Three-Node VOICES Core System

1.0 Introduction

The Virtual Open Innovation Collaborative Environment for Safety (VOICES) platform enables effective and efficient testing in a safe and secure environment to accelerate the deployment of cooperative driving automation (CDA) systems on U.S. roadways. VOICES facilitates a distributed synthetic test environment (DSTE) that connects various resources (within a test facility and among different remote test sites) to enable the interaction of concurrent tests in synchronous or asynchronous mode. As a result, developers from different entities can use VOICES to collaborate in creating a joint test bed environment, performing cooperative testing, and validating system-to-system interoperability.

VOICES is a scalable test platform with a built-in database of traffic scenarios and transportation systems management and operations use cases. As the testing grows in size and complexity, VOICES becomes more valuable to the various stakeholders' categories. It is envisioned that, over time, the collaborated efforts among different users will lead to a comprehensive and valuable set of test scenarios to both developers and evaluators. These test scenarios will cover both typical and edge cases.

The development of the three-node VOICES Core is an important milestone in the VOICES project and envisioned to have the main building blocks required for an operational and scalable VOICES minimum viable product (MVP).

2.0 Objectives

The objectives of the VOICES Core are to demonstrate:

- Technical feasibility, potential value, and applications of a distributed live, virtual, and constructive (LVC) test environment.
- Capability of the VOICES team to build the envisioned MVP capability.
- Extensibility to other domains and scalability to additional nodes that fully represent the transportation ecosystem.

To achieve these objectives, the VOICES Core is required to operate reliably and demonstrate a secure, distributed, and scalable LVC integrated environment operated through a user portal to execute use case testing.

3.0 VOICES Core Architecture

3.1 Reference Architecture

The general architecture of the three nodes and VOICES Core infrastructure is shown in Figure 1. The complete VOICES reference architecture is presented in detail in *the VOICES System Integration for Eco Approach and Departure Use Case paper*[1].

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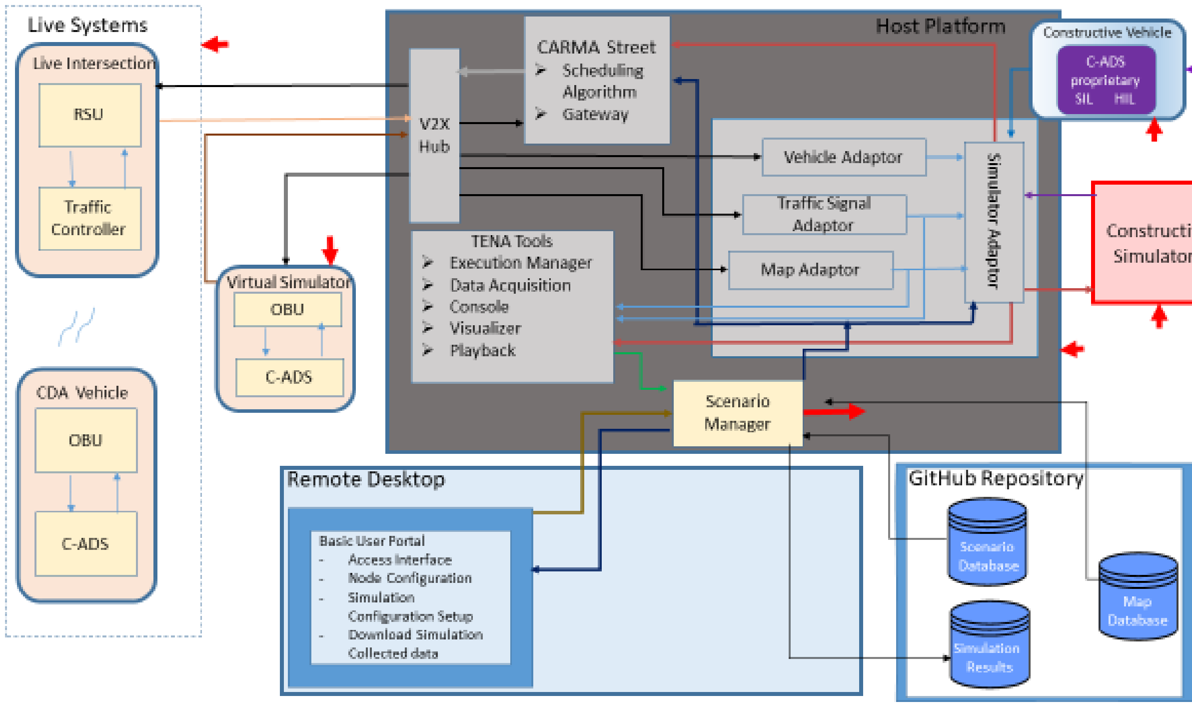
[1] Voices_Example_paperA2 - VOICES System Integration for Eco Approach and Departure Use Case.docx



OBU = On Board Unit; RSU = Road Side Unit; C-ADS = Cooperative Automated Driving System

Figure 1: Reference Architecture

The VOICES Portal is realized using a remote desktop that will allow the user to run the script to start the Test and Training Enabling Architecture (TENA) and the simulation items. User will then be able to monitor the simulation and the nodes connectivity, operation, configuration, and status in general through the TENA console.

The VOICES Repository to store the scenario and test databases, map database, and output simulation results is accomplished using the GitHub Repository.

The DSTE infrastructure for the VOICES environment will consist of containerized applications and virtual machines to provide pre-configured and secured test environments for individual test and experimentation scenario environments. The containerization technology and virtual machines will be determined and implemented by the VOICES DSTE administrators. The solution will be selected based on high availability, open-source licenses, and security features available to provide an environment that is low in requirements for administrators' time and user learning curves.

3.2 VOICES Core Physical Architecture and Distributed Hardware and Software Demonstration

The VOICES network is reliant on a network that connects facilities together to participate in distributed testing. Below is the approach to testing the components to the network in this initial phase of the project:

- Install NODE at Turner Fairbank Highway Research Center (TFHRC) located in McLean, VA.

- Connect THFRC to the MASTER NODE at the Scientific Research Corporation (SRC) site in Augusta, GA.
- Connect THFRC to Leidos site in Springfield, VA.

Basically, the network establishes communication via IPsec tunnel between an isolated V-LAN on the I2 network[2,3] and two remote sites: Leidos-Springfield and SRC-Augusta to demonstrate the VOICES connection concept. This connection will allow for testing VOICES collaboration and use case demonstrations at TFHRC. Figure 2 illustrates one configuration of this network.

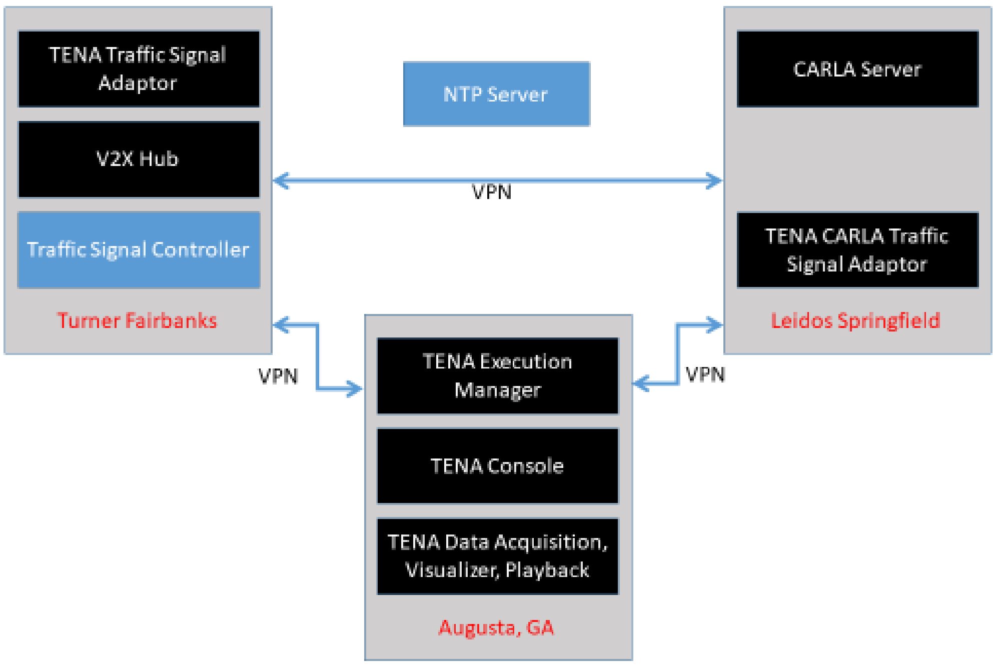


Figure 2: Three-Node Physical Architecture

Using this configuration, a physical traffic signal state will be integrated into a virtual environment with distributed software and hardware. Sites are connected via virtual private networks (VPN) and transmit data to each other as TENA Stateful Distributed Objects (SDOs) allowing verification of successful connections between TENA Adaptors at the Leidos and Augusta data centers.

4.0 Platooning Demonstration Using VOICES Core

A Cooperative Adaptive Cruise Control (CACC) example is described in the System Goals[4] paper. A platoon is a coordinated CACC comprised of a vehicle string in which multiple vehicles are driving under coordinated longitudinal and possible lateral control. Platooning reduces energy consumption of operation, and improves the road capacity and efficiency for overall traffic.

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[2] https://en.wikipedia.org/wiki/Internet2
[3] https://internet2.edu/community/about-us/
[4] VOICE System Goals paper on Confluence

Figures 3 and 4 illustrates the architecture of two options for platooning demonstration using VOICES Core.

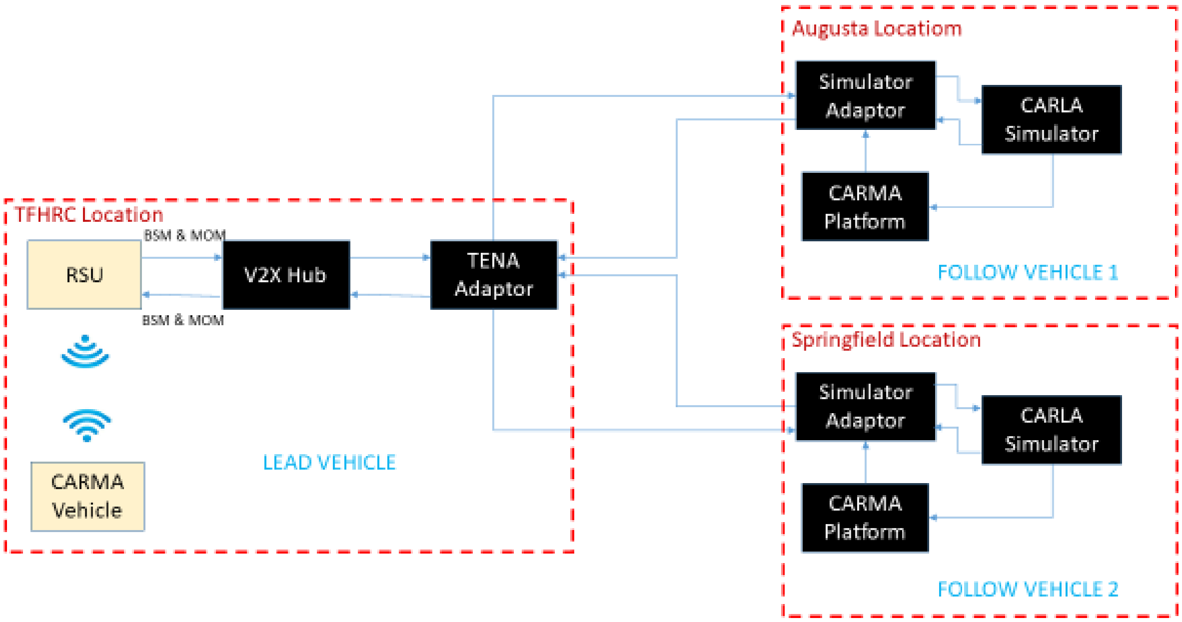

Figure 3: Platooning Architecture for Option 1 Demonstration

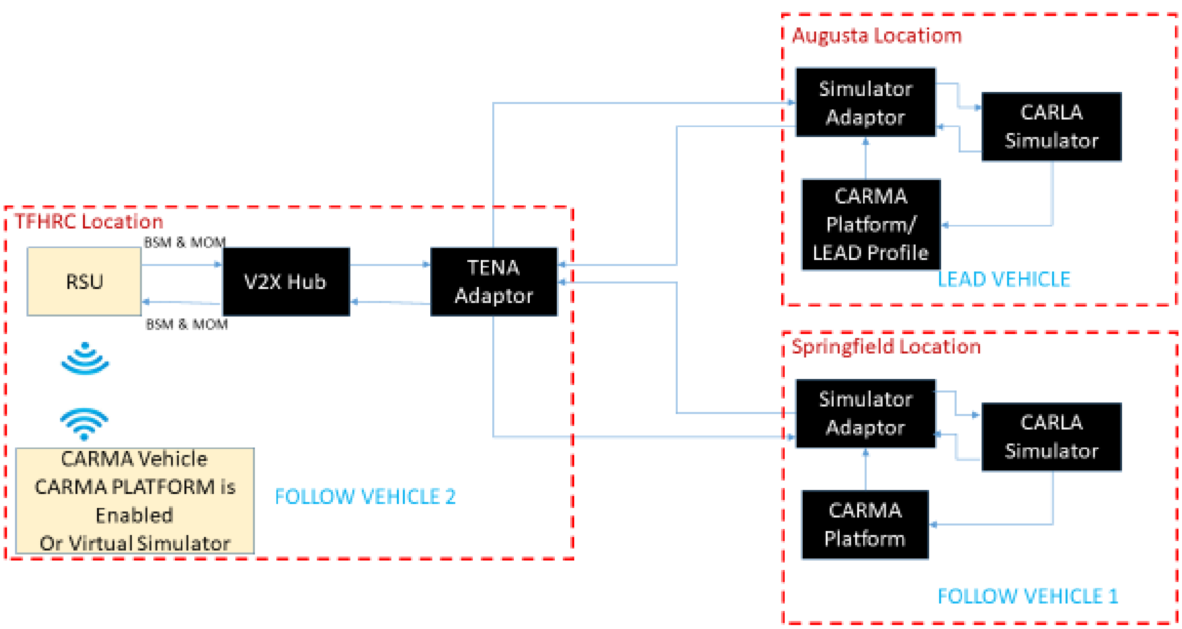

Figure 4: Platooning Architecture for Option 2 Demonstration

The lead platoon vehicle is the Live element of the distributed system, located at TFHRC. The two following platoon vehicles are the constructive elements of the distributed system and are located at the Springfield and Augusta sites. Any of these constructive elements can be substituted by virtual simulator, as described in the CACC example.

Two main functional messages will be communicated among the network: Basic Safety Message (BSM) and Mobility Operations Message (MOM). The MOMs are not standardized messages and have the following four messages: Mobility Request, Mobility Response, Mobility Path, and Mobility Operation. *The specific details of the platooning demonstration are not yet developed.*

5.0 Network Diagram for VOICES Core

The 3-nodes VOICES Core network diagram topology is shown in Figure 5. This reflects the architecture illustrated in Figure 3.

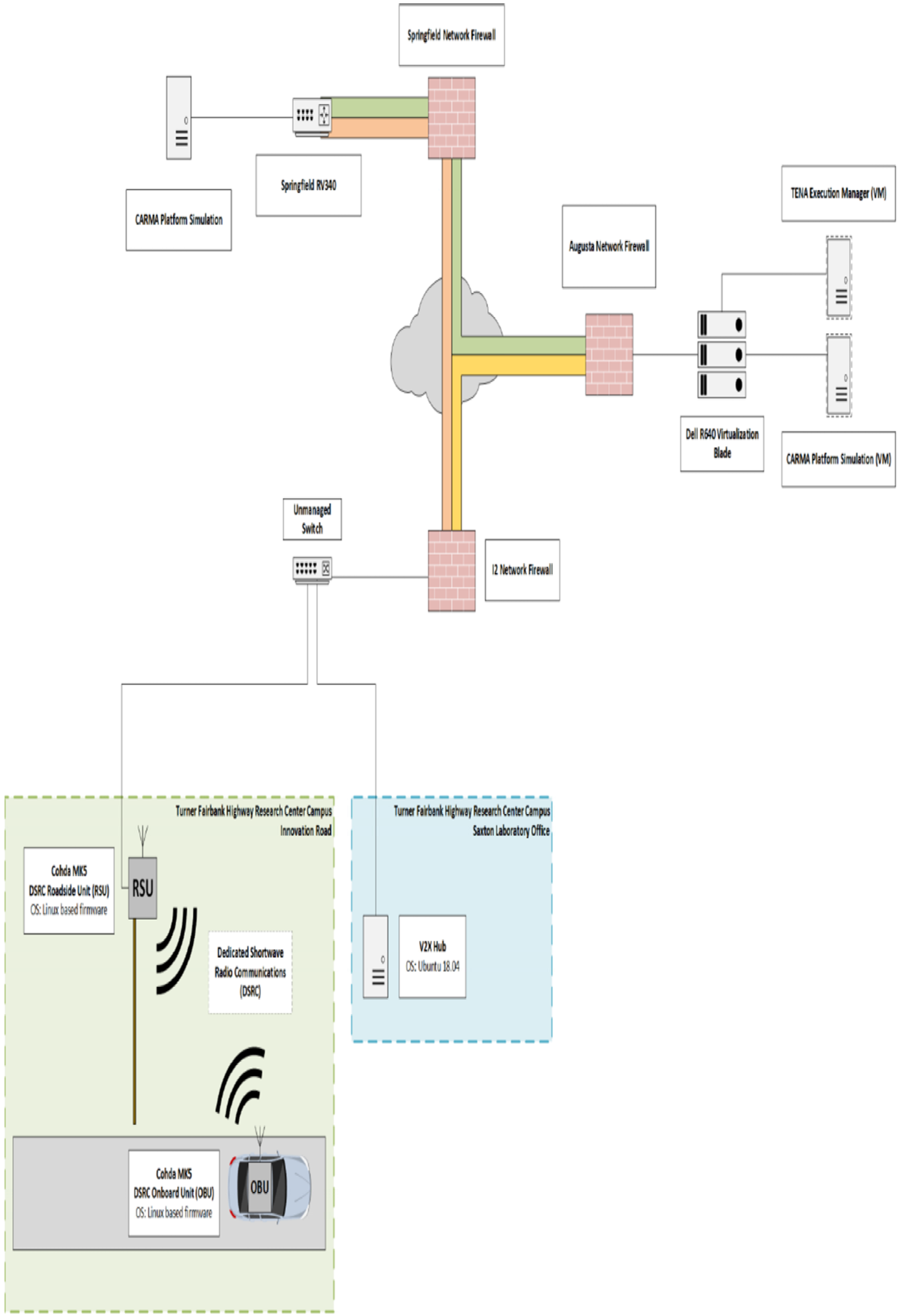

Figure 5: VOICES Core Network Topology

6.0 VOICES Core Phased Approach

The first demonstration for the VOICES core happened early this year by creating a constructive twin to the live traffic light signal within the TFHRC garage/laboratory environment. A live traffic light Signal Phase and Timing (SPAT) message was passed through the TENA middleware to the CARLA simulator and the output of the simulator was visualized and verified to be in sync with the live signal phase. Both live and constructive elements were co-located at TFHRC.

If we consider the initial design and architecture as Technology Readiness Level (TRL)[5,6] 1-2, the completed garage demonstration meets TRL3- Proof-of-Concept status. Moving on from the VOICES Core from the TRL3 garage POC, VOICES Core development will follow the TRL progression starting from the unit testing validation through the Community of Practice (CoP) use case demonstration, followed by Technology Transfer (T2) and the VOICES platform change of ownership:

- TRL4: Component testing is completed.
    - All the individual components of the VOICES Core are working per design.
    - Individual components metrics are reported.
- TRL5: System integration testing is completed.
    - System is operational. All components in the VOICES core are working together per design.
    - Network and data relaying performance metrics are reported.
    - No use-case(s)
- TRL6: Basic demonstration of distributed VOICES platform (hardware and software):
  a) With fixed live object (traffic light) as illustrated in Figure 2.
  b) Two tests run concurrently
    - A fixed-live remote traffic light twin is added, with acceptable delay.
    - Two tests are successfully executed in secure manner.
    - Reporting issues and metrics are generated.
- TRL7: Moving live with constructive demonstration with map database.
    - A mobile-Live vehicle is added.
    - Both moving live vehicle and its constructive twin are moving in synced location on the same map. Delay is in acceptable range.
    - Reporting issues and metrics are generated.
- TRL8: LVC demonstration using integrated CARMA system. Example: Platooning as described in Figures 3 and 4.
    - Successful platooning string with acceptable headway disturbance compared to fully constructive demonstration.
    - Reporting issues and metrics are generated.

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[5] https://highways.dot.gov/research/exploratory-advanced-research/research/technology-readiness-assessment-work-ear-program
[6] https://en.wikipedia.org/wiki/Technology_readiness_level

   - ➢ Successfully connect the Volpe driving simulator as the fourth node.
   - ➢ Successfully scale the nodes up to TBD.
- TRL9: T2 and platform delivery.

7.0 VOICES Core Testing and Validation

7.1 Operational Readiness Tests

The following set of tests are aimed to validate the operational readiness of the VOICES Core. They address three main testing categories: unit testing, integration testing, and network testing.

I. Unit Testing
   a. Input/output verification
   b. Memory leak
   c. Profiling (measure processing time: attempt to detect any bottleneck)

I. Data Integration Testing within Single Site
   a. Data are transmitted, flowing, and recovered correctly.
   b. Throughput testing
   c. Memory usage

II. Data Integration Testing among the Three Sites
   d. Data are flowing correctly.
   e. Throughput testing (Example: multiple OBU devices outputting at their I/O ports BSM messages at 100 Hz rate).

III. Connectivity
   a. Test node to node connectivity.
   b. Successful connections between TENA adaptors at different sites.
   c. Verify connectivity diagnostic via TENA console (example: disconnecting one of the nodes)

IV. Accessibility
   a. Test different levels of accesses among different sites
   b. Test I2 access

V. Operation Continuity
   a. Test normal operation using basic data (Example: system running in diagnostic mode and monitored for a week).
   b. Stress test

VI. Flexibility
   a. Test different combinations of configurations (software and hardware) at different sites, basically changing the locations of software and hardware among the three sites.

VII. Time Stamp
   a. Verify time stamp from NTP server to data in all sites.
   b. Verify time stamp from GPS server to data in all sites.

VIII. Latency[7]
   a. Baseline latency between sites using ping testing.
   b. Latency between SDO publication and reception.

IX. Synchronization
   a. Check start of the test command in all sites.
   b. Check finish of the test command in all sites.

X. Check data collection (TENA Data Collection System (TDCS)) is working by collecting time stamped data originated from the three sites.

XI. Map Message Test
   a. Test map message passed and used correctly in all locations.

7.2 Functionality Tests

The following functionality tests are aimed to validate basic functionalities of the VOICES Core as a distributed and scalable LVC integrated environment operated through user portal and executing some of the CoP use cases:

I. User interface (Portal)
II. Scenario manager
III. Secure and controlled access to the system
IV. Privacy and cybersecurity protection
V. Accommodating one user conducting own test and using the CARMA product
VI. Accommodating two remote users conducting same test using CARMA product and test scenario database
VII. Accommodating parallel testing by one user (own test) and by two cooperating users (conducting own test but different from the one user).
VIII. Live testing using fixed object (traffic signal controller) and moving object (CDA equipped vehicle)
IX. Virtual testing by linking a driving simulator to VOICES via node
X. Constructive testing (simulation tools) with virtual and live testing
XI. Replay capability
XII. Data collection
XIII. Data visualization
XIV. Map message across the sites and components
XV. CoP test use case

[7] The VOICES Core network is a mesh topology. There is difference in the time delay between the mesh and hub architecture. The main contribution for the delays will not be whether VOICES using the IPSEC tunnel or a log in VPN. Rather, it will be the actual transport layer of the commercial internet, the bandwidth into the various locations, and the route via the internet that the traffic takes. The planned set up might be able to help mitigate this (i.e., the mesh preventing multiple trips across the country just to get across town), but the major issue is partly out of the VOICES team’s control. The team will document how it was set up, the results as baseline, and what might be done to improve it for future tests/builds.

XVI. Accessing scenario database
XVII. Scalability

8.0 VOICES Core Basic Components and Tasks

Figure 6 illustrates the basic components of the VOICES Core. Figure 7 illustrates the building tasks for the VOICES Core.

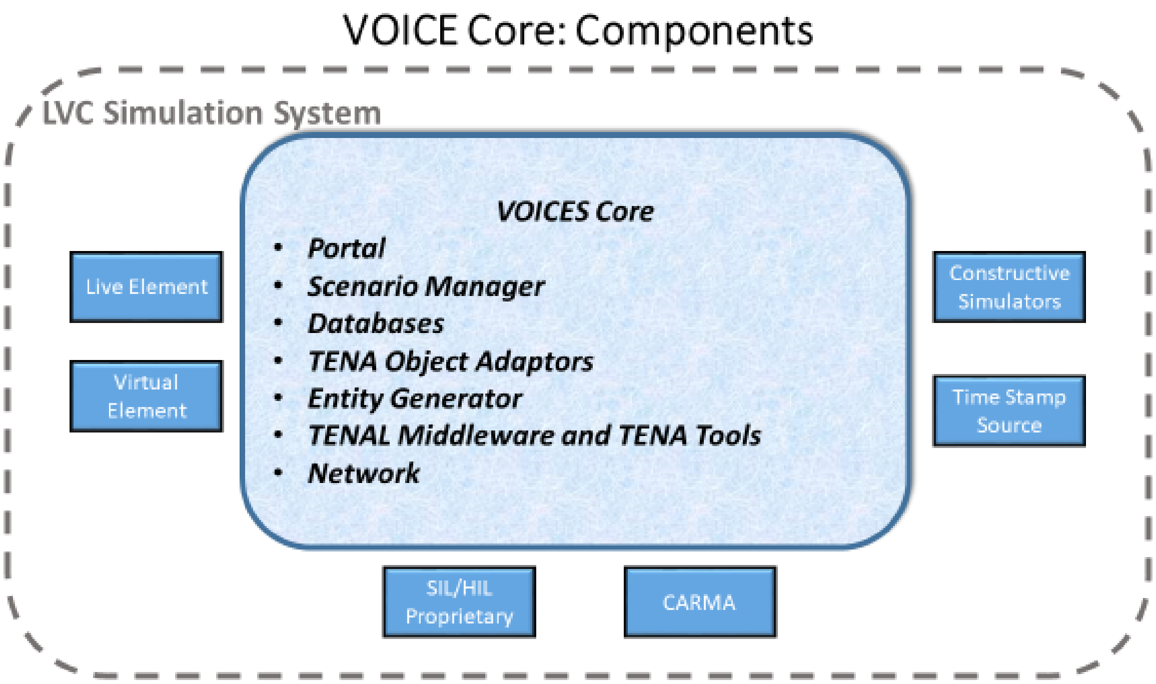

Figure 6: Voices Core Components

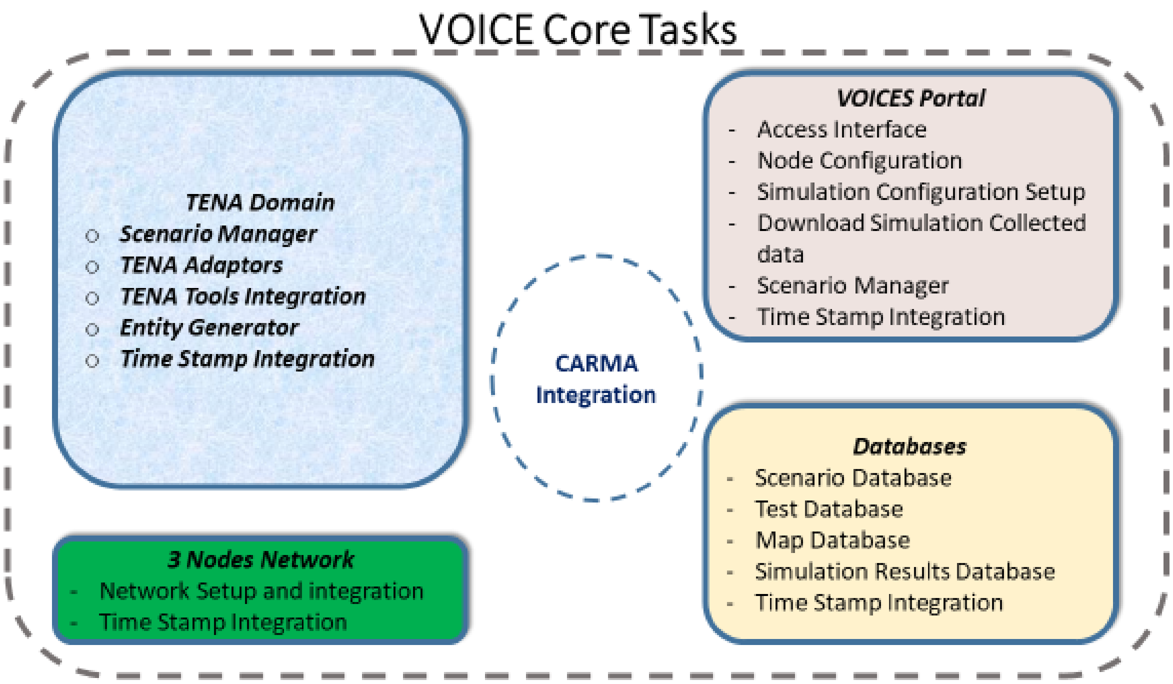

Figure 7: Voices Core Tasks