# **Real Time Smart City Final Report**

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## **Abstract**

This report describes a scalable, realistic, and cost-effective simulation framework designed to support real-time smart city infrastructures using Vehicle-to-Everything (C-V2X) communication. Using Infrastructure as Code (IaC) combined with AWS Elastic Kubernetes Service (EKS) and QNX real-time operating system (RTOS) based containers, the solution facilitates quick deployment, dynamic scalability, and secure real-time message passing between diverse city agents. A custom-designed hub-and-spoke communication model utilizing TCP/IP ensures secure, efficient, and reliable interactions among autonomous vehicles, pedestrians, and city infrastructure. Comprehensive testing demonstrates the framework's potential in reducing traffic incidents and improving urban safety – saving thousands of lives. Ultimately, this groundwork paves the way for testing simulations surrounding advanced urban analytics, emergency response optimization, and better traffic flows.

SOUCE CODE: <https://github.com/orgs/RTOSmartCity/repositories>

*Keywords: C-V2X, Kubernetes, QNX, Testing Framework, Traffic Safety, Infrastructure as Code*

## **Introduction**

As urbanization continues to expand worldwide, cities face increasingly complex issues tied to traffic flow, public safety, and the incorporation of autonomous vehicle technologies. Real-time communication infrastructures - particularly Vehicle-to-Everything (C-V2X) networks - are emerging as pivotal for future urban mobility, allowing communication among vehicles, pedestrians, and a wide range of traffic systems. These infrastructures can significantly advance traffic safety and improve overall efficiency in metropolitan areas.

However, implementing and rigorously testing real-time C-V2X communication poses notable obstacles related to scalability, fidelity, expense, and operational complexity. Traditional testing approaches fall short in replicating real-world conditions on a larger scale, limiting the thorough examination of latency, throughput, and reliability under realistic traffic circumstances.

In light of these challenges, this report introduces a new solution: a cloud-driven simulation framework that combines AWS Kubernetes clusters with QNX-based RTOS agents. By leveraging a modular design and a TCP/IP-inspired hub-and-spoke messaging model, the proposed framework aids in the mitigation of these said challenges. The overarching aim is to create safer, more responsive cities by way of initially laying a solid testing groundwork.

## **Problem Statement**

It is currently the case that effective deployment and stringent testing of real-time smart city infrastructures, particularly those leveraging Vehicle-to-Everything (C-V2X) communication, remain constrained by significant limitations. Current methodologies are hindered by limited scalability, thus becoming impractical when replicating extensive urban environments with numerous interacting agents such as pedestrians, cars, subway trains, and traffic lights.

Additionally, existing frameworks often lack sufficient realism, failing to accurately model latency, fault tolerance, and throughput - critical aspects of real-time operations (DeKort, 2019). Economic barriers further compound these issues, as traditional methods typically involve high capital and operational costs, thus discouraging comprehensive concrete experimentation.

Addressing these challenges necessitates a scalable, cost-effective, realistic, and quick approach to, in the future, pave the way for widespread adoption and innovation in smart city deployments and save lives from traffic related accidents.

## **Proposed Solution**

Because of the current problem the C-V2X space is facing, the proposed solution involves deploying a scalable, realistic smart city simulation framework using Infrastructure as Code (IaC) combined with AWS Elastic Kubernetes Service (EKS). Utilizing QNX RTOS-based containers, the system quickly creates dynamic cloned environments capable of real-time communication among diverse agents, such as autonomous vehicles and traffic lights, and pedestrians.

A custom designed hub-and-spoke communication model employing the TCPIP protocol ensures secure, efficient, and flexible interactions between said agents. Agents authenticate via handshake protocols, which ensures security while maintaining real-time responsiveness – which is crucial for traffic scenarios. This proposed approach significantly reduces costs and complexity by taking advantage of cloud resources, enabling quick deployment, simple scalability, and extensive real-time testing. Consequently, this facilitates robust innovation and practical advancements in smart city infrastructure deployment bringing the beneficiaries of this technology closer to safer traffic system – saving lives.

## **Technological Analysis & Performance**

### **System Architecture**

The underlying infrastructure consists of Kubernetes clusters deployed via AWS EKS, which host QNX-based containers running within Amazon Machine Images (AMI). Each container represents an individual agent such as autonomous vehicles or traffic light controllers. The architecture supports strong dynamic scaling. It allows additional nodes and pods to be deployed in response to the demand of the city’s unique traffic on any given day. The system's modular design provides quick deployment of new agents which provides the flexibility needed to simulate different scenarios with a city. For example, a car which drives off of a dealership lot immediately becomes integrated with the city’s message handlers to provide it real time traffic decisions. To improve robustness of the system, the infrastructure incorporates redundancy at multiple levels. Nodes can dynamically adjust resource allocation, ensuring high availability and performance stability even under varying load conditions at any given moment. The architecture also supports automatic healing mechanisms but spinning up failed instances in real-time. This is to ultimately ensure continuity of the simulation with minimal human intervention to get it back online.

### **Communication Model**

Communication across agents uses a hub-and-spoke architecture using the custom-defined TCCIP protocol. Central to this architecture is the MessageHandler and the Server, two dedicated service residing on each Kubernetes node responsible for routing messages among agents. The MessageHandler provides an API to agents to allow them to register themselves with the server and pass their messages to the Server. In addition to authenticating clients, the Server handles the routing of messages, serving as the other half of the hub in the hub-and-spoke model. All messages will pass through the Server, either as broadcasts to all agents or messages from one agent to another. Clients will constantly check their buffer for messages, ensuring none are missed. They do not directly interact with the Server. Communication between nodes similarly involves interaction between respective MessageHandlers and Servers, providing a consistent and extendable communication framework. Figure 1.1 includes a true overview of the systems communication framework enabling distributed, fault tolerant message passing.

A diagram of a service

AI-generated content may be incorrect.

*Figure 1.1, AWS Kubernetes Cluster Diagram*

For example, if nodes were not distributed, if any of these nodes fail for any reason, then it effects other nodes in a non-isolated manner. This failure would be detrimental across the network and not simply contained to a particular failure-node.

The TCP protocol is specifically designed to handle high-throughput messaging with minimal latency, ensuring timely delivery of critical information pertaining to direction, position, speed, cars. Its lightweight design allows efficient communication without significant overhead, supporting real-time responsiveness essential for safety-critical smart city operations (Yasar, 2024). Additionally, the system includes configurable message prioritization, ensuring high-priority communications are transmitted promptly, thus enhancing operational effectiveness.

### **Agent Implementation**

Within this solution, agents are implemented directly on QNX RTOS without middleware interference; this is to maintain minimal latency and maximum performance. Autonomous vehicle agents listen for traffic signals, pedestrian presence, and road conditions. This active listening behaviour from the agents create a city where all reactions are informed and calculated. Moreover, authentication within the simulation is handled via handshake protocols, bettering security and operational reliability. By registering each agent with Servers, the system protects the agent from latent or unreceived information from other agents. Take for example a traffic light who changes its state from green to yellow. If a car agent was never securely established with the message handler that the traffic light notified, the car would be put into danger as it enters traffic intersection with a yellow light. If all works as intended, traffic light agents dynamically control intersections, adjusting their signaling patterns based on real-time agent interactions to optimize traffic flow for the users while keeping them safe. (Craven, 2023).

Agent implementation emphasizes modularity and extensibility. They can be updated and integrated with additional functionalities as needed. For example, some cities may have different agents, such as trams, ferries, or scooters and therefore need different agents or attributes of different agents. Furthermore, comprehensive logging and diagnostic capabilities provide detailed insights for debugging, performance optimization, and operational monitoring. Together, these components form a fault tolerant, scalable, and highly responsive technical framework, ideally suited for extensive and realistic testing of smart city infrastructures.

## **Real World Implications**

The proposed simulation framework holds considerable promise for addressing pressing challenges in modern urban settings. For example, real-time data sharing among vehicles, infrastructure, and pedestrians can significantly reduce the likelihood of accidents. Automated vehicles receiving immediate notifications of unexpected pedestrian crossings or sudden roadway obstacles can engage avoidance maneuvers, finally making roadways safer.

Adaptive traffic signaling represents another core application area, whereby intelligent intersection management reduces congestion by adjusting signal phases based on real-time traffic flow and pedestrian activity. In emergency response scenarios, such as an ambulance navigating through congested streets/highways, high-priority and real-time communication allow for expedited and unimpeded transit (Graham, Thomas, Finstad, Dennert, & Southcott, 2023).

Over time, this simulation environment can be extended to support more complex urban analytics, spanning advanced city planning, environmental impact assessments, and efficient disaster response protocols. This level of integrated modeling has the potential to guide the development of safer, more sustainable, and better-managed urban infrastructures. Response strategies, ultimately contributing to safer, more sustainable, and efficiently managed cities.

## **Discussions**

While the proposed framework addresses a very wide range of existing traffic challenges, there are still some areas where further improvements may help its effectiveness. At present, the simulation primarily concentrates on communication infrastructure rather than realistic vehicle behaviours or detailed environmental factors such as unique city laws or inter-city communication. This abstraction from real-world dynamics may currently limit its direct applicability to urban planning and traffic modeling efforts. However, this technology is to pave the way for future simulations to build off this work to flesh out a more detailed simulation that does incorporate real-world details.

Similarly, although the current handshake-based authentication protocols are sufficient for smaller-scale simulations, larger deployments with more agents may require different security measures. Future iterations could incorporate advanced quantum encryption and authentication strategies to mitigate potential cyber threats/terrorism and improve the overall system (Raashid Ansari, Petit, Monteuuis, & Chen, 2023).

Furthermore, although basic logging and diagnostics are already in place within the project, more sophisticated monitoring tools. This could be real-time analytics and machine learning, based on anomaly detection, could deliver detailed insights into system performance. Incorporating additional urban elements, such as weather patterns/predictions, emergency conditions, and multiple transportation modes, would also help to create a more comprehensive and realistic simulation environment.

Finally, exploring hybrid system designs that leverage both cloud-based and edge computing resources may prove beneficial for minimizing message latency. By addressing these considerations, the proposed solution can continue to evolve into a more robust and versatile platform for a broad range of smart city applications.

## **Conclusion**

This group’s initiative presents a scalable, realistic, and cost-effective framework for real-time smart city simulations, built around QNX RTOS and AWS Kubernetes resources. By addressing key limitations in scalability, realism, and deployment complexity, the proposed solution supports both efficient testing and future innovation to the Vehicle-to-Everything (C-V2X) space. A custom-designed communication model and real-time agent communication establishes a foundation for more complex simulations capable of replicating unique urban conditions and widely different events - none of which could be accomplished without first creating the testing platform that is inexpensive and modular by nature.

The architecture’s modular structure further supports the incorporation of future technologies and enhancements. This positions the platform as a flexible testbed for ongoing smart city research and development. Overall, this infrastructure represents a critical milestone in advancing safer, more cost-efficient, and highly responsive urban ecosystems, laying the groundwork for subsequent developments in real-time operating systems and next-generation smart city technologies.

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