Statement, Use Cases, and Requirements Draft:
  - https://datatracker.ietf.org/doc/draft-ietf-cats-usecases-requirements/
  - Four ITS use cases can be included as an appendix.
- Also, we can also keep developing this draft as an individual draft as solutions for CATS ITS with implementation guidelines:
  - This draft can serve Applicability of CATS to ITS Use Cases by considering the CATS Framework.
    - https://datatracker.ietf.org/doc/draft-ietf-cats-framework/