NIST Technical Note 2186

Modeling Public Safety Communication Scenarios: School Shooting Incident

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Abstract

Public safety practitioners performing day-to-day activities and responding to incidents communicate in ways that are very different from the general public. In order to determine if a particular technology or network deployment can meet the performance requirements critical to first responders, sound and detailed scenarios are needed. In this document, we present a fictional school shooting scenario involving a large number of responders, vehicles, and applications, over a 4-hour period. We describe, in detail, the location of the users, the type of applications used and their usage patterns. We also present a basic network deployment using Long Term Evolution (LTE) and describe the implementation of such a scenario in the open-source ns-3 simulation platform so it can serve as a baseline for future research.

Key words

Public Safety Communication; Incident Modeling; Network Simulation.

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Abbreviations

3GPP Third Generation Partnership Project.

AVL Automatic Vehicle Location.

BCA Bureau of Criminal Apprehension.

CDF Cummulative Distribution Function.

CRF Constant Rate Factor.

D2D Device to Device.

DC Deployable Camera.

DL Downlink.

eMBMS evolved Multimedia Broadcast Multicast Service.

EMS Emergency Medical Service.

EMT Emergency Medical Technician.

FPS Frames Per Seconds.

GPS Global Positioning System.

HTML Hypertext Markup Language.

HTTP Hypertext Transfer Protocol.

IC Incident Command.

ICS Incident Command System.

IMS IP Multimedia Subsystem.

LTE Long Term Evolution.

MCPTT Mission Critical Push-To-Talk.

NG911 Next Generation 911.

NR New Radio.

OSEC Operations Section.

PGW Packet Gateway.

PSAP Public Safety Answering Point.

PSC Public Safety Communication.

PTT Push-To-Talk.

QoS Quality of Service.

RMS Records Management System.

SA Staging Area.

SC School Camera.

SGW Serving Gateway.

SWAT Special Weapons And Tactics.

TC Traffic Camera.

UC Unified Command.

UE User Equipment.

UL Uplink.

VoLTE Voice over LTE.

1. Introduction

This document describes a high school shooting scenario representing one of the many use cases that first responders may encounter. The scenario is inspired by the work from Televate for the State of Minnesota based on input from first responders and described in [1]. However, modifications were made to some of the assumptions and additional details were introduced to generate more reproducible results when conducting research based on this scenario. Therefore, while [1] can provide additional background information, it is not required to use this document. For example, higher video data rates, increased web traffic, and the use of Mission Critical Push-To-Talk (MCPTT) for voice communication are included in this scenario. The description of this scenario uses the building blocks defined in [2] and illustrated in Fig. 1. As such, this document is organized as follows: in Section 2, we provide a detailed technology-independent description of the incident. In Section 3, we define the networking capabilities provided during the incident for a basic Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) deployment. Finally, in Section 4, we provide a description of the implementation made in the simulator, ns-3, and included in the Public Safety Communication extension available in [3].

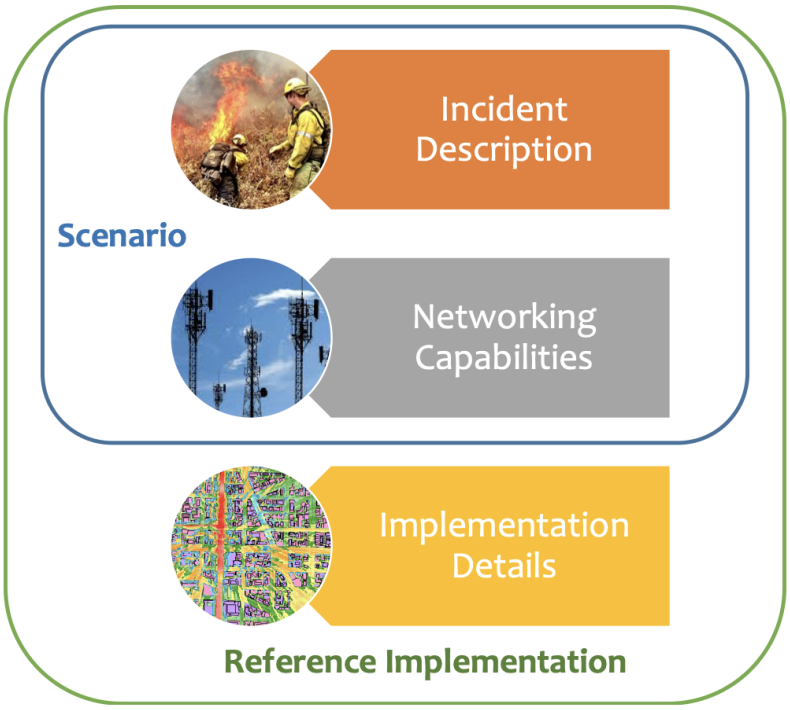

Fig. 1. Public safety scenario development building blocks.

2. Incident Description

2.1 High Level Description

This incident provides an active shooter scenario at a large high school involving casualties. The scenario includes more than 100 public safety responders representing strike teams (i.e., Special Weapons And Tactics (SWAT)), Law Enforcement (for perimeter security), Emergency Medical Service (EMS), Fire, and Incident Command (IC) / Unified Command (UC). The incident response is fully underway 60 minutes into the scenario and lasts a total of 245 minutes. Throughout the duration of the incident, first responders make use of voice, real-time video streaming, telemetry, biometrics, and other applications.

2.2 Context

Similar to [1], the incident is assumed to occur in mid-January during a snowstorm. This indicates heavy snowfalls, strong winds, and freezing ice. There are approximately 2000 students in school at the time an unidentified male begins to open fire with a small caliber weapon.

2.3 Incident Area

The incident area layout is shown in Fig. 2, with dimensions and locations listed in Table 1. For simplicity, all positions are relative to the center of the outer perimeter, shown as position (0,0) in Fig. 2. The incident area is divided into four key areas: outer perimeter, inner perimeter, UC, and Staging Area (SA). In this scenario, it is assumed that the school building is the only building that provides an indoor environment, while all other areas are considered outdoors. This assumption is made since it is likely that the high school building will be surrounded by open areas such as parking lots, football fields, baseball fields, and tennis courts.

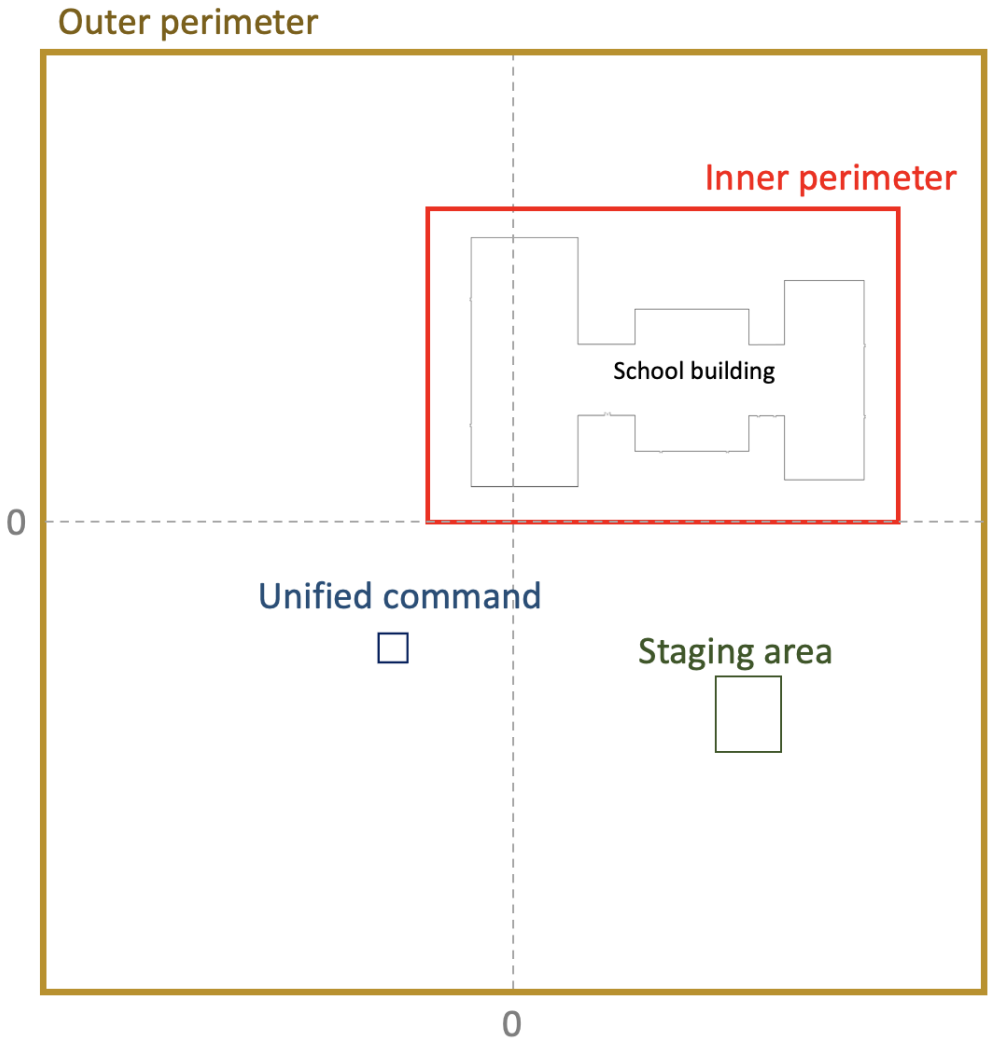

Fig. 2. Incident layout and key areas.

A layout of the school building with exterior dimensions is shown in Fig. 3. The building, made with concrete walls, is assumed to have a single level and a height of 6 m. There are two types of classrooms: rectangular ones (15 m x 10 m), and square ones (10 m x 10 m). There are other specific areas such as an Auditorium (30 m x 30 m), Gymnasium (20 m x 30 m), Cafeteria (30 m x 30 m), Kitchen (15 m x 30 m), and Library (20 m x 30 m). The floor plan is shown in Fig. 4.

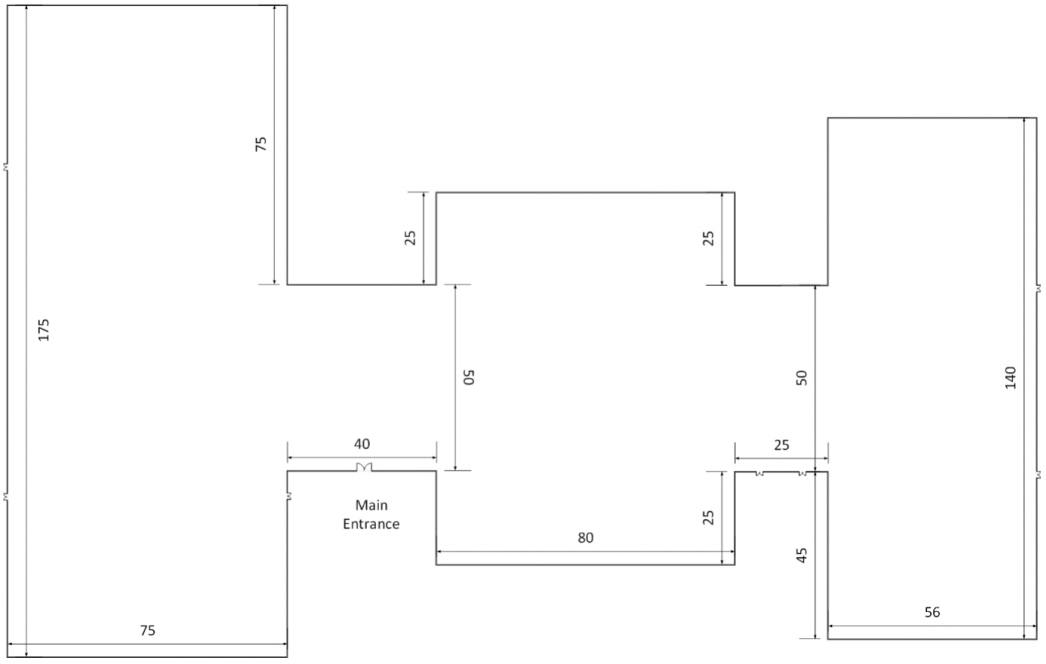

Fig. 3. Dimensions (in m) of school building.

Table 1. Location and dimensions of key areas and school building.

Area	**Location (m, m)**	**Dimensions (m x m)**
Outer perimeter	0, 0	600 x 600
Inner perimeter	100, 100	300 x 200
Unified command	-75, -50	10 x 10
Staging area	150, -75	30 x 40
School building	100, 100	276 x 175 (bounding box)

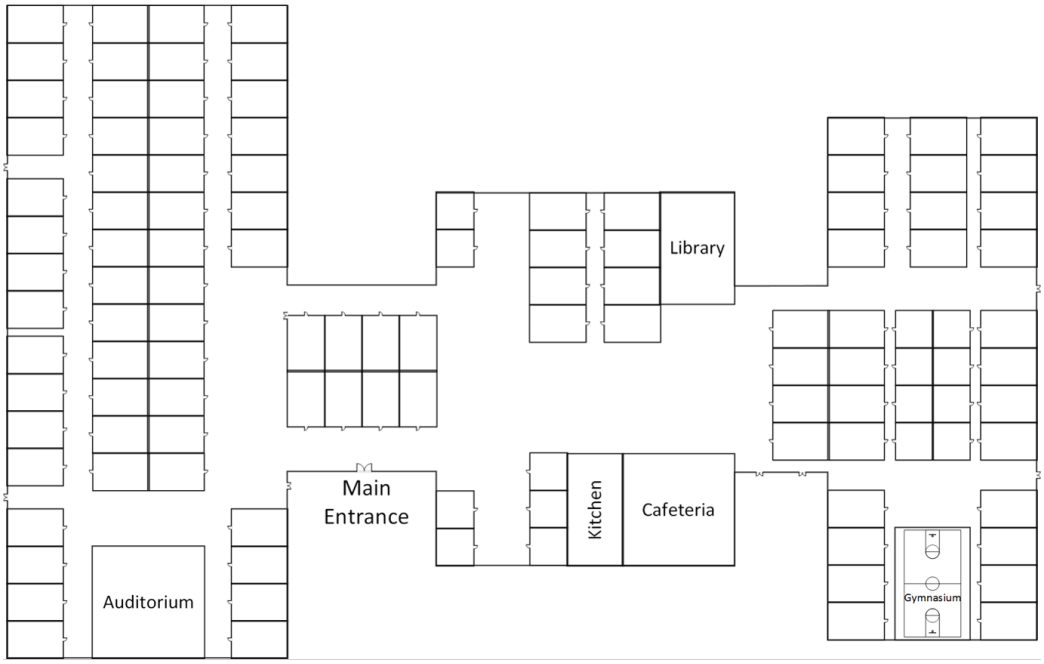

Fig. 4. School building floor plan.

2.4 First Responder Personnel

Taken directly from [1], the Incident Command System (ICS) organization is shown in Fig. 5, with colors denoting the location of the team members with regard to the key areas identified in Section 2.3. They are divided into three main groups, namely the Operations Section, Planning Section, and Logistics Section, each lead by a Chief located at the UC. Another grouping of the first responders, based on their roles in the response is shown in Table 2, which also lists the number of responders in each team.

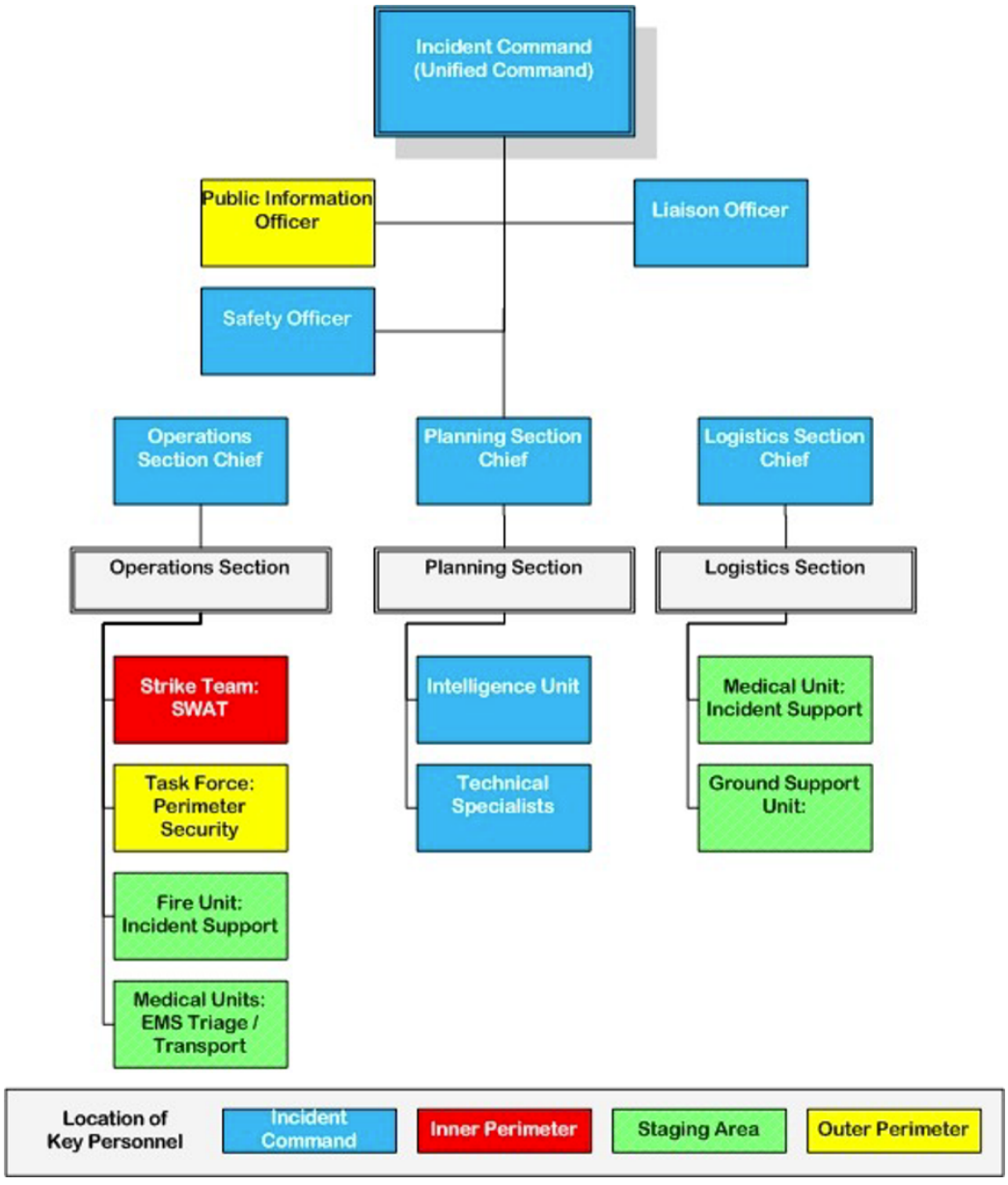

Fig. 5. ICS organizational chart.

Table 2. First responder personnel.

Group	Count	Description
Task Force	68	The Task Force Contingent will be responsible for the security of the inner and outer perimeters and crowd control. There are 12 roadblocks with four officers per roadblock, and the remaining 20 officers will be located at fixed positions to handle crowd control.
Unified Command	12	The UC Contingent consists of the IC, Liaison Officer, Operations Section (OSEC) Chief, Planning Section Chief, Logistics Section Chief, Safety Officer and members of the Planning Section: the Intelligent Team (three total, including the negotiator) and Technical Specialists (three total).
Strike Team	16	The Strike Team Contingent is made up of four teams of four SWAT officers each.
Operations Section	12	The remaining member of the Operations Section will consist of the Fire and Medical Units. The Fire Contingent consists of two engines (three responders per engine) and the EMS Contingent consists of three ambulances with two Emergency Medical Technicians (EMTs) per ambulance. The Fire and EMS Units will remain at the SA until as directed by the OSEC Chief.

2.5 Equipment

The following non-personnel assets involved in the incident are shown in Table 3. Note that this is not an exhaustive list of all the equipment used by first responders, but the ones likely to involve some means of communication. In addition, there are several assets that the first responders can access to help respond to the incident, such as traffic cameras, and those that are listed in Table 4.

Table 3. First Responder equipment available during incident.

Type	Count	Description
Patrol cars	34	Two patrol cars are present at each roadblock. Eight roadblocks are setup along the outer perimeter and four along the inner perimeter. There are also 10 cars for the 20 officers patrolling the area.
Mobile command center	1	Large vehicle used as UC for the incident.
SA mobile unit	1	Vehicle used at the SA for coordination with UC.
Fixed situational awareness cameras along perimeter	4	Cameras that can be deployed by the SWAT teams.
Throw phone	1	Phone to be used to communicate with offender.
Fire engines	2	Engines from the Fire Contingent that are located at the SA.
Ambulances	3	The ambulances from the EMS Contingent that are located at the SA and will be used to retrieve injured victims.
Computers	8	Five computers are installed in the mobile command center and three at the SA to access voice, data, and video.
Helicopter	1	Helicopter to monitor activities from the air.

Table 4. Other equipment at the disposal of first responders.

Type	Count	Description
Traffic cameras	4	Local traffic and street cameras are available to provide additional situational awareness.
School cameras	5	School cameras are accessible to provide additional situational awareness.

2.6 Timeline of Events

A timeline and description of key events that occur during the incident are shown in Table 5. For each event, we define a name to easily refer and derive other timing information throughout the remaining of the document.

Table 5. Key events.

Time (min)	Description	Event Name
0	Start time of the incident. The offender injured 10 people with critical to minor wounds. The offender then proceeded to break into an occupied classroom and take hostages.	E1_Incident_Start
Between 3 and 5	First law enforcement officers (Task Force) on scene. Roadblocks are setup.	E2_TaskForce_Arrive
Between 10 and 30	Strike team arrives at SA and starts moving to deploy at the entrances of the school building.	E3_SWAT_Arrive
Between 10 and 30	Fire and EMS Units arrive and are sent to the staging area. A helicopter also arrives at the scene.	E4_FireEMS_Arrive
Between 3 and 30	The IC, Intelligence Unit, and technical specialists arrive. The UC is declared and setup.	E5_UC_Setup
30	Inner and outer perimeters are secured; Staging Area Operations Section and Logistics Section are setup. Non-responder personnel within inner and outer perimeters are evacuated and witnesses are questioned.	E6_Perimeters_Ready
60	Strike teams deploy inside the school building and conduct room-by-room clear and secure until they reach the offender's location.	E7_SWAT_Deploy
120	SWAT teams reach the immediate incident area and start negotiations with the offender.	E8_Offender_Found
180	Offender is subdued.	E9_Interdiction
185	Incident area is fully secured. Victims are retrieved.	E10_Incident_Secured
195	Ambulances leave the scene to bring victims to hospital.	E11_EMS_Departure
245	Incident closed out.	E12_Incident_End

2.7 Location and Mobility Information

This section describes user and asset locations throughout the incident. Fig. 6 illustrates the outdoor deployment of personnel and assets while Fig. 7 shows their locations inside the school building. Details about the coordinates and mobility of each unit are specified in Appendix A.

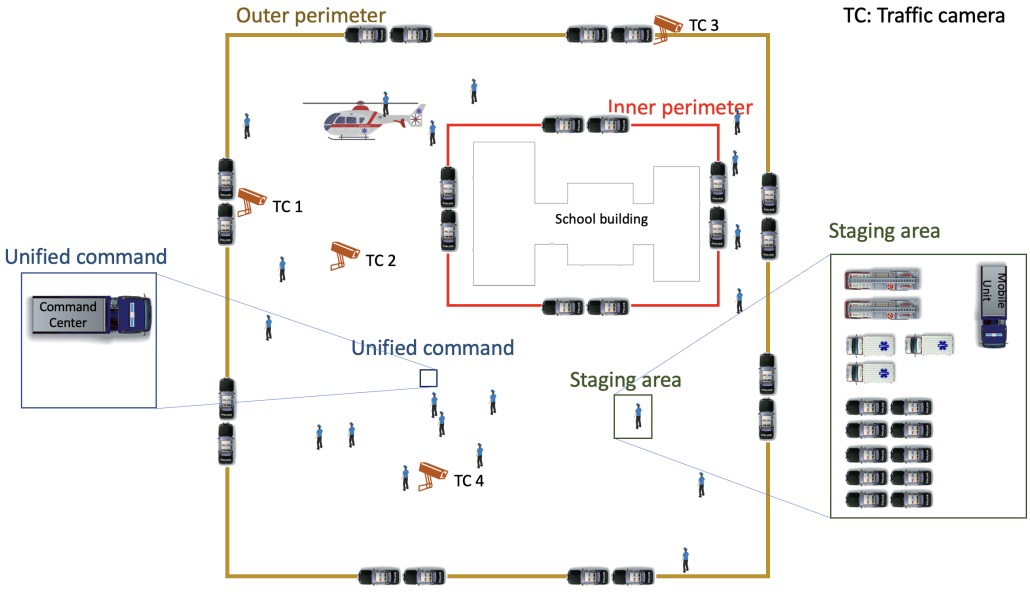

Fig. 6. Outdoor unit deployment.

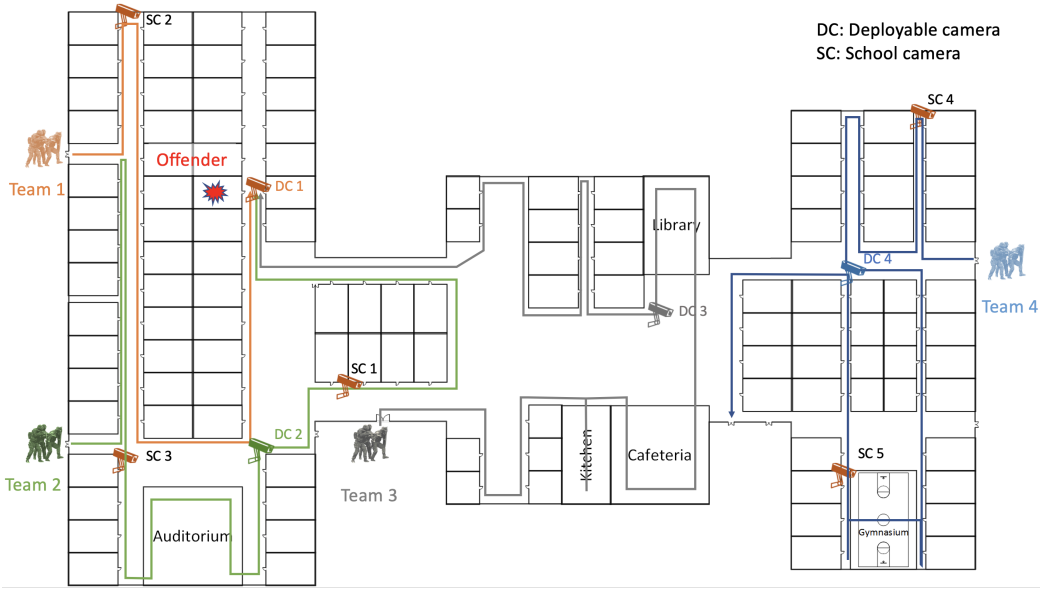

Fig. 7. Indoor deployment and mobility.

2.7.1 Task Force

Upon arrival (E2_TaskForce_Arrive), the roadblocks are setup along the outer and inner perimeters to control access to the incident area. Each roadblock has two vehicles and two officers per vehicle, and their fixed locations are shown in Fig. 6.

An additional 20 patrol officers are deployed throughout the scene upon arrival to assist with crowd control inside the outer perimeter (but not inside the school building) until the incident is closed out (E12_Incident_End). Their fixed locations are also shown in Fig. 6.

2.7.2 SWAT Teams

Upon arrival (E3_SWAT_Arrive), the SWAT teams go to the SA to receive instructions on where to deploy and start moving to their assigned location outside the school building at a speed of 1 m/s. The path taken by each team is shown in Fig. 8.

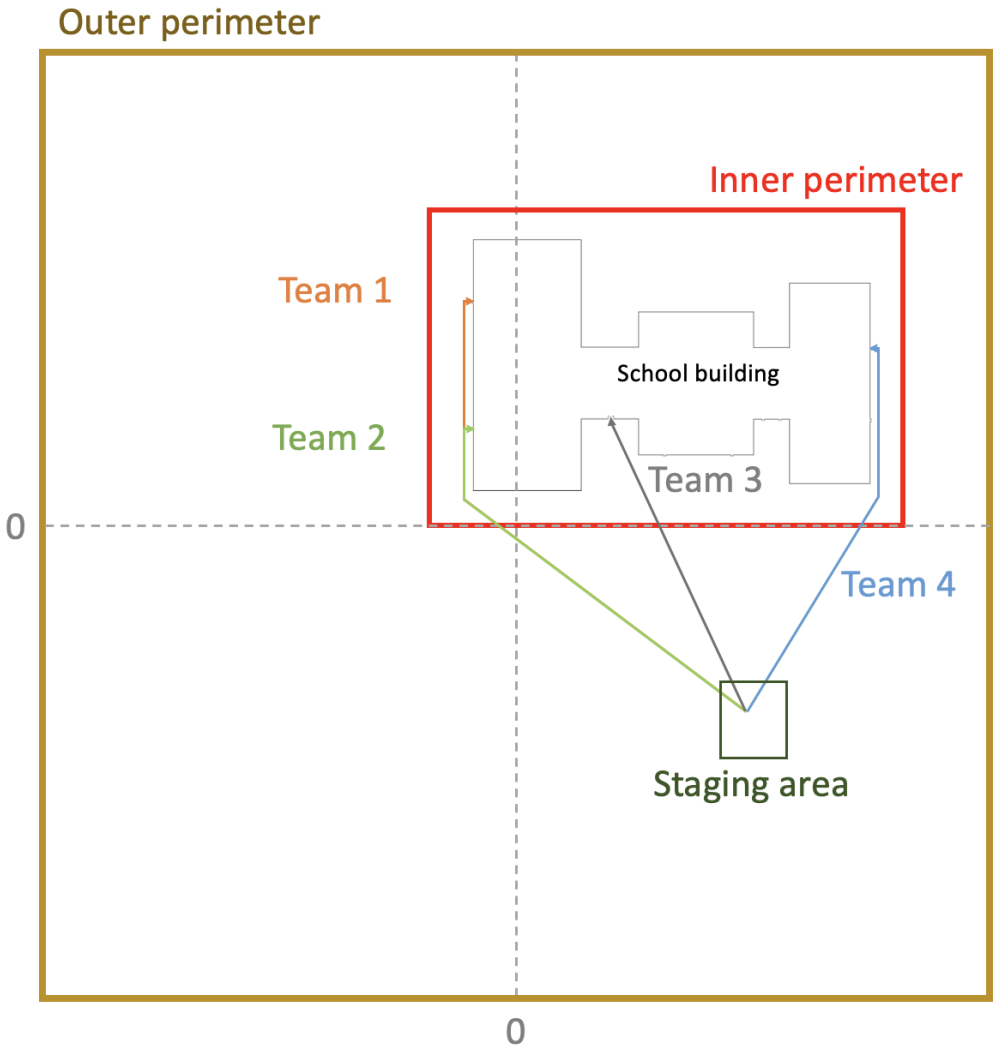

Fig. 8. SWAT teams outdoor deployment.

When the teams receive the order to move throughout the school building and conduct a room-by-room clear and secure in search of the offender (E7_SWAT_Deploy), they follow the paths shown in Fig. 7. The teams move at a speed of 1 m/s and spend 2 min to clear each room. Team 1, Team 2, and Team 3 converge to the location of the offender while Team 4 leaves their side of the building once cleared. They are active until the incident area is fully secured (E10_Incident_Secured).

2.7.3 Unified Command

Once the UC is setup (E5_UC_Setup), the personnel stays inside the mobile command center until the incident is closed out (E12_Incident_End).

2.7.4 Firefighters

Upon arrival (E4_FireEMS_Arrive), firefighters are staying near their vehicles while located at the SA until the incident is closed out (E12_Incident_End).

2.7.5 Emergency Medical Technicians

Upon arrival (E4_FireEMS_Arrive), the ambulances and EMTs move to the SA. Once the incident area is secured (E10_Incident_Secured), the EMTs drive the ambulances near the main entrance of the school building at a speed of 10 m/s, spend 10 minutes retrieving three critically injured victims before taking the victims to the hospital. Each stage of the deployment is shown in Fig. 9 with details specified in Appendix 5.

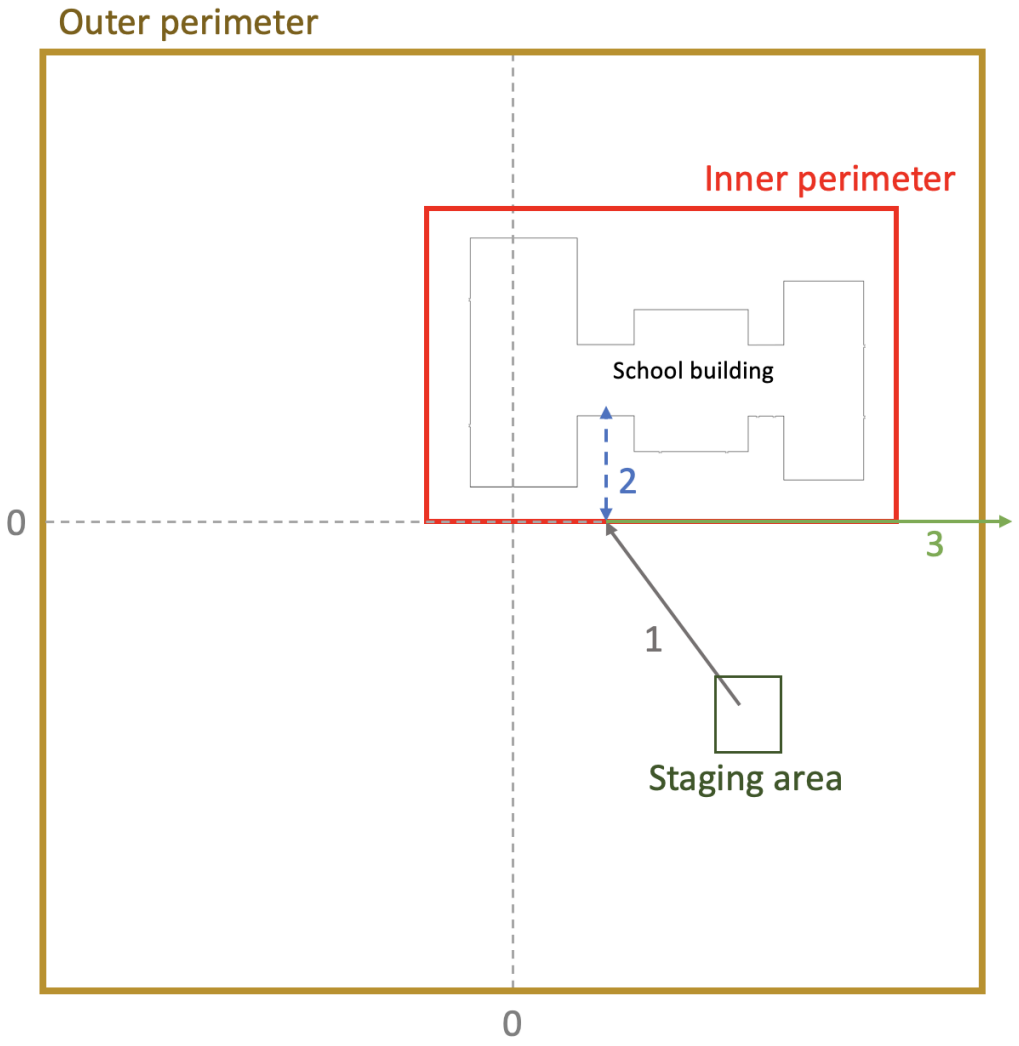

Fig. 9. Ambulances and EMTs deployment.

2.7.6 Helicopter

The helicopter is hovering over the incident area after being called by the UC (E5_UC_Setup) until the area is secured (E10_Incident_Secured). Its location is shown in Fig. 6.

2.7.7 School Cameras

The School Cameras (SCs), numbered 1 to 5, are located near the main entrance of the building and throughout the school building as shown in Fig. 7. They are accessible by the UC and SA once setup (E5_UC_Setup and E6_Perimeters_Ready) to provide additional situational awareness.

2.7.8 Traffic Cameras

The locations of the four Traffic Cameras (TCs), numbered 1 to 4, are shown in Fig. 6. They are accessible by the UC and SA once setup (E5_UC_Setup and E6_Perimeters_Ready) to provide additional situational awareness.

2.7.9 Deployable Cameras

Each SWAT team is equipped with a Deployable Camera (DC), numbered 1 to 4, that can be used to increase situational awareness in the room where hostages are present. They are activated when dropped by the SWAT teams at the location shown in Fig. 7.

2.8 Communication Needs

Throughout the incident, it is critical that the various units are able to communicate with each other to provide status updates and receive orders. Table 6 defines those communication needs and specifies which entity/group needs to send information to another entity/group, and at what time the communication needs to occur.

Table 6. Communication needs.

ID	Purpose	Source(s)	Destination(s)	Start (min) / Stop (min)
1	Responders assigned to the task force need to report their status and receive orders from the OSEC chief located at the UC.	Task Force, OSEC chief	Task Force, OSEC chief	E2_TaskForce_Arrive / E12_Incident_End

2	Members of each SWAT team need to report their status, communicate with each other during deployment and receive orders from the OSEC chief located at the UC.	SWAT teams, OSEC chief	SWAT teams, OSEC chief	E3_SWAT_Arrive / E10_Incident_Secured
3	Members of the Fire and EMS teams need to report their status and receive orders from the OSEC and logistic chief located at the UC.	Fire, EMS, OSEC chief, logistic chief	Fire, EMS, OSEC chief, logistic chief	E4_FireEMS_Arrive / E12_Incident_End
4	Personnel at the UC must be able to communicate with each other.	UC contingent	UC contingent	E5_UC_Setup / E12_Incident_End
5	UC contingent is monitoring the SWAT teams' surroundings, position, and health status. Information is used for decision making.	SWAT teams	UC	E7_SWAT_Deploy / E10_Incident_Secured
6	SA contingent is monitoring SWAT teams' surroundings, position, and health status. Information is used for deciding if medical units are needed.	SWAT teams	SA	E7_SWAT_Deploy / E10_Incident_Secured
7	Once the offender is found, UC contingent needs to monitor the offender's activities and surrounding.	Offender	UC	E8_Offender_Found / E9_Interdiction

8	Once the offender is found, contact must be made and maintained with the negotiator to resolve the hostage situation.	Offender	Negotiator	E8_Offender_Found / E9_Interdiction
9	UC contingent needs to access online information such as school building plans, utility information, record management, and criminal databases.	Remote server accessed through Internet	UC	E5_UC_Setup / E12_Incident_End
10	After setup, the UC contingent will leverage access to street cameras to monitor activities in the outer perimeter.	Street cameras	UC	E5_UC_Setup / E12_Incident_End
11	After setup, the SA contingent will leverage access to street cameras to monitor activities in the outer perimeter.	Street cameras	SA	E6_Perimeters_Ready / E12_Incident_End
12	After setup, the UC contingent will leverage access to school cameras to monitor activities in the inner perimeter.	School cameras	UC	E5_UC_Setup / E12_Incident_End
13	After setup, the SA contingent will leverage access to school cameras to monitor activities in the inner perimeter.	School cameras	SA	E6_Perimeters_Ready / E12_Incident_End

14	After setup, the UC contingent will leverage information from the hovering helicopter to monitor activities inside the outer perimeter.	Helicopter	UC	E5_UC_Setup / E10_Incident_Secured
15	After setup, the SA contingent will leverage information from the hovering helicopter to monitor activities inside the outer perimeter.	Helicopter	SA	E6_Perimeters_Ready / E10_Incident_Secured
16	The locations of all assets used during the incident are being monitored by the UC contingent to ensure proper deployment.	All public safety vehicles	UC	E5_UC_Setup / E12_Incident_End
17	The locations of all assets used during the incident are being monitored by the SA contingent to ensure proper deployment.	All public safety vehicles	SA	E6_Perimeters_Ready / E12_Incident_End
18	Personnel at the UC and SA must stay in constant communication throughout the duration of the incident to ensure efficient incident management.	UC	SA	E6_Perimeters_Ready / E12_Incident_End
19	SA contingent needs to access record management and criminal databases.	Remote server accessed through Internet	SA	E6_Perimeters_Ready / E12_Incident_End

20	After EMTs retrieve injured victims, assistance from the hospital physician is needed and patients' vitals are sent to the hospital.	EMS Units	Trauma care physician	E10_Incident_Secured / E11_EMS_Departure
21	As the general public shares information with 911 operators, this information is forwarded to the UC contingent	911 call center	UC	E5_UC_Setup / E12_Incident_End
22	As the general public shares information with 911 operators, this information is forwarded to the SA contingent.	911 call center	SA	E6_Perimeters_Ready / E12_Incident_End

3. Networking Capabilities

In this section, we describe a fictional network deployment surrounding the incident previously described. In this deployment, we assume a dedicated public safety LTE network deployment consisting of one cell tower providing coverage for the entire incident area. Information about the network infrastructure and services used are described in the following sections.

3.1 Network Infrastructure

For this scenario, we assume the network deployment illustrated in Fig. 10. It is composed of a single 3-sector cell tower, i.e., eNodeB, for providing wireless coverage at the location of the incident. To support the various applications used by the first responders on different jurisdictions, access to several servers is needed. A dedicated public safety server hosts applications used by first responders such as voice, video, and data. A school server is accessed for retrieving videos from the school cameras, a server from the city is accessed for retrieving videos from the traffic cameras, and a public server is accessed for maps and other online information.

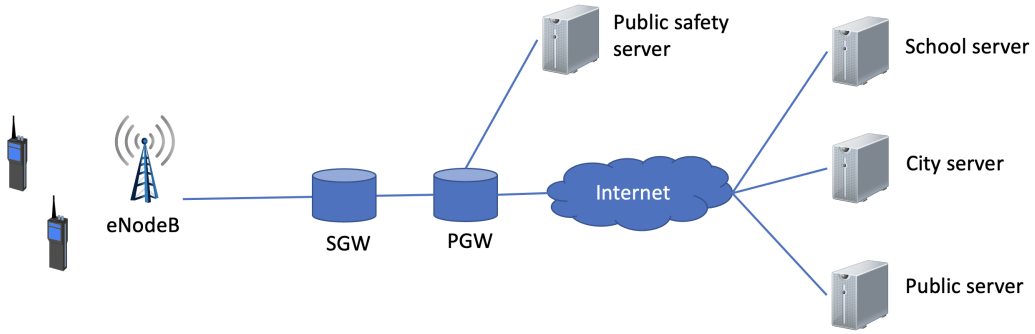

Fig. 10. Deployment overview.

3.1.1 Core Network

The LTE network supports IPv6 networking. We assume that all the links in the LTE core (eNodeB to Serving Gateway (SGW), SGW to Packet Gateway (PGW), and PGW to internet) have similar characteristics as described in Table 7. Configuration of the application servers is specified in Section 3.2. We also assume that processing delays at the SGW and PGW are negligible.

Table 7. LTE core link configuration.

Parameter Name	Value
Network technology	IEEE 802.3ab 1000BASE-T
Data rate (Gb/s)	1
Link delay (ms)	10

3.1.2 Radio Access Network

The system configuration is shown in Table 8 and the eNodeB configuration in Table 9. We note that unlike [1], the network does not support multicast technology.

Table 8. System configuration.

Parameter Name	Value
Bandwidth (MHz)	10 in uplink and 10 in downlink
UL Earfcn	23 330 (Band 14)
DL Earfcn	5 330 (Band 14)
Frequency reuse	1

Table 9. eNodeB configuration.

Parameter Name	Value
Location (m, m)	-100, -100
TX power (dB)	46
Noise figure (dB)	5
Antenna height (m)	32
Antenna model	3GPP TR 36.814 Table A.2.1.1-2 Case 3
Max. antenna gain (dBi)	16
Number of sectors	3
Sector orientation (degree)	0, 120, 240

3.1.3 Subscriber Devices

We assume that two types of LTE devices are used during the incident. The first is a handheld device carried by first responders. The second is a vehicular modem located on top of vehicles such as patrol cars, fire engines, ambulances, mobile command units, and the SA mobile unit. A vehicular modem is used as the single point of access to the network for all equipment located inside the vehicle. For example, computers located inside the mobile command units are using the same modem to access the application servers. The characteristics of the two types of LTE devices are shown in Table 10.

Table 10. LTE handheld and vehicular device configurations.

Parameter Name	Value
UE category	12
TX power (dBm)	23
Noise figure (dB)	9
Antenna height (m)	1.5
Antenna model	Isotropic
Number of TX antennas	1
Number of RX antennas	2
Handheld devices	
Max. antenna gain (dBi)	0
Battery (mAh)	3000
Vehicular devices	
Max. antenna gain (dBi)	4
Battery (mAh)	Adequate for the duration of the incident

3.2 Services and Applications

This section describes the services and applications used by first responders to support voice, video, and data communication. It also includes a description of the services that

are not part of the first responder network but accessed during the incident, such as traffic and school cameras. Traffic information such as packet size, when provided, is at the application level and does not include any overhead that the network may add.

3.2.1 MCPTT Service

To support mission critical voice communication during the incident, we assume the availability of 3GPP's MCPTT application [4]. The MCPTT application server is running on the public safety server connected directly to the PGW as shown in Fig. 10. Each first responder's handheld LTE device supports the MCPTT application.

First responders are divided into the following four groups, and users belonging to multiple groups are able to switch their active group as needed:

- TaskForce: 69 users (68 officers assigned to task force + OSEC chief)
- SWAT: 17 users (16 members + OSEC chief)
- FireEMS: 14 (6 fire + 6 EMTs + OSEC chief + Logistic chief)
- UC: 12 users

We assume that all users are already affiliated with their groups when the incident starts.

Activities amongst the different groups, i.e., the ratio of active talk time over a certain period of time (also called activity factor), will vary based on the events that occur during the incident. For the Task Force group, we assume a constant level of activity at 5 % throughout the incident as they are used for crowd control. The SWAT group is divided into three periods of activities. When they first arrive, the SWAT teams go to the SA waiting to be dispatched to the school building and have a low level of activity (10 %). When they deploy inside the school building and conduct the room-to-room search, the team members provide more frequent updates to indicate which rooms are cleared and if they find any remaining school personnel or students, thus increasing the level of activity to 50 %. Once the offender is subdued, the level of activity decreases to 10 %. Fire and EMS units are busy when they arrive while preparing for possible victims with a level of activity at 30 %. Subsequently, the activity increases to 40 % when the EMS units reach the school building to retrieve the victims, then decreases to 10 % once all the victims are treated at the SA. For the UC group, we assume a constant level of activity at 5 % since the UC contingent is mostly collocated at the UC truck. A summary of the start and stop times of the MCPTT application is listed in Table 11.

Table 11. MCPTT activities.

Group	Start time (min)	Stop time (min)	Activity factor (%)
TaskForce	E2_TaskForce_Arrive	E12_Incident_End	5
SWAT	E3_SWAT_Arrive	E7_SWAT_Deploy	10
	E7_SWAT_Deploy	E10_Incident_Secured	50
	E9_Interdiction	E10_Incident_Secured	10
FireEMS	E4_FireEMS_Arrive	E6_Perimeters_Ready	30
	E6_Perimeters_Ready	E7_SWAT_Deploy	40
	E7_SWAT_Deploy	E12_Incident_End	10
UC	E5_UC_Setup	E12_Incident_End	5

3.2.2 Tactical Telemetry

In order to know the location of each member of the SWAT teams, a Global Positioning System (GPS) application is available on the responder's device. The telemetry application is activated when the members are deployed (E7_SWAT_Deploy) until the incident is secured (E10_Incident_Secured). The application sends position information at 1 s intervals. Each location update generates 88 Bytes of application data uploaded onto the public safety server and 8 Bytes of data are sent back to the client application on the responder's device for acknowledgement. Information about the start and stop times of the telemetry application is listed in Table 12. The telemetry information is viewed by the UC and SA personnel via the incident management application (Section 3.2.8).

Table 12. Tactical telemetry activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
SWAT members	E7_SWAT_Deploy	E10_Incident_Secured	100

3.2.3 Biometrics

The monitoring of vital signs for the SWAT team members as well as the EMS patients is carried out by using an application that sends biometric information once every 10 s to the public safety server. Each biometric update uses 7 Bytes. The application is activated when the SWAT team members are deployed (E7_SWAT_Deploy) and remains active until the incident is secured (E10_Incident_Secured). For the EMS patients, the application is used when the patients are retrieved (shortly after E10_Incident_Secured) until the incident ends (E12_Incident_End). Biometrics information can then be viewed by the UC and SA personnel via the incident management application (Section 3.2.8). Information about the start and stop times of the application is listed in Table 13.

Table 13. Tactical biometrics activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
SWAT members	E7_SWAT_Deploy	E10_Incident_Secured	100
Ambulances	E10_Incident_Secured	E12_Incident_End	100

3.2.4 Video Steaming Service

The first responders are equipped with several devices capable of sending live video streams to a media server located on the public safety server in real time and made accessible to other units, such as UC and SA. There are several sources of videos used during the incident: each member of a SWAT team is equipped with a helmet camera that is turned on when they enter the school (E7_SWAT_Deploy) and turned off after the incident is secured (E10_Incident_Secured). In addition, each team has one deployable camera that is activated when deployed by each unit while securing the school building at the locations shown in Fig. 7 and turned off when the incident is secured (E10_Incident_Secured). The throw phone used to communicate with the offender is able to stream video in stealth mode from the moment the offender is found (E8_Offender_Found) until the moment they are subdued (E9_Interdiction). The helicopter is equipped with a camera to stream while in the air from its deployment (E5_UC_Setup) until the incident is secured (E10_Incident_Secured). Finally, EMS vehicles are equipped with cameras to be able to stream videos to hospitals and doctors on call when the patients are retrieved (shortly after E6_Perimeters_Ready) until the incident ends (E12_Incident_End). Information about the start and stop times of the video streams is listed in Table 14.

All video streams use the H.264 codec with a resolution of 1280 pixels x 720 pixels with progressive scan, 30 Frames Per Seconds (FPS), and a Constant Rate Factor (CRF) of 25. Since the evolved Multimedia Broadcast Multicast Service (eMBMS) is not available in this network, each viewer requires a separate data stream.

Table 14. Video service activities.

Camera	Start time (min)	Stop time (min)	Activity factor (%)
Helmet cameras	E7_SWAT_Deploy	E10_Incident_Secured	100
DC 1	E8_Offender_Found	E10_Incident_Secured	100
DC 2	E7_SWAT_Deploy + 46	E10_Incident_Secured	100
DC 3	E7_SWAT_Deploy + 28	E10_Incident_Secured	100
DC 4	E7_SWAT_Deploy + 27	E10_Incident_Secured	100
Throw phone	E8_Offender_Found	E9_Interdiction	100
Helicopter	E5_UC_Setup	E10_Incident_Secured	100
Ambulances	E10_Incident_Secured	E11_EMS_Departure	100

3.2.5 Voice Service

The throw phone given to the offender during the negotiations uses Voice over LTE (VoLTE) over the public safety band 14. The traffic between the throw phone and the negotiator phone goes through an IP Multimedia Subsystem (IMS) server located on the public safety server. Communication between the offender and the negotiator starts when the offender is found (E8_Offender_Found) until the offender is subdued (E9_Interdiction). Information about the start and stop times of the voice streams are listed in Table 15.

Table 15. Voice service activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
Throw phone and negotiator phone	E8_Offender_Found	E9_Interdiction	40

3.2.6 Video Conference Service

For communication between personnel at the UC and the SA, a video conference call is established once both areas are setup (E6_Perimeters_Ready). Both UC and SA connect to the conference server located on the public safety server and use a large display connected to a computer for handling the video call. Once started, the call lasts until the incident ends (E12_Incident_End) as shown in Table 16. The video system uses the H.264 video codec at 1920 pixels x 1080 pixels resolution with interlaced scanning, 30 FPS, and a CRF of 25, with a G.722 audio codec.

Table 16. Video conference service activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
Computer at UC and at SA	E6_Perimeters_Ready	E12_Incident_End	100

3.2.7 Automatic Vehicle Location Service

A GPS-Based Automatic Vehicle Location (AVL) system is used to track public safety vehicles and assets. The upload or reporting occurs every 15 s by sending 1408 Bytes of data to the public safety server and receiving 128 Bytes. There are 34 instances in perimeters for patrol cars, two fire engines, three ambulances, one mobile command center, one SA mobile unit, and one helicopter. A computer at the UC and one at the SA running incident management software are pulling the information from the public safety server. Information about the start and stop times of the applications are listed in Table 17.

Table 17. AVL Service activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
Patrol cars	E2_TaskForce_Arrive	E12_Incident_End	100
Fire engines	E4_FireEMS_Arrive	E12_Incident_End	100
Ambulances	E4_FireEMS_Arrive	E12_Incident_End	100
Helicopter	E5_UC_Setup	E12_Incident_End	100
Mobile command center	E5_UC_Setup	E12_Incident_End	100
SU mobile unit	E6_Perimeters_Ready	E12_Incident_End	100

3.2.8 Data Service

There are a number of data applications that are being used by the first responders at the UC and SA to obtain information on the school layout, consulting criminal records, and running updates. The usage of each data application is as follows:

- Two computers used by the Intelligence team at the UC for web-based research are requesting 15 non-graphical web pages per hour and 30 graphics rich web pages per hour each. Non-graphic pages are 632 kB in size on average and graphic pages are 2232 kB in size on average.
- Five computers at the UC are accessing the Records Management System (RMS) and Bureau of Criminal Apprehension (BCA) databases, and are requesting or writing 10 instances of data per minute each. Each read/write is 16 kB. Another three computers at the SA are also accessing the RMS database, and are requesting or writing 10 instances of data per minute each.
- Two computers at the UC are used to download satellite images and maps. Each computer requests data every five minutes. Each update is composed of a 4.5 kB request and a graphical response of 4 MB.
- Two computers are used by the UC personnel to download building and utility plans upon setup. Each computer generates a request of 4.5 kB in size and downloads a 10 MB file within 30 s of each other.
- One computer at the UC and one at the SA are constantly pulling data from the incident management application. Part of the information shown via the incident management application is the telemetry and AVL updates. The application transmits 40 kb/s of data and receives 128 kb/s, constantly.
- One computer at the UC receives Next Generation 911 (NG911) videos collected by the Public Safety Answering Point (PSAP) from the general public. The video clips have a medium resolution of 1280 pixels x 720 pixels at 30 FPS with progressive scanning. Videos are constantly being received throughout the duration of the incident.

All data applications run from the time the UC or SA is setup (E5_UC_Setup and E6_Perimeters_Ready, respectively) until the end of the incident (E12_Incident_End), indicating that all computers are operational throughout the whole incident, as shown in Table 18.

Table 18. Data service activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
UC	E5_UC_Setup	E12_Incident_End	100
SA	E6_Perimeters_Ready	E12_Incident_End	100

3.2.9 School Cameras

The school has five cameras that constantly stream videos to the school server where the recordings are being stored and made available for viewing. All video streams use the H.264 codec with a resolution of 1280 pixels x 720 pixels with progressive scanning, 30 FPS, and CRF of 25. When the UC and SA are setup (E5_UC_Setup and E6_Perimeters_Ready), they obtain credentials necessary to view the live streams from all the cameras until the incident ends (E12_Incident_End). Information about the start and stop times of the video streams is listed in Table 19.

Table 19. School camera activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
Computer at UC	E5_UC_Setup	E12_Incident_End	100
Computer at SA	E6_Perimeters_Ready	E12_Incident_End	100

3.2.10 Traffic Cameras

There are four traffic cameras within the perimeter that are accessed by the UC and SA when their setup is complete. All video streams use the H.264 codec with a resolution of 1920 pixels x 1280 pixels with progressive scanning, 1 FPS, and a CRF of 25. When the UC and SA are setup (E5_UC_Setup and E6_Perimeters_Ready), they obtain credentials necessary to view the live streams from all the cameras until the incident ends (E12_Incident_End). Information about the start and stop times of the video streams is listed in Table 20.

Table 20. Traffic camera activities.

User(s)	Start time (min)	Stop time (min)	Activity factor (%)
Computer at UC	E5_UC_Setup	E12_Incident_End	100
Computer at SA	E6_Perimeters_Ready	E12_Incident_End	100

3.2.11 Mapping of Applications to Communication Needs

Table 21 lists the applications and the communication need(s) (listed in Table 6) that they fulfill. Also included is the number of instances of each application. In some cases, the application is divided into instances that push data to the server and instances that receive data from the server.

Table 21. Mapping of application to communication needs.

Application	Communication need (ID)	Number of instances
MCPTT	1, 2, 3, and 4	108
Tactical telemetry	5, 6	16
Biometrics	5, 6, and 20	16
Video streaming	5, 6, 7, 10, 11, 12, 13, 14, and 15	Streaming: 25, Viewing: 52
Voice	8	2
Video conference	18	2
AVL	16 and 17	42
Web	9 and 19	2
RMS-BCA	9 and 19	8
Satellite/maps	9 and 19	2
Building plans	9 and 19	1
Incident management	5, 6, 9, and 19	2
NG911	21 and 22	2

4. Implementation Details

There are several ways to analyze the performance of an incident. In some cases, the applications' data rates and activity factors are used to determine the average and peak demands that the network must support, as done in the original study [1]. However, such analysis does not capture the dynamic behaviors of the users, the propagation environments, or the applications which can lead to sudden spikes of data or poor network conditions. System level simulators like ns-3 are often used investigate those problems and support many existing wired and wireless technologies as well as many protocols and applications. In the past several years, we have developed an extensive set of extensions that focuses on networking capabilities and applications used or needed by first responders, and made them publicly available in [3]. Some of those Public Safety Communication (PSC) specific features include MCPTT, LTE Device to Device (D2D), User Equipment (UE)-to-network relays, and new implementations of generic applications like Hypertext Transfer Protocol (HTTP) and video streaming. Those extensions have allowed us to implement the school shooting scenario described in this document using ns-3. In this section, we highlight the parameter configurations of the major components of the simulations, including modeling the school building, propagation model, and application settings. The model documentation provided in [3] provides the remaining implementation information.

4.1 Building Model

ns-3's support for building is currently limited to boxes that can have specific characteristics such as building type, exterior wall type, number of floors, and number of rooms (in the x-axis and y-axis). Therefore, the school building has the simplified layout shown in Fig. 11 with configuration parameters shown in Tables 22 and 23. The school building is composed of five ns-3 buildings. Note that since the propagation models used for indoor communication (as specified in Section 4.2) only consider the distance between the devices, the room layout is not taken into account and therefore we only define a single room per building.

Fig. 11. ns-3 building dimensions.

Table 22. ns-3 building dimensions.

Building	Location center (m, m)	Dimensions (m x m)
A	-0.5, 100	75 x 175
B	57, 87.5	40 x 50
C	117, 87.5	80 x 90
D	169.5, 87.5	25 x 50
E	210, 87.5	56 x 140

Table 23. ns-3 buildings configuration.

Parameter	Value
Building type	Commercial
Exterior walls type	ConcreteWithWindows
Number of floors	1
Number of rooms	1
Height (m)	6

4.2 Propagation and Channel Models

In order to support the different types of propagation environments facing the first responders in this scenario (outdoor-to-outdoor, outdoor-to-indoor, indoor-to-indoor), the implementation uses the *Hybrid3gppPropagationLossModel* that is described in the model documentation [3].

4.3 Application Models

4.3.1 Generic Application Design

Unless specified otherwise, the applications implemented follow a request-response traffic pattern where the client sends requests messages to the server that replies with a response message. The client generates requests following an on-off model, where "on" periods are called sessions. Random variables are associated with the inter-packet interval, number of packets in a session, and the inter-session interval. A visual representation of the client application model is shown in Fig. 12.

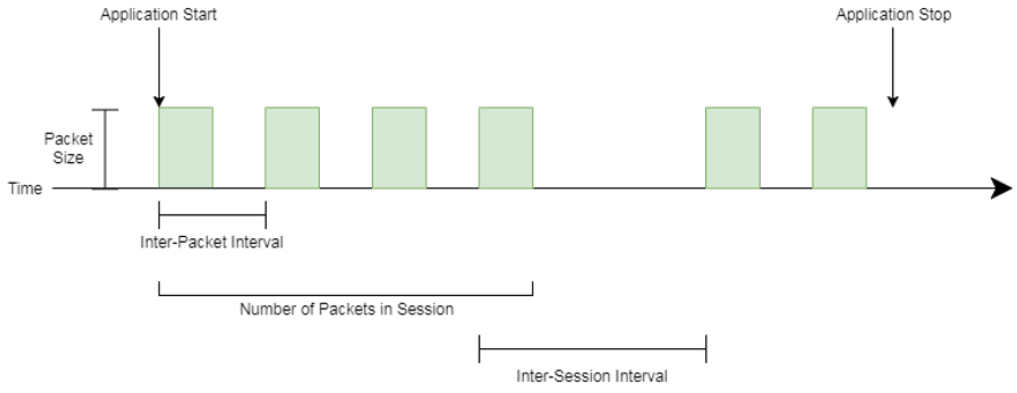

Fig. 12. Client application model.

On the server side, a response is generated as soon as a request arrives unless the previous response was sent within the minimum inter-response time, in which case it is delayed. The server application is thus configured using random variables for the packet size and

minimum inter-response time. A visual representation of the server application model is shown in Fig. 13.

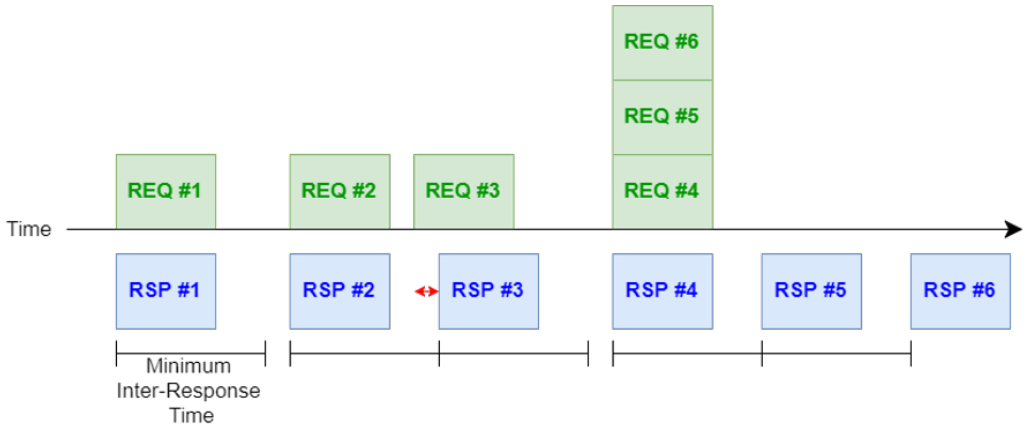

Fig. 13. Server application model.

4.3.2 Generic Application Configurations

Table 24 lists the configuration parameters for the applications using the generic model described in Section 4.3.1.

Table 24. Generic application configuration parameters.

ID	Application Name	Downlink (DL) Packet Size (B)	Uplink (UL) Packet Size (B)	Inter-packet Interval (s)	Packets per session	Session Interval (s)
1	Tactical Telemetry	8	88	1	60	0
2	Biometrics	0	7	10	6	0
3	Phone Voice	384	384	0.111	1 296	216
4	RMS-BCA DB Access	16 384	16 384	6	10	0
5	Satellite Imagery	4 194 304	4 608	0	1	300
6	Building and Utility Plans	10 485 760	4 608	0	1	14 700
7	Video Conference Audio	384	384	0.111	1 296	0
8	AVL Asset Reporting	128	1 408	15	4	0
9	Incident Management	2 185	683	1	60	0
10	Traffic Camera	1 152	1 152	0.24	4	0

4.3.3 MCPTT Application Configuration

The MCPTT service is configured for prearranged, on-demand group calls in automatic commencement mode. Therefore, SIP messages are exchanged during call initiation, periodically throughout the call, and at the end of a call. During a call, floor control messages are sent to facilitate communication amongst the group members participating in the same call. During a call with an active speaker, the speaker will transmit data packets, i.e., voice samples, that are 60 B in size at 12 kb/s. The activity of notional MCPTT users and group calls defined in Section 3.2.1 is determined by an MCPTT pusher orchestrator that autonomously controls the Push-To-Talk (PTT) activity of the notional users in each group call. This orchestrator is configured so that talk sessions occur to match the desired activity factor, while users are active 100 % of the time within each talk session.

4.3.4 Video Services Configuration

All applications in this scenario that have a video component make use of the PSC video streaming model, except for the traffic cameras. This model considers the video's resolution and frame rate to determine the inter-arrival times and sizes of packets to match a real video stream. For example, the Video Conference application video system uses the H.264 video

codec at 1920 pixels x 1080 pixels resolution with interlaced scan, 30 FPS, and CRF of 25. Therefore, an instance of a video streaming model is configured for the video system that uses a Cummulative Distribution Function (CDF) of the inter-arrival times and packet sizes of a video that has a resolution of 1920 pixels x 1080 pixels at 30 FPS. For the traffic cameras, a generic application (as described in Section 4.3.1) is used to model 1 FPS.

4.3.5 Web Services Configuration

The web application described in Section 3.2.8 at the UC and SA vehicles makes use of a PSC web application model. This model simulates plain HTTP request/response traffic for Hypertext Markup Language (HTML) pages with embedded objects. The non-graphical web applications described in Section 3.2.8 are configured so that the client sends an HTTP request every four seconds, and server responds with a single HTML page that is 632 kB in size on average. The graphical applications are configured so that the client sends an HTTP request every two seconds, and the server responds with an HTML page that contains 15 embedded objects on average, that are 148 kB in size on average.

4.3.6 Bearer Configuration

Even though the ns-3 LTE implementation supports the configuration of dedicated bearers, this version of the scenario implementation configures each user with a single default bearer. This bearer is used to carry the traffic from all the applications.

4.4 Protocol Implementations

The description of the protocols used in the scenarios are available in the ns-3 PSC documentation.

4.4.1 Mobility

The users were placed and moved according to the description in Section 2.7 and Appendix A.

4.4.2 Code Availability

The scenario implementation is distributed as part of the ns-3 PSC extension [3] and include support for NetSimulyzer [4] to visual and study the network performance as shown in Fig. 14.

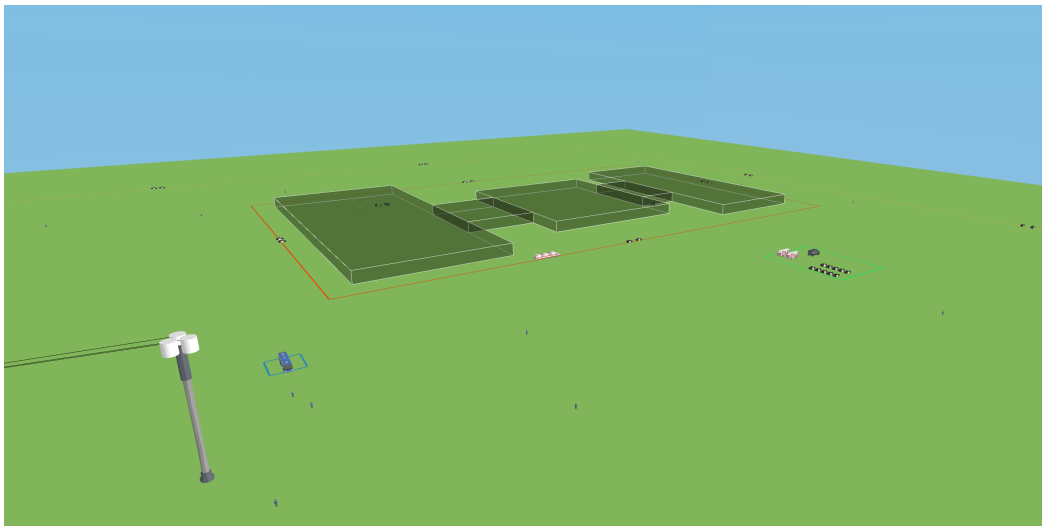

Fig. 14. Screenshot of scenario using NetSimulyzer.

5. Conclusions and Future Work

Evaluating the impact of new technologies on public safety communications require the definition of scenarios that capture the behavior of first responders and their communication needs. In this paper, we provided a detailed description of a notional school shooting incident in a high school. Based on a scenario created using input for public safety personnel, we updated some of the assumptions to reflect modern technologies. The scenario was also implemented in the ns-3 simulator and made publicly available so it can be easily studied and expanded to investigate other means of communication for first responders. For example, we plan to evaluate how 3GPP's New Radio (NR) cellular technology can improve coverage and capacity to support such a large scale scenario. Additional enhancements to the models will also be considered such as the use of dedicated bearers to handle different application Quality of Service (QoS) requirements or the use of MCData and MCVideo to supplement MCPTT capabilities.

References

[1] Televate (2011) Minnesota Department of Public Safety; Public Safety Wireless Data Network Requirements Project Needs Assessment Report Phase 1-Task 4/Deliverable 2. Available at https://dps.mn.gov/divisions/ecn/programs/armer/Documents/Minnesota_Needs_Assessment_Report_FINAL.pdf.

[2] Rouil R, Liu C, Izquierdo Manzanares A (2019) Guidelines for generating public safety benchmark scenario set. https://doi.org/10.6028/NIST.IR.8247.

[3] National Institute of Standards and Technology (2018) Public Safety Communication modeling tools based on ns-3. Available at https://github.com/usnistgov/psc-ns3.

[4] Black E, Gamboa S, Rouil R (2021) Netsimulyzer: A 3D network simulation analyzer for ns-3. *Proceedings of the Workshop on Ns-3* (Association for Computing Machinery, New York, NY, USA), p 65–72. Available at https://doi.org/10.1145/3460797.3460806.

Appendix A: Detailed Mobility and Location Information

A.1 Personnel and assets with fixed location

Many of the personnel and assets are assumed to have a fixed location once they are deployed at the incident. Table 25 describes their locations. The Note column provides additional information such as the height of the devices where relevant.

Table 25. Location of personnel and assets with no mobility.

User or Asset	Location	Note
Roadblock 1 / Vehicle 1	-100, 300	Two officers are in the car
Roadblock 1 / Vehicle 2	-95, 300	Two officers are in the car
Roadblock 2 / Vehicle 1	100, 300	Two officers are in the car
Roadblock 2 / Vehicle 2	105, 300	Two officers are in the car
Roadblock 3 / Vehicle 1	300, -100	Two officers are in the car
Roadblock 3 / Vehicle 2	300, -95	Two officers are in the car
Roadblock 4 / Vehicle 1	300, 100	Two officers are in the car
Roadblock 4 / Vehicle 2	300, 105	Two officers are in the car
Roadblock 5 / Vehicle 1	100, -300	Two officers are in the car
Roadblock 5 / Vehicle 2	105, -300	Two officers are in the car
Roadblock 6 / Vehicle 1	-100, -300	Two officers are in the car
Roadblock 6 / Vehicle 2	-95, -300	Two officers are in the car
Roadblock 7 / Vehicle 1	-300, -100	Two officers are in the car
Roadblock 7 / Vehicle 2	-300, -95	Two officers are in the car
Roadblock 8 / Vehicle 1	-300, 100	Two officers are in the car
Roadblock 8 / Vehicle 2	-300, 105	Two officers are in the car
Roadblock 9 / Vehicle 1	97, 200	Two officers are in the car
Roadblock 9 / Vehicle 2	103, 200	Two officers are in the car
Roadblock 10 / Vehicle 1	250, 103	Two officers are in the car
Roadblock 10 / Vehicle 2	250, 97	Two officers are in the car
Roadblock 11 / Vehicle 1	103, 0	Two officers are in the car
Roadblock 11 / Vehicle 2	97, 0	Two officers are in the car
Roadblock 12 / Vehicle 1	-50, 97	Two officers are in the car
Roadblock 12 / Vehicle 2	-50, 103	Two officers are in the car
SA Mobile unit	157, -65	Vehicle equipped with data and video conference capability
Fire engine 1	144, -58	Three firefighters are in the truck
Fire engine 2	144, -63	Three firefighters are in the truck
Ambulance 1	137, -68	Two EMTs are in the ambulance
Ambulance 2	137, -72	Two EMTs are in the ambulance
Ambulance 3	145, -68	Two EMTs are in the ambulance

User or Asset	Location	Note
Patrol car 1	137, -79	Car for patrol and crowd control units
Patrol car 2	145, -79	Car for patrol and crowd control units
Patrol car 3	137, -82	Car for patrol and crowd control units
Patrol car 4	145, -82	Car for patrol and crowd control units
Patrol car 5	137, -85	Car for patrol and crowd control units
Patrol car 6	145, -85	Car for patrol and crowd control units
Patrol car 7	137, -88	Car for patrol and crowd control units
Patrol car 8	145, -88	Car for patrol and crowd control units
Patrol car 9	137, -91	Car for patrol and crowd control units
Patrol car 10	145, -91	Car for patrol and crowd control units
Patrol Unit 0	-3, -71	Task Force unit assigned to crowd control
Patrol Unit 1	-79, 184	Task Force unit assigned to crowd control
Patrol Unit 2	-239, 51	Task Force unit assigned to crowd control
Patrol Unit 3	263, 76	Task Force unit assigned to crowd control
Patrol Unit 4	-153, 202	Task Force unit assigned to crowd control
Patrol Unit 5	-288, 203	Task Force unit assigned to crowd control
Patrol Unit 6	266, 201	Task Force unit assigned to crowd control
Patrol Unit 7	-263, 9	Task Force unit assigned to crowd control
Patrol Unit 8	-167, -95	Task Force unit assigned to crowd control
Patrol Unit 9	-74, -81	Task Force unit assigned to crowd control

User or Asset	Location	Note
Patrol Unit 10	275, -7	Task Force unit assigned to crowd control
Patrol Unit 11	-89, -118	Task Force unit assigned to crowd control
Patrol Unit 12	253, 120	Task Force unit assigned to crowd control
Patrol Unit 13	-16, -120	Task Force unit assigned to crowd control
Patrol Unit 14	-24, -232	Task Force unit assigned to crowd control
Patrol Unit 15	156, -297	Task Force unit assigned to crowd control
Patrol Unit 16	-196, -94	Task Force unit assigned to crowd control
Patrol Unit 17	224, -206	Task Force unit assigned to crowd control
Patrol Unit 18	-77, -72	Task Force unit assigned to crowd control
Patrol Unit 19	131, -139	Task Force unit assigned to crowd control
Helicopter	-150, 200	Hovering at an altitude of 450 m
School camera 1 (SC 1)	47, 72.5	Located 2.5 m high
School camera 2 (SC 2)	-23, 187.5	Located 2.5 m high
School camera 3 (SC 3)	-23, 42.5	Located 2.5 m high
School camera 4 (SC 4)	222, 157.5	Located 2.5 m high
School camera 5 (SC 5)	200, 42.5	Located 2.5 m high
Traffic camera 1 (TC 1)	-290, 60	Camera is on top of 3.6 m pole
Traffic camera 2 (TC 2)	-200, 40	Camera is on top of 3.6 m pole
Traffic camera 3 (TC 3)	275, 300	Camera is on top of 3.6 m pole
Traffic camera 4 (TC 4)	-40, -200	Camera is on top of 3.6 m pole
Deployable camera 1 (DC 1)	16, 152.5	Placed near classroom door
Deployable camera 2 (DC 2)	22, 55.5	Placed in hallway
Deployable camera 3 (DC 3)	138, 96.5	Placed in hallway
Deployable camera 4 (DC 4)	198, 105.5	Placed in hallway

A.2 Personnel with mobility

The location and mobility of users and assets during the incident are shown in Table 26. For each mobile unit, the table lists the time and speed at which the entity starts moving to a given destination. Once the destination is reached, the entity stays there until the next movement. For each unit, the first entry shows the initial location.

Table 26. Location of personnel and assets with mobility.

Unit	Time (s)	Destination X	Destination Y	Speed (m/s)
SWAT team 1	0	150	-75	0
	600	-42	8.5	1
	809	-42	144.5	1
	945	-40	144.5	1
	3600	-22	144.5	1
	3616	-22	152.5	1
	3744	-22	162.5	1
	3874	-22	172.5	1
	4004	-22	182.5	1
	4134	-16	182.5	1
	4260	-16	172.5	1
	4390	-16	162.5	1
	4520	-16	152.5	1
	4650	-16	142.5	1
	4780	-16	132.5	1
	4910	-16	122.5	1
	5040	-16	112.5	1
	5170	-16	102.5	1
	5300	-16	92.5	1
	5430	-16	82.5	1
	5560	-16	72.5	1
	5690	-16	62.5	1
	5820	-16	56.5	1
	5826	16	56.5	1
	5858	16	62.5	1
	5984	16	72.5	1
	6114	16	82.5	1
	6244	16	92.5	1
	6374	16	102.5	1
	6504	16	112.5	1
	6634	16	122.5	1
	6764	16	132.5	1
	6894	16	142.5	1
	7024	16	152.5	1
SWAT team 2	0	150	-75	0
	600	-42	8.5	1
	809	-42	55.5	1
	856	-40	55.5	1
	3600	-22	55.5	1

Unit	Time (s)	Destination X	Destination Y	Speed (m/s)
SWAT team 2	3616	-22	63.5	1
	3744	-22	73.5	1
	3874	-22	83.5	1
	4004	-22	93.5	1
	4134	-22	106.5	1
	4267	-22	116.5	1
	4397	-22	126.5	1
	4527	-22	136.5	1
	4657	-22	49.5	1
	4864	-22	39.5	1
	4994	-22	29.5	1
	5124	-22	19.5	1
	5254	-14	19.5	1
	5382	-14	43.5	1
	5526	14	43.5	1
	5674	14	19.5	1
	5818	22	19.5	1
	5946	22	29.5	1
	6076	22	39.5	1
	6206	22	49.5	1
	6336	22	55.5	1
	6342	37	55.5	1
	6357	37	75.5	1
	6377	43	75.5	1
	6503	53	75.5	1
	6633	63	75.5	1
	6763	73	75.5	1
	6893	79	75.5	1
	6899	79	107.5	1
	6931	73	107.5	1
	7057	63	107.5	1
	7187	53	107.5	1
	7317	43	107.5	1
	7447	22	107.5	1
	7468	22	152.5	1
SWAT team 3	0	150	-75	0
	600	57	60.5	1
	3600	57	63.5	1
	3601	88	63.5	1
	3632	88	52.5	1
	3763	88	42.5	1

Unit	Time (s)	Destination X	Destination Y	Speed (m/s)
SWAT team 3	3893	101	42.5	1
	4026	101	52.5	1
	4156	101	62.5	1
	4286	101	68.5	1
	4292	115	68.5	1
	4306	115	42.5	1
	4452	115	68.5	1
	4598	128	68.5	1
	4611	128	42.5	1
	4757	156	42.5	1
	4905	156	132.5	1
	5115	138	132.5	1
	5253	138	96.5	1
	5289	121	96.5	1
	5306	121	102.5	1
	5432	121	112.5	1
	5562	121	122.5	1
	5692	121	132.5	1
	5822	118	132.5	1
	5945	118	122.5	1
	6075	118	112.5	1
	6205	118	102.5	1
	6335	118	96.5	1
	6341	101	96.5	1
	6358	101	132.5	1
	6394	88	132.5	1
	6527	88	122.5	1
	6657	88	116.5	1
	6663	78	111.5	1
	6674	21	111.5	1
	6731	21	152.5	1
SWAT team 4	0	150	-75	0
	600	240	8.5	1
	724	240	110.5	1
	826	238	110.5	1
	3600	222	110.5	1
	3616	222	121.5	1
	3747	222	131.5	1
	3877	222	141.5	1
	4007	222	151.5	1
	4137	220	151.5	1

Unit	Time (s)	Destination X	Destination Y	Speed (m/s)
SWAT team 4	4139	220	115.5	1
	4175	203	115.5	1
	4192	203	121.5	1
	4318	203	131.5	1
	4448	203	141.5	1
	4578	203	151.5	1
	4708	198	151.5	1
	4833	198	141.5	1
	4963	198	131.5	1
	5093	198	121.5	1
	5223	198	105.5	1
	5239	220	105.5	1
	5261	220	99.5	1
	5507	220	89.5	1
	5757	220	79.5	1
	6007	220	69.5	1
	6257	220	51.5	1
	6395	220	41.5	1
	6525	220	31.5	1
	6655	220	21.5	1
	6785	220	31.5	1
	6795	197	31.5	1
	6938	197	21.5	1
	7068	197	41.5	1
	7208	197	51.5	1
	7338	197	69.5	1
	7596	197	79.5	1
	7846	197	89.5	1
	8096	197	99.5	1
	8346	197	105.5	1
	8352	163	105.5	1
	8386	163	99.5	1
	8512	163	89.5	1
	8642	163	79.5	1
	8772	163	69.5	1
	8902	163	59.5	1
Ambulance 1	0	137	-68	0
	11100	44	0	10
	11712	400	0	5

Unit	Time (s)	Destination X	Destination Y	Speed (m/s)
Ambulance 2	0	145	-68	0
	11100	52	0	10
	11712	400	0	5
Ambulance 3	0	137	-72	0
	11100	48	0	10
	11711	400	0	5
EMTs - Ambulance 1	0	137	-68	0
	11100	44	0	10
	11172	44	70	2
	11577	44	0	2
	11712	400	0	5
EMTs- Ambulance 2	0	145	-68	0
	11100	52	0	10
	11172	52	70	2
	11557	52	0	2
	11712	400	0	5
EMTs-Ambulance 3	0	137	-72	0
	11100	48	0	10
	11171	48	70	2
	11506	48	0	2
	11711	400	0	5

Appendix B: Applications Deployment

Table 27 details the list of applications deployed in each unit involved in the incident and when those applications are active.

Table 27. Applications per unit.

Unit	Number of units	Number of instances per unit	Application	Start time (min)	Stop time (min)
Task Force members	68	1	MCPTT	E2_TaskForce_Arrive	E12_Incident_End
Strike Team members	16	1	MCPTT	E3_SWAT_Arrive	E10_Incident_Secured
		1	Tactical telemetry	E7_SWAT_Deploy	E10_Incident_Secured
		1	Biometrics	E7_SWAT_Deploy	E10_Incident_Secured

Unit	Number of units	Number of instances per unit	Application	Start time (min)	Stop time (min)
		1	Video (streaming)	E7_SWAT_Deploy	E10_Incident_Secured
UC members	12	1	MCPTT	E5_UC_Setup	E12_Incident_End
Firefighters	6	1	MCPTT	E4_FireEMS_Arrive	E12_Incident_End
EMTs	6	1	MCPTT	E4_FireEMS_Arrive	E12_Incident_End
Negotiator (UC member)	1	1	VoLTE	E8_Offender_Found	E9_Interdiction
Patrol cars	34	1	AVL	E2_TaskForce_Arrive	E12_Incident_End
Mobile command center	1	1	AVL	E5_UC_Setup	E12_Incident_End
		1	video conference	E6_Perimeters_Ready	E12_Incident_End
		16	video (viewing) helmet cameras	E7_SWAT_Deploy	E10_Incident_Secured
		5	video (viewing) school cameras	E5_UC_Setup	E12_Incident_End
		4	video (viewing) traffic cameras	E5_UC_Setup	E12_Incident_End
		1	video (viewing) helicopter	E5_UC_Setup	E10_Incident_Secured
		2	Web	E5_UC_Setup	E12_Incident_End
		5	RMS-BCA database access	E5_UC_Setup	E12_Incident_End
		2	satellite/maps	E5_UC_Setup	E12_Incident_End
		1	building plans	E5_UC_Setup	When downloads complete
		1	Incident management	E5_UC_Setup	E12_Incident_End

Unit	Number of units	Number of instances per unit	Application	Start time (min)	Stop time (min)
		1	NG911 video clips	E5_UC_Setup	E12_Incident_End
SA mobile unit	1	1	AVL	E6_Perimeters_Ready	E12_Incident_End
		1	video conference	E6_Perimeters_Ready	E12_Incident_End
		16	video (viewing) helmet cameras	E7_SWAT_Deploy	E10_Incident_Secured
		5	video (viewing) school cameras	E6_Perimeters_Ready	E12_Incident_End
		4	video (viewing) traffic cameras	E6_Perimeters_Ready	E12_Incident_End
		1	video (viewing) helicopter	E6_Perimeters_Ready	E10_Incident_Secured
		3	RMS-BCA database access	E6_Perimeters_Ready	E12_Incident_End
		1	Incident management	E6_Perimeters_Ready	E12_Incident_End
		1	NG911 video clips	E5_UC_Setup	E12_Incident_End
Fire engines	2	1	AVL	E4_FireEMS_Arrive	E12_Incident_End
Ambulances	3	1	AVL	E4_FireEMS_Arrive	E11_EMS_Departure
		1	Biometrics	E6_Perimeters_Ready	E11_EMS_Departure
		1	Video (streaming)	E6_Perimeters_Ready	E11_EMS_Departure
Helicopter	1	1	AVL	E5_UC_Setup	E10_Incident_Secured
		1	Video (streaming)	E5_UC_Setup	E10_Incident_Secured

Unit	Number of units	Number of instances per unit	Application	Start time (min)	Stop time (min)
DC 1	1	1	Video (streaming)	E8_Offender_Found	E10_Incident_Secured
DC 2	1	1	Video (streaming)	E8_Offender_Found	E10_Incident_Secured
DC 3	1	1	Video (streaming)	E8_Offender_Found	E10_Incident_Secured
DC 4	1	1	Video (streaming)	E8_Offender_Found	E10_Incident_Secured
Throw phone	1	1	VoLTE	E8_Offender_Found	E9_Interdiction
		1	Video (streaming)	E8_Offender_Found	E9_Interdiction