TEXAS PROJECT DELIVERY FRAMEWORK

Technical Architecture

Design Document

Project Planning

PROTOTYPE BLUETOOTH LOW ENERGY PREEMPTION PROXIMITY ALERT SYSTEM

Prepared for:

Texas Department of Transportation

Project No. 0-7004
Improve System Emergency Response Performance in the Houston District Using Connected Vehicle Technology

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Table of Contents

1. Background Information

Emergency response services play a vital role in saving lives and minimizing property damage when major events or incidents occur, and it is critical for emergency vehicles (EVs) to travel to their destinations while maximizing the timeliness and safety of their trip. However, traffic safety and efficiency are a concern for both EVs and civilian vehicles as EVs are in-route to calls, especially at intersections where conflicting vehicle paths are a risk. To improve safety and efficiency, the existing EV preemption systems allow an EV to request signal preemption (i.e., a green phase to be granted for the approach with the EV) at signalized intersections. The EV turns on the emergency sirens and strobe lights to alert nearby vehicles of its arrival. However, there is no alternative way of warning nearby vehicles when the drivers cannot be alerted properly by the sirens and lights.

The recently developed mobile proximity warning system using *Bluetooth* low energy (BLE) technology may provide a way to broadcast signal preemption status inside vehicles near the intersection. The basic concept is that (1) a microprocessor in the traffic signal cabinet detects the approaching EV; (2) the microprocessor sends out a *Bluetooth* beacon broadcast to a beacon-aware software application on a mobile device, such as a smartphone carried inside the vehicles; and (3) the application broadcasts the alert message based on an active signal preemption or another predefined event. The beacon broadcast can alert nearby vehicles to the EV presence.

This document provides a system overview of the proposed prototype BLE proximity alert system for EV preemption at signalized intersections. It provides information about the existing and the BLE proximity alert enabled preemption systems, the system components and interfaces between them, the planned capabilities, and the system architecture.

2. Technology Profile

Description The proposed BLE proximity alert system provides an alternative way of warning drivers of the presence of EVs near signalized intersections.	
Project Type	_X_ New System __ Upgrade and/or Augmented System
System Required by Statute	_X_ No __ Yes ▪ Which local law / directive mandate the creation of a solution?
Mission Criticality	__ No _X_ Yes ▪ Is the system part of a mission essential function?
Solution Scope	_X_ Internal Use *(Solution is for internal use within the agency)* ___ Government Wide *(Solution which will be shared or is common amongst governmental entities)* ___ Business Partners *(Solution is used by select vendors, providers, or partners to the agency)* __ Public *(Solution is generally available to public constituents)*
Delivery of Functionality	__ Functionality delivered over time _X_ Functionality delivered all at once
Estimated Number of Users	Total: 30 By Audience: Citizen: ______ Employee: _20_ Contractor:______ Other: _X_=> Emergency Response Service Providers: 10 __ Not Applicable
Estimated Annual Customer Growth Rate	Percentage: _________ By Audience: Citizen: ______ Employee: _____ Contractor:______ Other:_____ _X_ Not Applicable

Estimated Data/Storage	_X_ <1 GB __1- 99 GB __100-999 GB __1-999 TB __ >1 PB __ Not Applicable
Estimated Annual Customer Growth Rate	_X_ <1 GB __1- 99 GB __100-999 GB __1-999 TB __ >1 PB __ Not Applicable
External Interfaces	_X_ No __ Yes __ Not Applicable Estimated number of interfaces: ______ Please list any known interfaces that will be modified or developed: =>

3. Availability & Reliability

Production Hours of Operation	Select all that apply. __ Citizen __ Normal Business Hours (e.g. 8:00 am to 5:00 pm) __ Extended Business Hours (specify): ________________ __ 24 X 7 _X_ Employee __ Normal Business Hours (e.g. 8:00 am to 5:00 pm) __ Extended Business Hours (specify): ________________ _X_ 24 X 7 _X_ Government/Business Partner(s) __ Normal Business Hours (e.g. 8:00 am to 5:00 pm) __ Extended Business Hours (specify): ________________ _X_ 24 X 7
Production Availability	Uptime — Unplanned Downtime/month _X_ 99 (2 Nines) 7h 30m __ 99.5 4h 45m __ 99.9 (3 Nines) 1h 45m __ 99.99 (4 Nines) 5m __ 99.999 (5 Nines) 30s __ Other (specify): Scheduled Downtime: __ Specify Amount:_________ _X_ Not Applicable
Performance	Highlight any peaks or spikes in the usage of the service?
Risk	What are the repercussions if the system fails? The proposed BLE system does not interfere with the existing EV preemption system. If it fails, the existing EV preemption system operates as usual and will not be affected.
Application Backup Requirements	Full Back-up: __ Daily __ Weekly Incremental Back-up: __ Hourly __ Daily __ Weekly _X_ Not Applicable

4. Technology System Design Overview

Existing EV preemption systems are designed to give EVs, after detecting a preemption request signal, a green light on their approach to a signalized intersection while providing a red light to the conflicting approaches. Figure 1 shows the architecture of the existing EV preemption systems.

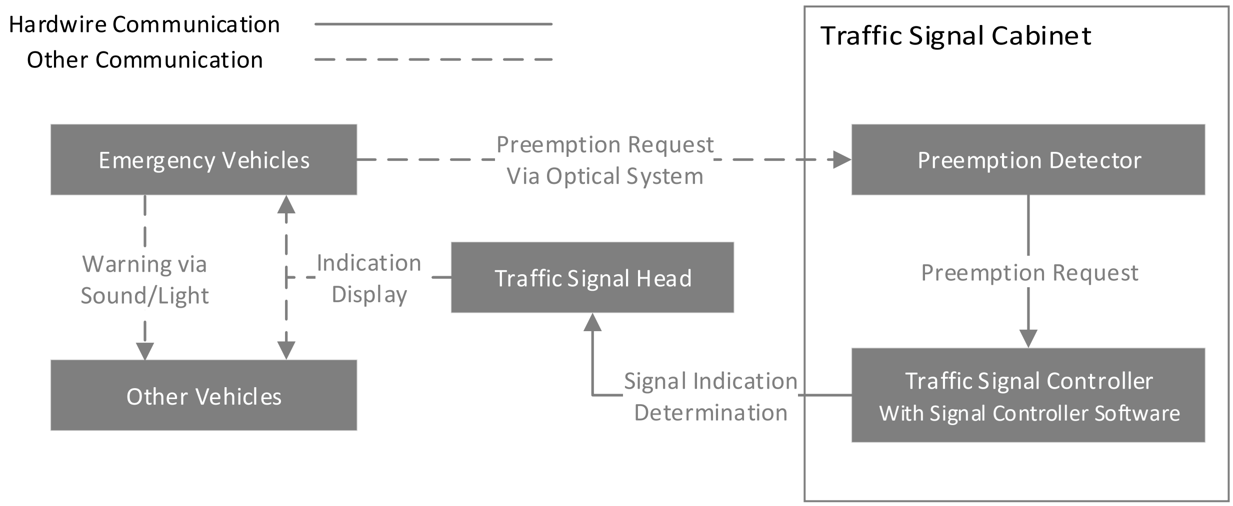

Figure 1. Emergency Vehicle Warning in Existing Emergency Vehicle Preemption Systems

As shown in Figure 1, EVs arrive at a signalized intersection with their sirens and strobe lights on. They are able to request signal preemption for their approaches using a signal preemption request system. The request is often serviced on a first-come, first-served basis. If the preemption is granted to a specific approach, the traffic signal head on this approach will display a green indication, and signal heads on conflict approaches will show red indications. This will allow the EVs to pass through the intersection.

During the whole process, drivers in nearby vehicles rely on the outside sound and visual input from the EVs (including sirens and strobe lights) for receiving warnings about the arrival and departure of the EVs. When the drivers are not properly notified about the presence of the EVs due to various reasons (distraction, lack of line of sight, etc.), the risk of collision between the EVs and other vehicles is increased.

With recent advancements in wireless communication technologies, an alternative method of EV warnings is available. Figure 2 illustrates the proposed basic system architecture for the BLE proximity alert prototype system for EV preemption at signalized intersections.

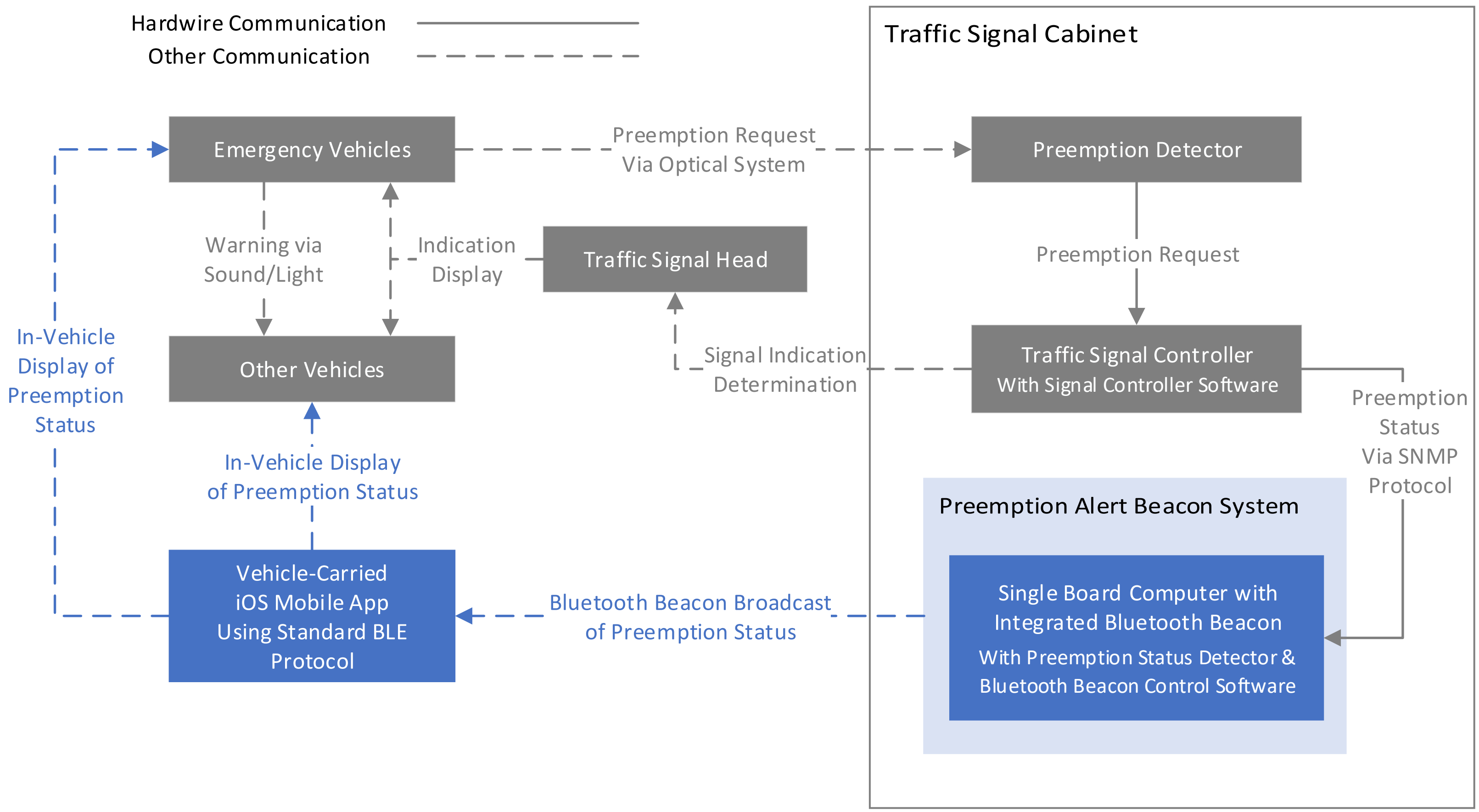

Figure 2. *Bluetooth* Low Energy Proximity Alert System Architecture for Emergency Vehicle Preemption

With modern traffic signal controllers, the status of signal preemption on each approach at the intersection is stored on the signal controller. The preemption status can be queried using the Simple Network Management Protocol (SNMP). As shown in Figure 2, in the BLE proximity alert system, a preemption alert beacon system is added inside the traffic signal cabinet and can communicate with the signal controller using SNMP “Get” commands. Software on a separate single-board computer frequently polls the preemption status of each intersection approach. Upon detection of an approach or approaches with an active preemption event, the software on the single-board computer initiates a BLE beacon broadcast using an onboard radio. A mobile application running on iOS-capable devices will be programmed to specifically look for beacon broadcasts related to signal preemption status. When a broadcast message is detected, the application will alert users of the preemption event with visual, audible, and/or tactile messages.

The BLE alert system has an omnidirectional broadcast pattern and thus does not require line of sight. Drivers who carry the BLE alert enabled mobile devices can receive warnings about EVs once they are within the range of the BLE broadcast, which can be 400 ft or more from the signal cabinet. EVs can also utilize the BLE alert system for receiving confirmation about the preemption status and alerts of other EVs nearby.

5. Technical Architecture

The existing EV preemption systems at signalized intersections consist of two subsystems: the traffic signal system and the preemption signal detection system. The traffic signal system is the basic system needed for intersections where signalized operation is deemed necessary for mobility and/or safety concerns. It consists of a set of electronically and nonelectronically operated traffic control devices. The electronically operated devices include a traffic signal cabinet, a signal controller, signal heads and traffic detectors for each intersection approach, signal poles, mast arms, pole foundations, and necessary electronic accessories (power supplies, conduits, wires, etc.). Nonelectronic devices include traffic signs and pavement markings.

To improve safety and facilitate EV response, many agencies have added the preemption signal detection system to signalized intersections. The EV preemption system is designed to give, upon detection of a preemption request signal, a green light to EVs on their approach while providing a red light to conflicting approaches. Preemption signal detection technologies being employed today include sound-based, light- or infrared-based, hard-wire-based, radio-based, and global positioning system (GPS)–based systems. Figure 3 provides an illustration of the components of most of the current EV preemption systems that use an optical preemption detection system.

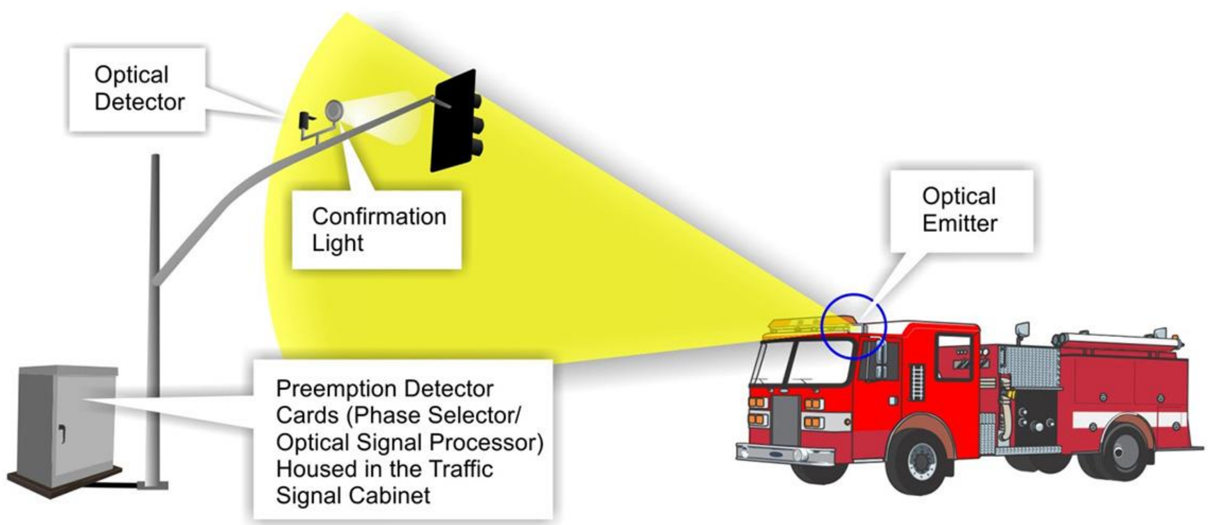

Figure 3. Emergency Preemption Detection System at Signalized Intersections

The optical preemption detection system includes an optical emitter installed on the EV, an optical detector installed on the mast arm at the intersection, and an optical signal processor housed inside the signal cabinet. The emitter is normally wired so that it automatically activates when the emergency lighting is active. As the EV approaches the intersection, the optical detector senses the optical pulses from the emitter and transmits electrical signals to the optical signal processor. The optical signal processor then sends a preemption request to the proper input of the traffic controller about the presence of the EV. The traffic controller then safely manipulates the traffic signals according to a preprogrammed algorithm. Depending on where the traffic controller was in its normal routine, the vehicle will receive a green light after a minimum of 3 seconds. Traffic signals that are already green will stay green until the vehicle passes.

The new system will add a new subsystem, the BLE proximity alert prototype system, to the existing preemption system for facilitating EV preemption warning. The following table lists the major technologies that will be used in developing the BLE prototype system.

Hosting	__ State Data Center (DCS) __ Software as a Service (SaaS) __ Government Cloud (AWS, Microsoft Azure, IBM) _X_ Other, Please Specify: Standalone software component running inside traffic signal cabinet. __ Unknown __ Not Applicable
DCS Exemption	__ No __ Yes __ Unknown _X_ Not Applicable
Development Approach	__ Commercial Off The Shelf (COTS) __ Open Source _X_ Custom __ Unknown __ Not Applicable (Please provide a list of any known commercial or open source software)
Type of Processing	__ Batch and/or online _X_ Transaction processing and/or analytical reporting __ Not Applicable
Application Approach	__ Microservices _X_ SOA __ N Tier __ Monolithic __ Other (specify): __ Unknown __ Not Applicable
Development Platform	__ J2EE __ .NET _X_ Other: Python/iOS Swift _______Version __ Unknown __ Not Applicable
Application Communication Technologies	Service Interface: SNMP _X_ Web Services (HTTP, XML, SOAP, WSDL, UDDI) __ Public Facing

	_X_ Internal Facing __ Messaging / Message Queuing __ Unknown __ Not Applicable
System Integration Technologies	__ XML __ Web Services _X_ Messaging __ IIOP __ Adaptors __ Secure FTP __ Proprietary API via ___________ _X_ Other (specify): SNMP __ Unknown __ Not Applicable
Operating System	__ Windows Server _X_ Linux (Specify): Debian __ Unix __ zOS _X_ Other __ Unknown__ Not Applicable
Database Technology	__DB2 __ MySQL __Oracle __SQL Server __Other (Please specify _______________) __ Unknown _X_ Not Applicable
Data Reporting Solution(s)	List: => __ Unknown _X_ Not Applicable

*** Disclaimer: Any technologies listed above have been provided solely for convenience, the information provided is not intended to be exhaustive nor does it indicate product endorsement*

6. System Security

User Authentication	__ Within the Solution Being Developed __ Existing Identity & Access Management Solution (IAM) __ New Identity & Access Management Solution (IAM) _X_ Not Applicable
User Access Requirements	__ Internet __ Extranet _X_ Not Applicable
Compliance / Data	__ Personally Identifiable Information (PII) __ Personal Health Information (HIPAA) __ Criminal Justice Information Services (CJIS) __ Payment Card Industry (PCI) __ Federal Tax Information (FTI) __ Other: (Describe) _X_ Not Applicable
Secure Storage	Data Encryption __ Column __ Row __ Table __ Database using AES encryption __ Other (Explain: ________________________________) _X_ Not Applicable
Secure Transport	__ SSL/TLS __ *Other Scenario where data is persisted on in transit (specify)*: _X_ Not Applicable
Data Distribution	Will the system distribute information outside of the agency? _X_ Yes __ No __ Not Applicable If Yes, to what entities: Real-time traffic signal preemption status will be sent to users (emergency services personnel/TxDOT maintenance vehicles) with a specific mobile app running on an iOS-capable device in close proximity of a traffic signal cabinet.

Risks	What are the business risks of this system from a security and privacy perspective? None. All information interactions will be self-contained in the traffic signal cabinet with the exception of the *Bluetooth* beacon broadcast that the preemption alerts. The beacon broadcast will only be accessible to authorized users, such as emergency management and TxDOT maintenance personnel. No incoming *Bluetooth* connections to the microcontroller will be permitted.

7. Preliminary System Design Description

This section provides a detailed description of the BLE proximity alert enabled emergency preemption system at signalized intersections. The proposed new system adds a *Bluetooth* alert beacon system to the existing emergency preemption system. For the proposed system to function properly, the existing emergency preemption system that consists of the traffic signal system and the optical preemption system needs to function properly. Section 5 of this document provides a detailed description of the components in the existing preemption system. This section describes the components of the *Bluetooth* alert beacon system and the interfaces between these components.

7.1 System Components

Table 1 lists the major electronic components of the proposed system and their residing places.

Table 1. Components of the BLE Proximity Alert Enabled Emergency Preemption at Signalized Intersections

Name of Subsystem	Name of Component	Physical Location	Component Type	Existing/New
Traffic Signal System	Traffic Signal Cabinet	Roadside	Hardware	Existing
	Traffic Signal Controller	Traffic Signal Cabinet	Hardware	Existing
	Traffic Signal Head	Mast Arm/Span Wire	Hardware	Existing
	Signal Control Software	Traffic Signal Controller	Software	Existing
Optical Preemption System	Optical Emitter	Emergency Vehicle	Hardware	Existing
	Optical Detector	Mast Arm/Span Wire	Hardware	Existing
	Optical Signal Processor	Traffic Signal Cabinet	Hardware	Existing
BLE Preemption Alert Beacon System	Single-Board Computer	Traffic Signal Cabinet	Hardware	New
	Integrated *Bluetooth* Beacon	Single-Board Computer	Hardware	New
	iOS-Capable Device with BLE Radio	Vehicle	Hardware	New
	Preemption Status Detector	Single-Board Computer	Software	New
	Bluetooth Beacon Control Software	Single-Board Computer	Software	New
	iOS Mobile Application	iOS-Capable Device	Software	New

The added alert beacon system is comprised of a single-board computer with an integrated *Bluetooth* beacon, an iOS-capable device, and three software programs. The single-board computer is housed inside the traffic signal cabinet. Two software programs will be installed on the single-board computer for detecting the preemption status and controlling the *Bluetooth* beacon, respectively. An iOS mobile application will be developed for receiving the *Bluetooth* beacon signal and displaying the preemption status. The iOS application will be installed on iOS-capable devices with a BLE radio. The iOS-capable devices will be carried by authorized drivers or vehicles, such as emergency responders/vehicles and TxDOT maintenance personnel/vehicles. The following section describes these added components.

7.1.1 Hardware Components

The BLE alert beacon system adds three hardware components to the existing emergency preemption system at signalized intersections: a single-board computer, a *Bluetooth* beacon integrated on the single-board computer, and an iOS-capable device.

7.1.1.1 Single-Board Computer

The alert beacon system will use an off-the-shelf single-board computer to provide control and interfacing of the preemption alert process. The single-board computer is built on a single circuit board and contains functional computer components including a microprocessor, input/output, and memory. It provides a low-power computing solution and a low-profile architecture. Most of the off-the-shelf single-board computers have an industrial temperature range of −40°C to 85°C. These features allow the single-board computer to be housed inside a traffic signal cabinet to connect with the traffic signal controller for the prototype development.

7.1.1.2 Integrated *Bluetooth* Beacon

Integrated on the single-board computer is a *Bluetooth* beacon. The BLE beacon is comprised of a small radio transmitter and a 2.4 Ghz antenna. The beacon is based on the BLE protocol, which is part of the new *Bluetooth* 4.0 standard. BLE allows devices to communicate with each other by transferring small amounts of data at 1 Mbps transmission speed. Compared with the 2–3 Mbps for *Bluetooth* 2.0 and up to 24 Mbps for *Bluetooth* 3.0 in *Bluetooth* Classic, BLE consumes much less battery power.

In the BLE alert beacon prototype application, the beacon located inside the traffic signal cabinet will broadcast BLE signals in an omnidirectional pattern. While the specification for BLE states that the signal can be broadcast up to 400 ft, the actual range can be extended or reduced greatly depending on the type of 2.4 Ghz antenna installed. This BLE signal contains information obtained from the traffic signal controller about the preemption status. The information will trigger specific actions according to a predefined configuration relevant to the signalized intersection (e.g., the approach direction).

7.1.1.3 Client Device

The beacon broadcast BLE signals can be detected by most smartphones and tablets built since 2012. However, since Android phones vary widely, some models might support BLE while others support an older version of *Bluetooth*. Most of the iOS-capable devices have a radio that supports BLE: iPhone 4 and newer, iPad 3rd generation and newer, and iPad mini and newer. The project team will use the Apple iOS-capable devices for detecting the BLE beacon broadcast, which will trigger actions predefined on the mobile devices. The devices will be carried by authorized drivers and/or vehicles in the initial testing and implementation stages.

7.1.2 Software Interfaces

The proposed *Bluetooth* preemption alert beacon system will add three software programs to the existing emergency preemption system: the preemption status detection program, the *Bluetooth* beacon control program, and an iOS mobile application for beacon alert messaging. These programs provide four interfaces of different functions. For experimental and testing purposes, an additional interface will be added for simulating preemption requests as an alternative to relying on EVs to send optical signals to trigger the preemption inputs.

7.1.2.1 Preemption Request Simulation Environment

The existing emergency preemption systems often adopt the optical system. The emitter on the EV sends out an optical signal that is converted into electrical signals upon detection by the optical detector at the intersection. The electrical signals trigger a preemption request at the optical signal processor, and a call for preemption is then placed into the traffic signal controller. The traffic signal controller reacts properly to the call, and the preemption status of the controller software will change to reflect the preempt input and traffic signal indication outputs for the affected approaches.

Modern signal controllers and their software follow the National Transportation Communications for ITS Protocol (NTCIP) standard 1202. The NTCIP 1202 protocol allows applications external to the traffic signal controllers to convey requests to access or modify values stored in the signal controller. These values are referred to as objects, and objects that can be grouped together to define certain control, parameter, or status of the controllers are referred to as nodes. For preemption, the Preempt Parameters node contains 28 objects that support preempt functions for the controller, and the Preempt State object provides the status on which state the associated preempt is in. Given the traffic signal controller software that follows the NTCIP 1202 protocol, the EV preemption request process can be simulated by using a utility program to directly place a preemption input into the controller. Figure 4 shows the architecture of this simulation interface in a lab environment setting.

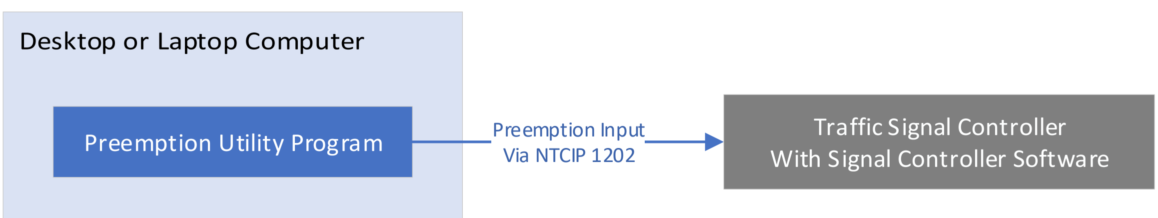

Figure 4. Preemption Request Simulation Interface for BLE Alert Beacon System

The preemption utility program can be installed on a desktop or laptop computer. Connection between the computer and the traffic signal controller uses an ethernet cable. The utility program will access the controller preemption parameters using the object identifiers defined by the NTCIP 1202 protocol. The Preempt Control State object can be accessed and modified to place a preemption request input. The protocol has the following definition for this object:

> *This object when set to ON (one) shall cause the associated preempt actions to occur unless the actions have already been started by the physical preempt input. The preempt shall remain active as long as this object is ON or the physical preempt input is ON. This object when set to OFF (zero) shall cause the physical preempt input to control the associated preempt actions.*

7.1.2.2 Signal Preemption Status Access

Once the traffic signal controller receives the preemption request, either from EVs or from the utility program, the associated preempt actions will occur on the traffic signal controller. The Preempt Status object of the traffic signal controller software stores the preempt number that is currently being serviced in the controller. The Preempt State object provides more information about whether a preempt input is active and whether a preempt service is active.

A software module will be developed to access the status of the preemption stored on the controller by utilizing SNMP commands. This preemption status detection module will be installed on the single-board computer, which will be connected to the traffic signal controller using an ethernet cable. The software will continually issue SNMP Get requests via the User Datagram Protocol (UDP) to the signal controller to obtain the status of preemption at each approach of the signalized intersection. The requests will occur frequently (within seconds or less) in order to minimize the latency of the preemption status alerts. The signal controller responds with a status message indicating whether a signal preemption is active for any of the approaches. Figure 5 illustrates the interface.

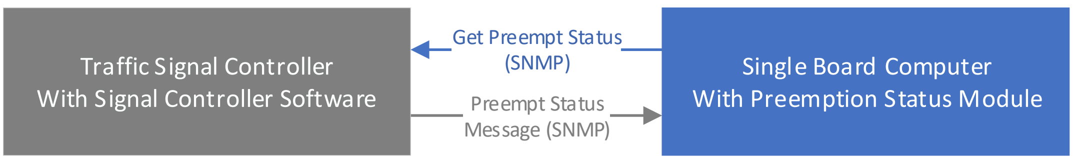

Figure 5. Preemption Status Access Interface for BLE Alert Beacon System

7.1.2.3 *Bluetooth* Low Energy Radio Beacon Broadcast Activation

When a positive preemption status is detected from any of the intersection approaches, the BLE radio beacon will broadcast beacon signals containing the preemption status information that indicates which approaches are currently being preempted. A BLE radio beacon software module will be developed and installed on the single-board computer to communicate with the preemption status module. The positive preemption status will activate a beacon broadcast by the BLE radio beacon. The broadcast will indicate which intersection approaches are currently being preempted. In a scenario where no approaches are preempted, the beacon broadcast will not be active. Figure 6 illustrates the beacon broadcast activation interface.

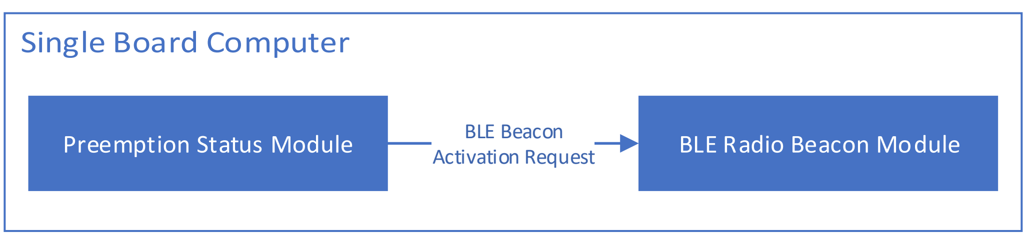

Figure 6. BLE Radio Beacon Broadcast Activation Interface for BLE Alert Beacon System

7.1.2.4 *Bluetooth* Low Energy Beacon Broadcast Detection

The beacon broadcast messages will contain the status of signal preemption and potentially other signal status messages for each intersection approach. Smartphones, such as Apple iPhones, are equipped with the ability to recognize specific beacon broadcast messages if the message identifier is programmed into an application running on the device. In the test environment for this project, an Apple iOS mobile application capable of interpreting the beacon broadcast messages will be developed. When the mobile device installed with this iOS application is in close proximity of the intersection, the application will recognize and decode the beacon broadcast from the single-board computer. Figure 7 illustrates the beacon broadcast detection interface.

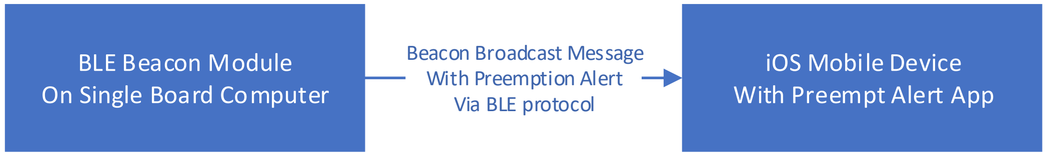

Figure 7. BLE Beacon Broadcast Detection Interface for BLE Alert Beacon System

7.1.2.5 In-Vehicle Preemption Alert Messaging

Once decoded by the iOS application, the preemption status originally transmitted from the traffic signal controller will be converted into alert messages. The iOS application will display the appropriate safety messages to users to alert them of an active signal preemption event and the presence of an EV at or near the intersection on all approaches (e.g., north, south, east, west). The alert messages will be displayed inside the authorized vehicles using visual, audible, or tactile messages.

7.2 System Security Consideration

The BLE preemption alert beacon system does not interfere with the existing emergency preemption system at signalized intersections. The existing optical preemption system remains enacted. The manual preemption request process will only occur during the prototype development stage under a lab simulation environment by modifying the Preempt Control State object on the traffic signal controller using the preemption utility program. The traffic signal controller used in the simulation environment operates in an isolated local network without access to any government or agency network. For prototype testing under the controlled environment and in the field where the traffic signal controller is connected to an agency network, the preemption request will only stem from the existing optical preemption system. Any testing activities of preemption requests from the EVs will be carefully planned and approved by TxDOT and the participating emergency response agency before being executed.

The communication between the traffic signal controller and the BLE preemption alert beacon system is essentially an information query process. The preemption detection detector running on the single-board computer accesses the read-only Preemption Status (or Preemption State) object to obtain the preemption status value stored on the traffic controller. No read-and-write objects will be accessed beyond the preemption request simulation environment.

The BLE preemption alert beacon broadcast is a one-way communication process. The BLE beacon broadcasts BLE signals containing preemption status information, and the iOS BLE capable devices detect and decipher the signals and then push a preemption alert message to authorized users. No data will be collected from the users.

Appendix A: Definitions

Term	Acronym	Definition
Bluetooth Low Energy	BLE	A wireless communication technology standard using the *Bluetooth* 4.0 (or newer) core specification that transmits smaller amounts of data and consumes less power than classic *Bluetooth*
Emergency Vehicle	EV	Vehicles providing emergency response services
National Transportation Communications for ITS Protocol	NTCIP	A family of standards that provides both the rules for communicating and the vocabulary necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system
Simple Network Management Protocol	SNMP	An application layer protocol that uses User Datagram Protocol port number 161/162
User Datagram Protocol	UDP	A communications protocol for establishing low-latency and loss-tolerating connections between applications

Appendix B: Record of Changes

Version Number	Date	Author/Owner	Description of Change
0	03/31/2020	Texas A&M Transportation Institute	Initial Submission