STREMS: A Smart Real-time Solution Toward Enhancing EMS Prehospital Quality

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***Abstract*—Emergency medical service (EMS) systems are public services that provide quick response, transportation as well as appropriate emergency medical care to the emergent patient. For EMS, every second is critical. Unfortunately, current EMS systems have many challenges: lack effective communication between EMS providers and hospital professionals, less attention on care quality and limited resources of medical equipment and personnel. Motivated by this, in this paper, we explore the use of wearable sensing, smart mobile device as well as video technology to propose STREMS: an efficient smart real-time prehospital communication system for EMS. Specifically, we first introduce a cost-effective wearable physiological sensing solution to support multi-dimensional telemetry monitoring for an ambulance operating at as Basic Life Support, a type of EMS service level without sophisticated medical equipment or paramedics. Then we propose to build a cloud-based real-time data sharing platform, enabling automated streaming all gathered prehospital data (*e.g.*, vital signs, EKG and image/short videos about accident scene) to the hospital prior to ambulance arrival, thus giving a more complete figure about the incoming patient. This can significantly decrease the handoff time and improve the efficiency at the hospital. Additionally, a live point to point video communication is proposed to support EMS telemedicine to enhance prehospital care quality through directly video conversation to assist EMS providers in consultation, triage, early medical examination and treatment. We implemented STREMS as an Android mobile app and evaluated its feasibility over the broadband cellular network in the city of Detroit. In a moving context, our results demonstrate STREMS can successfully deliver 100% of emergency data to the hospital in less than 1.5s, on average 0.75s for reporting a new case and 0.05s for health data. As the live video with 1280 $\times$ 720 pixel resolution, STREMS only works when the vehicle speed is less than 40MPH.**

Keywords: Emergency Medical Service (EMS); real-time prehospital communication; prehospital care quality; wearable sensing

I. Introduction

Emergency Medical Services (EMS) are dedicated to providing out-of-hospital medical care, transport to definitive care, and other medical transport to patients with illnesses and injuries, with the goal of providing timely transportation and satisfactory medical treatment for emergent conditions [1]. In the US, EMS is commonly provided by Fire Departments. In general, most EMS agencies provide service at two levels. One is Basic Life Support (BLS), provided by Emergency Medical Technicians (EMTs), which can provide basic medical care such as bleeding control, basic airway support, oxygen delivery, and patient stabilization. The other is Advanced Life Support(ALS), requiring more highly skilled paramedics who can provide a higher level care such as the interpretation of the patients heart rhythm, administration of drugs, complex airway support, and other therapies. ALS requires more robust and expensive equipment, with the ability to measure multiple health parameters (*e.g.*, vital signs, 12-Lead EKG), while BLS just contains the basic first aid set with very limited health data collection capacity. Unfortunately, the former is much expensive than the latter. In the Detroit Fire department, every ALS ambulance has a complex monitor/defibrillator from Physio-Contro [2], this adds $30,000 to the cost of each ambulance. Due to budget limitation, some EMS agencies, especially public entities, are unable to equip as many ALS units as may be desirable in their area. The Detroit Fire Department has 25 ambulances in total, only nine of which are ALS [3]. So EMS faces the challenges of resource scarcity to provide appropriate care quality the patients need.

Historically, EMS systems in the United States have evolved from EMS1.0 with fast patient transport ambulance service (*i.e.* horizontal taxicab) before the early of 1970s to EMS2.0 with the provision of lifesaving and emergency mitigating medical services as it is today [4]. Despite of the evolution of prehospital care in much of the focus, the EMS2.0 is still on response speed and transportation time, lacking of consideration of care quality, patients satisfaction and outcome. Currently, the EMS system is undergoing transformation into a system more integrated with health care as a whole [5]. Unfortunately, the technologies and techniques widely used by most EMS agencies might delay such transformation as they still depend on the traditional and less efficient EMS solutions used in the 1990s. For instance, many ambulances still rely on radio to communicate with the hospital. The radio signal may fail to transmit a clear picture about an accident scene or the patient's health condition including current vital signs, EKG and historical medical record to the hospital. When a patient arrives at hospital, the doctors or nurses in ER often need to ask questions and prehospital medical records to collect such information. The prehospital medical record may not be complete till long after the patient's arrival. Obviously, a lot of hand-off communications will be involved, which can definitely delay patient care and cause errors.

Motived by current challenges and limitations, this work is aimed at improving the communication quality through seamlessly and accurately delivering multi-dimensional telemetry data to the ER regardless of the underlying EMS care level,

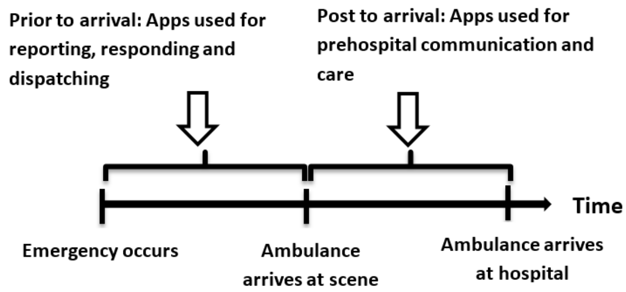


Fig. 1: The taxonomy of mobile solutions for EMS.

while enhancing the prehospital care quality by offering an effective video-based telemedicine platform to extend the medical care from ER to the moving ambulance. Recent advances in integrated wearable sensing have made continuously physiological monitoring a reality. The physiological sensors along with wearable devices allow us automatically collect multiple health parameters at the same time. Meanwhile, the rapid growth of video technologies in conjunction with the broadband cellar network makes the EMS telemedicine more feasible. And the proposition of building dedicated broadband network for EMS First Responder Network Authority (FirstNet) [6] will further remove the technical barriers of wireless robust data transmission on a moving ambulance.

In recent years, a variety of mobile apps have been developed to enhance the EMS efficiency. These apps could be roughly framed as two groups according to whether they are designed to be used before the arrival time of ambulance or after, as illustrated by Fig.1. The goal of prior to arrival is to improve the performance of emergency call taking, response and dispatch; while post arrival apps are designed for the professionals on the ambulance and at the hospital, aiming at improving the prehospital data communication and care quality.

In this paper, our work will fall into the second group. To be specific, we propose STREMS, a novel, smart and efficient real-time prehospital system, aimed at simultaneously improving EMS data sharing efficiency and prehospital care quality through leveraging a range of best-in-class technologies. First, we apply the wearable sensing solution into the EMS context to enable automatically multi-dimensional telemetry, which can significantly reduce the time of data collection allowing EMS crew pay more attention to the patient. More importantly, for the patient on BLS ambulance, EKG will be available all the time, which is beneficial to ER physician in diagnosis and treatment decision making. We also use other embedded sensors to collect more rich data to describe the emergency, such as still images or video clips from camera sensor. Secondly, we will build a cloud-based real-time prehospital data communication platform between field EMS and the emergency department in the hospital, automatically streaming all collected emergency data including vital signs, EKG, and other critical information to ER. This will give ER professionals a more complete picture about the incoming patient. To improve the prehospital care quality, we will build a live two-way video communication to support EMS telemedicine, allowing EMS provider to request for remote consulting and guide treatment and transport decisions. This may also help to prevent uneeded EMS transports. We implemented STREMS as an Android app on the Google Nexus 7 tablet and tested it in the city of Detroit with three different scenarios: *Downtown* with extensive skyscrapers around, *Midtown* with less high buildings, and *Highway* with faster vehicle speeds. Our extensive outdoor experiments show that STREMS can successfully deliver 100% of health data in less than 0.05 s. The live video data in our system is workable when the moving speed is less than 40 MPH , with about 1s latency and 2% frame loss rate for both 1280×720 and 1920×1080 video.

The reminder of this paper is organized as follows. In Section II, we review existing mobile solutions for EMS. The system design goals and system architecture are presented in Section III, followed by the prototype implementation in Section IV. Detailed evaluation in terms of latency and data loss rate are reported in Section V. We conclude this paper and point out the future work in Section VI.

II. Related Work

EMS systems provide transportation and medical care to maximize survival probability of patients. Historically, a lot of technologies have been adapted to achieve this goal, in which the 911 telephone based report and response system and the radio communication scheme are important elements for the early EMS system. Recently, the unprecedented growth in mobile smartphone and wireless communication are impacting the EMS in a new way. Numerous mobile apps have been developed to improve EMS efficiency. Basically, these apps could roughly be divided into two groups: one is about the efficient emergency reporting and responding systems. Second is developed for EMS providers and professionals in ER, mainly focusing on efficiency improvement in terms of prehospital data sharing and care, which will be elaborately discussed in Section II-B and II-C. We will end this section by discussing the health management system because we will integrate with such system to obtain more personal information used for early family member notification and primary care doctor notification.

A. Emergency Reporting

These apps take advantage of the smartphone's wireless communication function and GPS module to accelerate the speed of emergency report and response, thus the patient could be treated as early as possible, leading to the increase of survival probability. For example, TrackerAsisst [7] invented by a former police officer actually turns the smart phone into a mobile tracking device. For convenient use, this app integrates the personal tracing, emergency alerts and incident reporting into one package. Once emergency occurs, this app will send an emergency text messages or emails with a map of your current location to all of the emergency contacts pre-programmed into the phone. This app also supports home screen one click 911 call. It is widely used as an electronic medic alert for seniors. Similar with TrackerAsist, ManDown [8] is another medical alert mobile application with the ability of making a 911 call and notifying the emergency contacts along with GPS location. This app uses a motion sensor to monitor people's movement behavior, once no movement is detected in a fixed interval (*e.g.*, 1 day or 2 hours), the alert module and a personal safety GPS tracker will be triggered. The work in [9] proposed a mobile solution for fast and accurate medical emergency reporting.

B. Prehospital Communication

Motivated by the limitations of radio communications, a Cambridge startup developed a mobile app Twiage [10] that allow paramedics or EMT send the patient's vital signs,EKG and other data to the ER in the HIPAA-compliant way, while on route to the hospital. One GPS based tracking system is also implemented to estimate the patient's arrival time. The counterpart of the mobile Twiage is the web dashboard version in the hospital, through which the treatment team have a clear information about all incoming patients: know when will they arrive, which room will they go, what are their current health condition. TrackEMS [11] is another smartphone or tablet based electronic communication tool for EMS professionals, which allow them securely and efficiently stream emergency data (e.g. patient health condition, EKG images and videos/photos at the scene) to ER and Cath Lab before the patient arrival, thus eliminating the time-consuming or even duplicated verbal reports caused by current communication technology (e.g. radio or cell phone), and saving critical care time and potentially increasing survival rates. The most attractive feature of this APP is the consideration of protocol difference for EMS services across different states and regions. So it is not a one size fits all solution. In other words, it has the ability to be programmed and customized based on the geographic or demographic population as well as EMS and hospital protocols. Like Twiage, TrackEMS also has a dashboard version for hospital use. Another mobile based communication platform Pulsara [12] runs the same way of Twiage and EMStracke, sending real time field emergency data to the treatment team in hospital when the patients are being transported to hospitals. Note that this app originally is developed for the STEMI and stroke, and EMS module was recently added in the updated version. The updated Pulsara supports the secure instant message chat, a simple way for telemedicine in the EMS context.

C. Prehospital Care

Video technology based telemedicine is one effective way of enhancing prehospital care quality. In fact, video used in the EMS is not a new topic, which had been investigated a decade ago. The earliest project was piloted in 2006 by the Tucson Fire Department in Arizona 2006 [13], installing 17 video cameras on 17 ambulances which could provide a live video feed to doctors at a Level one trauma center. As the limitations of broadband coverage at that time, the municipal wireless network didn't support reliable live video transmission, dooming the failure of this project. In 2009, similar project trying to use two-way video in ambulance was launched by the East Baton Rough EMS in Baton Rouge, La. In spite of the mature of 3G, wireless live video transmission on a moving ambulance is still a technological barrier, leading to its fizzle. The advances of higher processing speed of mobile device and powerful cellar networks make the live streaming video as a reality. Inspired by the concept of adapting different transporting method used by the U.S. military forces in Afghanistan, Huston Fire Department launched a pilot project ETHAN [14], a real-time video chat based screening system, which allow the paramedics to engage in real time video consultation with a dedicated medical control physician. This program was designed to improve the utilization of EMS services in Huston since EMS resources are very limited in this area and statistics show that many 911 calls calls do not require transport to the emergency department. Another project [15] currently implemented in rural Virginia and San Francisco has the capability of enabling neurologists remotely performing accurate neurologic exams for the patients on the ambulance with stroke symptoms via video communication. This app is Stroke Target, since this disease is time critical, a short delay in treatment may result in a significant difference of patient outcome. This project paved the way of migrating the triage from hospital to ambulance. Note that this tablet app offers the prehospital medical care (i.e. medical diagnose), rather than merely emergency data transmission. E-Bridge from General Devices [16] is another mobile telemedicine app for EMS, supporting HIPAA-secure voice, text, photos, data, video clips and stream live conferencing for remote physician assistance as well as record and log functions for quality assessment, training and medical-legal documentation.

D. EMS Electronic Patient Care Reporting

A certified emergency medical service providing either BLS or ALS outside a hospital must complete an approved EMS report form for each patient treated. To save time and pay more attention on patient, currently, EMS professionals often rely on the electronic Patient Care Reporting (ePCR) products that allow them to collect patient information and care details electronically. Actually, a variety of hardware and software solutions are appearing on the market, such as the RescueNet ePCR from ZOLL [17], SafetyPad from OPEN Inc. [18], Field-Ready ePCR Tablet from WebMedicPro [19] , Critical Care from ImageTrend Inc. [20] and so on.

III. The STREMS System Design

In this section we first describe the design goals of STREMS, and then present the overall system architecture. Details follow as below.

A. Design Goals

STREMS is designed to enhance the medical care quality and patient's satisfaction for EMS with cost-effective wearable sensing and video based telemedicine technologies. In particular, our goal could be further described as the following.

Enabling collect multi-dimension telemetry for both ALS and BLS service: As we mentioned earlier, currently, in US many EMS organizations equip their ambulance with either ALS or BLS units, in which ALS represents higher level care from career based paramedic with more health data (*e.g.*, EKG, no EKG on BLS ambulance) collected by more advanced and expensive medical devices. However, it is usually cost-prohibitive to equip all ambulances with ALS. In fact, for the budget limited agencies, the number of ambulances with ALS is usually less than that with BLS. Instead of depending on the patient's health condition, the vehicle response may be based on its availability. This means that a BLS ambulance might be dispatched to a critical patient, making some key medical data (*e.g.* EKG and vital signs) unavailable to the doctors in emergency room. In fact, in some states, there have been some policies or training requirements for EMTs in obtaining12 Lead EKG data, but not interpreting them in BLS systems ([22], [23]). Additionally, telemetry is inaccessible on the BLS ambulance since vital signs are manually collected by EMTs. While for some critical patients, it is important to monitor their vital signs and EKG in a non-stop way. To address this gap, we will rely on the cost-effective wearable sensing technology to continuously monitor multiple health parameters.

Providing efficient prehospital communication platform between EMS and hospital: Most EMS agencies still use the radio technology to report emergency data such as Estimated Arrival Time (EAT), accident type, patient's vital sign, to name a few. However, radio-based verbal communication is error-prone due to interference and multiple units may not be able to communicate simultaneously. The smart mobile devices have gone through an incredible evolution during last decade, each device is packaged with GPS, camera, and a range of sensors, making it possible to describe the patient and incident in various different formats (*e.g.*, image or short video clip). Furthermore, the advances of broadband cellular network provide the basic conduit to stream all collected emergency data to the receiving hospital effectively. Collectively leveraging these technologies, we will build a novel prehospital communication solution, enabling real-time emergency data sharing with hospitals.

Providing video based EMS telemedicine solution to enhance prehospital care quality: For the time-sensitive disease (*e.g.*, stroke and cardiac arrest), early examination and intervention is extremely important. However, most EMTs associated with BLS service are volunteer based with relatively limited medical training and scope of practice, failing to correctly interpret EKG, ultrasound and the patient's symptoms. Even for the crews on ALS ambulance, the medical diagnosis procedure can only launch until the patient arrives at hospital. To further improve the prehospital care quality, we will leverage the video technology to build to a two-way point to point live video communication platform to support mobile telemedicine, which will allow even BLS EMTs do online live video consultation with paramedic or other medical control center, meanwhile, physicians remotely conduct medical evaluation if necessary.

Enabling retrieval of personal information and historical medical record from other system: As we know, Personal Health Record (PHR) plays a vital role in the process of treatment decisions making. However, PMH is usually unavailable for emergency physician. In the same way, the contact information of the family member and primary care doctor are often unavailable, leading to the delay of notifying family member and primary care doctor. To address these issues, we will integrate our system with other PHR gateways, EMS Patient Care Reporting (ePCR) system and other emergency backup mobile apps (*e.g.*, My Medical [24]) to pull all needed information in assisting medical diagnosis, treatment plan decision and emergency notification.

B. System Architecture

A conceptual and architectural depiction of the STREMS is illustrated in the Figure 2. The system consists of a field *EMS* element, a remote *Hospital* element and a centralized *Cloud Center*. Their coresponding capabilities are summarized in Table I.

The *EMS* element actually contains one or more emergency remote wearable sensing device and a mobile app, operated by EMS providers on the ambulance, with the capabilities of monitoring and collecting the patients EKG and vital signs, streaming these data to the hospital in real time via Bluetooth and broadband cellular network, enabling two-way live video point to point communication, as well as quick notification to family member and hospital. For our system, EKG will be always available regardless of dispatched ambulance service level. Besides health related data, EMS providers can also use the tablet embedded camera to take still image or short video clips about the incident scene and the patient's condition. Furthermore, the ambulance's physical location and EAT could be estimated by jointly using GPS technology and GPS-based navigation system, so as to save time on voice reporting. We also will implement the family member notification by developing an algorithm to automatically learn emergency contact information through accessing the ePCR (*e.g.*, SafetyPAD in Detroit Fire Department). A text message with a simple description about the emergency, patient's name and the receiving hospital's address is then sent out. Except for the point to point video communication, note that data obtained by the ambulance doesn't go directly to the hospital side, rather, the data goes to a secure cloud server, then to the hospital, as shown in Fig.2. Delay definitely exists in such communication mode. Thus, we will build a real-time database system [25], which could allow all its connected clients receive all updated data simultaneously. All new reported data from EMS ambulance will be immediately reflected on the hospital side, but still preserved in the cloud for future retrival and to satisfy regulatory requirements of preservation of all prehospital communication . This feature could be used to quickly notify hospital that a new patient is coming without needing a verbal report.

The *Hospital* can view all of the uploaded emergency data from *EMS*, giving ER a complete picture of all incoming patients and reducing handoff time when they arrive. Meanwhile, this part will allow emergency physicians or nurses build a live point to point video communication with prehospital personnel for additional medical examination, triage or other early medical intervention. Based on the incoming patient's symptoms and preliminary analysis, ER resources such as cath labs, operating rooms, and hospital beds can be activated or reserved as well. We will also integrate with other PHR system, allowing physicians access the patient's medical history to assist medical diagnosis. Another function is to automatically notify primary care doctor through email.

The remote *Cloud Center* will work as a backend server platform, containing live video communication server, database system and user authentication. Specifically, the responsibility of live video server is to build and manage the point to point video communication; the database system is used to store all reported emergency related data from ambulance including health data, still image or short video clips with respect to the occurred emergency as well as ambulance location and EAT; and the user authentication is to verify users identity to direct different user interface. In our system, we design

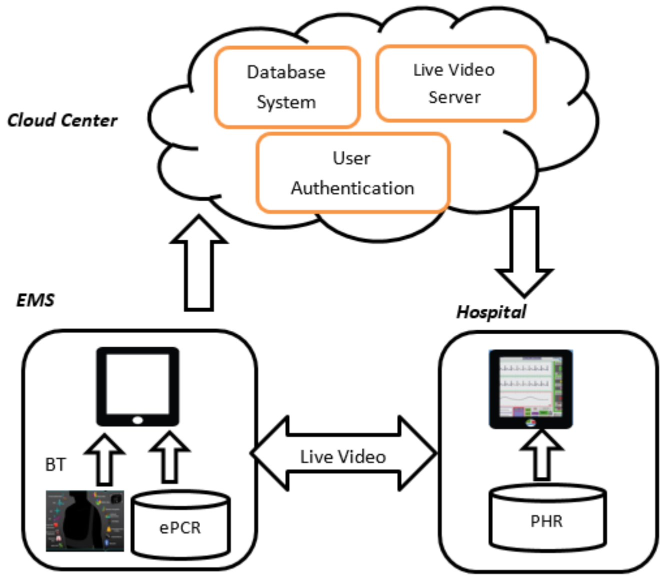


Fig. 2: The architecture of our scheme STREMS. BT and PHR mean Bluetooth and Personal Health Record, respectively.

TABLE I: Main Capabilities of STREMS

EMS	✦ Multi-dimensional telemetry monitoring
	✦ Delivering real-time prehospital data
	✦ Live video conversation with ER team
	✦ Quick family member notification
Hospital	✦ Visualizing prehospital data from EMS
	✦ Remote medical assistance via live video conversation
	✦ Quick primary care doctor notification
	✦ Accessing other databases to get personal health record
Control Center	✦ Storing medical and emergency related data
	✦ User authentication and management
	✦ Online video conversation management

two types of user for EMS providers, three types of user for professionals in emergency room. They are EMT /Paramedic and Physician/Nurse /Staff, respectively. As mentioned earlier, a real-time database system will be implemented to achieve real-time data synchronization between the ambulance and the hospital.

IV. STREMS Prototype Implementation

We implemented our system as a Tablet based Android app. The reason of choosing Android is due to its popularity, openness and easy access to the underlying hardware resource. A simple glance of the interface for EMS providers and hospital professionals is illustrated by Fig.4(a).The hardware we use is the Google Nexus 7 tablet with Android version 6.0.1. As the remote cloud server, we deploy a real-time

(a) Sensor Electronics Module (b) Belt

Fig. 3: The wearable sensing solution.

database system and user authentication scheme on Google Firebase cloud platform [26]. Since currently Firebase doesn't support live video communication, we separately deploy it in our lab, located in the campus of Wayne State University. Currently no real patient's data are involved at the demo test stage, so we didn't consider the data encryption and secure problem to make our system HIPAA- compliant. We will leave this part in the future work.

Our wearable sensing solution is built using the Equivital EQ02 LifeMonitor [27], which has two components: the Sensor Electronics Module (SEM) and the Sensor Belt, as shown by Fig. 3. The sensor belt is used to position the SEM on the left side of the chest, while SEM has the ability of sensing, recoding, intelligently processing measured health data as well as transmitting these data to other devices in wired or wireless way. We chose Equivital EQ02 LifeMonitor as it supports multi-parameter sensing and wireless Bluetooth communication, which can potentially eliminate the time consumption for health data collection by hand, allowing EMS providers pay more attention on the patient's care. It also provides the hot swap ancillary power packs for extended monitoring, which allow us to install 3rd party complementary sensors to support extended sensing function. In addition, it can work up to 48hrs without external power charge. This feature is very suitable for the EMS context without charging station on the moving ambulance. From the development standpoint, it provides the Java SDK API package, which can significantly shorten our development and production cycle.

Except for the wearable medical sensing, we also build our system on top of other default sensor readings. In particular, we use GPS and another navigation system to provide the EAT and the camera sensor to capture more rich information about the accident scene or patient's injure condition.

As our work is originally motivated by EMS resource scarcity both in hardware medical equipment and staffing training in the city of Detroit and will be ultimately used by Detroit Fire Department, for the EMS version, we integrate our system with SafetyPAD [18], an electronic ePCR system utilized by Detroit Fire Department. To be specific, the IT department from Detroit Public Safety generates a test records and provides us with a free Java API to access ePCR system to grab patient's personal information including name, DoB, SSN, emergency contact information and other basic information, which will automatically feed to the two notificaiton modules (*i.e.*, family member notificaiton and primary care doctor notification)

To apply our system into the real EMS context, there

(a) Health Data Visualization

(b) EKG when the sensor is worn correctly

Fig. 4: A simple glance of STREMS app.

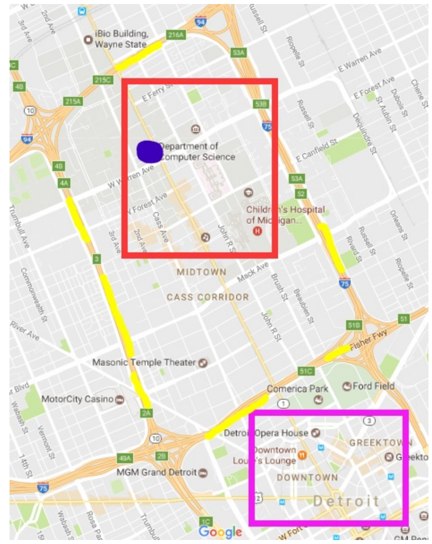


Fig. 5: GoogleMap view of three outdoor test areas, showing the locations of *Midtown* (inside red rectangle), *Downtown* (inside purple rectangle), and *Highway* (yellow highlighted highways that surround the city of Detroit).

are several challenges needs to be considered beforehand. From the technique perspective, we need to be much more careful about the active routing and EAT estimate. Today, many commuters rely on GPS based navigation system for routing, either on commercial GPS products or GPS mobile app (*e.g.*, Waze [28]) on the smartphone. Ambulances may use a variety of routing strategies but these are by no means universal or available in all systems. However, there are some issues if directly applying GPS products into the EMS context. Since these apps are not EMS dedicated, they fail to consider the emergency vehicle's unique travel pattern. For example, mobile apps (*e.g.*, Waze) can avoid the congestion caused by an accident. While it is possible the traffic accident is just the ambulance's destination. Emergency vehicles may use warning devices and dedicated travel lanes or shoulders. Therefore, routing avoiding the congestion and with traffic consideration might not be the optimal one for ambulance. In addition, the mobile apps build their routing models on a set of rules that normal vehicles much abide by in motion, while these rules don't apply for ambulances. In fact, the ambulance drivers can drive along the road shoulder or even cross the median area to drive on the oncoming lane. Sometimes they might also ignore the direction of one-way streets.

In addition, some non-technical barriers will absolutely affect the system performance as well. For instance, the live video solution for EMS telemedicine indicates that a physician in the receiving hospital should be available at the moment when a video call from ambulance is made. However, the physician in emergency department is very busy, they might not have enough time to respond each field call. Therefore, it is better to stream the field request call to a medical facility or dedicated EMS communication center with a number of certified nurses, EMS fellows and physicians, who are qualified to remotely assist EMS providers. Second, in the US, EMS standards and protocols are defined by the state law and all EMS agencies come in different shapes and sizes, showing great diversity in response configuration, staffing, service level and medical control, to name a few. This means our system needs to be flexible and configurable so it can be tailored to meet the unique operational requirements of each agency. A ”one size fits all” solution is not workable. At last, for the hospital side, it is different to grab the patient's personal historical record immediately since direct medical data electrical exchange usually requires the primacy care doctor's order.

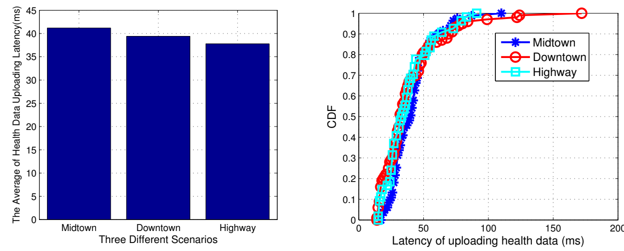
V. Performance Evaluation

In this section, we investigate STREMS's performance in terms of real-time data transmission over 4G LTE network in the outdoor moving context. We mainly observe the latency and data loss rate of transmitting regular emergency data and live video over 4G LTE network. The average bandwidth used for regular data transmission is around 5Mbps for downloading and 1.8Mbps for uploading. For the video data, we use another network with download speeds and upload speed as 11 Mbps and 6Mbps, respectively. The reason we tested our demo on two type network is due to the former couldn't successfully deliver the live video in the moving context. And our initial experiments demonstrated the failure of live video transmission when the moving speed is more than 20 MPH, with around 40% frame loss rate.

Since our work is targeted for the Detroit Fire Department, we conducted our experiments in the city of Detroit. Three most representative areas, also refereed as *Midtown*, *Downtown* and *Highway*, were chosen to run the EMS client, as shown by Fig.5. The underlying reason for such selection is based on the difference of road speed limit and building density which might affect the wireless signal strength. For example, the speed limit for the roads in the downtown area is 25 Mile Per Hour (MPH), yet this area is densely surrounded by numerous skyscrapers , as shown by Fig. 6(b). As the highway, even with more open area, the higher speed limit (55MPH) , moving in the tunnel or under bridge will bring another challenge for real data

(a) Midtown, Detroit (b) Downtown, Detroit

Fig. 6: Building style of the testing areas.



(a) Average latency of delivering health data (b) CDF of health data delivering latency

Fig. 7: The performance of delivering health data to hosptial.

transmission. Compared with the other two areas, midtown contains a large number of buildings less than 4 floors (see Fig.6(a)) and the vehicle cant move faster than 35MPH. Note that our test didn't cover all the roads in the Detroit midtown and downtown area. On the contrary, a small area was chosen instead, as shown by the red and purple rectangle in Fig. 5.

For each test area, we place the Equivital and a Google Nexus 7.0 with STREMS app developed for EMS in the car to simulate the EMS side in the ambulance. Regarding the hospital side, we still use Google Nexus 7.0 with our developed app for hospital use, which is deployed in our lab, located in the Department of Computer Science Department at Wayne State University (blue dot in Fig.5), via the campus Wi-Fi to access Internet. Due to the clock drift, the clock of these two devices needs to be synchronized before each test.

A. New Case Report

We start by observing the latency of reporting a new emergency case, which corresponds to the time duration from a field EMS provider clicking a SUBMIT button to the moment when the hospital side app receives a notification of new incoming patient. At this point, the transmitted data includes the emergency occurred time, location, EAT and patients personal information (name, DoB, home address), with the size of 150 bytes in total.

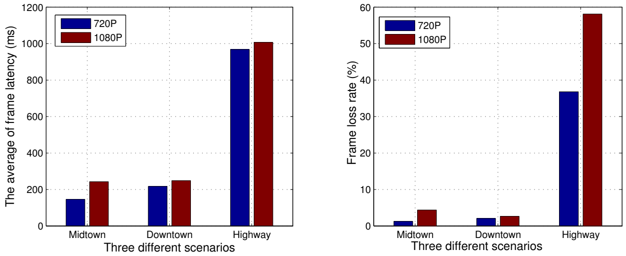
Within each test area, a couple of sample sites (10 for *Midtown* and *Downtown*, 6 for *Highway*) is chosen as the emergency scene, each site with 5 new case reporting events. As new case report usually occurs before the ambulance starts to move, these data was collected in a non-moving or slow moving (less than 15 MPH) vehicle. The average of new case report latency for *Midtown*, *Downtown* and *Highway* are 0.54s, 0.55s and 1.36s, respectively. Obviously, the latency behaves similarly for *Midtown* and *Downtown*, both are around 0.5s. Much as expected, the *Highway* is obviously inferior to other two, with the latency almost 1.4s. This might due to some selected sites are far from the nearest mobile mast base station. Meanwhile, the failure rate of new case reporting is observed as well. For these three tested areas, any reported case could be successfully received by the simulated hospital, so the failure rate is zero.

B. Health Data

In this section, we investigate the real time performance of delivering health data in the moving context. Here, the health data consists of heart rate, body temperature as well as breath rate, sampled from the Equivital, with a sampling rate of 4 measurements per hour. We drove a vehicle in the three chosen areas to observe the system performance in successfully delivering a group of new gathered health data to the hospital. The testing duration for *Midtown*, *Downtown* and *Highway* are 20 mins, 25 mins and 15 mins, and the corresponding moving speed range is between 20MPH to 35MPH, 12MPH to 20 MPH and 45MPH to 55MPH, respectively. Since our focus is on the system real time performance, in out experiment set up, rather than wearing the Equiviatl on a specific subject, we just placed it in the vehicle close to Google Tablet, ensuring the Bluetooth communication quality. Upon the arrival of new data from Equivital, the STREMS app for EMS will deliver all gathered sensor readings to the remote database, deployed at the Google Firebase cloud server, with the capability of immediately notifying the hospital side after finishing the database write operation. And the payload of each new data uploading is 8 byte, with the value of heart rate, body temperature and breath rate. The average of new health data uploading latency along with its CDF are depicted by Fig.7(a) and Fig.7(b), respectively. Surprisingly, the health data latency in the moving context is less than 40ms on average, regardless of testing area, much smaller than the latency of reporting a new case when the vehicle moving slowly or without motion. This is because the data size of health data is significantly smaller the scenario of reporting a new emergency case. Regarding the data missing rate, all the testing areas show no data loss, with 82 measurements in 20 mins for *Midtown*, 99 measurements in 25 mins for *Downtown*and 58 measurements in 15 mins for *Highway*.

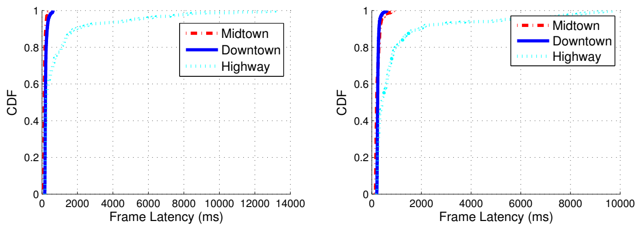
C. Live video

We observe the performance of live video communication between EMS and hospital. Again, the vehicle driving on the three chosen areas are used to simulate the ambulance on the road, the hospital app is deployed in Wayne State University. We use two set of 5-minitue video with different resolution qualities as the test data. They are 1280×720 (720P) and 1920×1080 (1080P), both including 30 frames per second. The results of average frame latency and frame loss rate are shown by Fig.8(a) and Fig. 8(b). As expected, the performance of 720P outperforms 1080P for all testing areas. And for both data set, the frame latency in *Midtown* is smaller than that in *Downtown*, indicating the high and dense buildings indeed affect the wireless signal. Overall the average frame latency for *Midtown* and *Downtown* is less than 200ms, and



(a) Average frame latency (b) Frame loss rate.

Fig. 8: The performance of streaming live vdieo.



(a) 720P Video (b) 1080P Video

Fig. 9: CDF of frame latency of streaming live video.

the corresponding frame loss rate are less than 5%. While for *Highway*, the performance is inferior to other two, with almost 1 second frame latency and more than 40% frame loss rate for both 720P and 1080P. This means the live video solution is not workable if directly transmitting video data over the 4G network when the moving speed is more than 50MPH.

VI. Conclusion & Future Work

In this paper we studied the mobile solutions for improving EMS efficiency and prehospital care quality. Based on a series of best-in-class technologies ranging from wearable sensing, smart device, video to broadband cellular network, we proposed a mobile real time prehospital system with the capabilities of telemetry monitoring multiple health parameters, real-time data sharing between the ambulance and hospital side, and point to point live video communication to support EMS telemedicine. Extensive outdoor experiments were presented to evaluate the system performance in terms of data (including video) transmission latency and loss rate. We conclude that our system is feasible for delivering real-time data to the hospital, since the latency for delivering regular emergency data is very small, most of them are less than 0.5s regardless of the vehicle moving speed.

There are two challenges need to be addressed in the future. First, as the live video transmission over 4G LTE, our experiments show that the frame loss rate in the test area of *Higway* can reach around 50%, which is unacceptable for our application scenario. We need to find the underlying reason and provide an efficient solution (*e.g.* video compression and analysis on the edge [29]) to solve this issue. Another is about HIPAA compliant. Since our app is medical related, involving transmitting and storing personal information and health data, we need to add the secure and privacy function into our system.

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References

[1] Emergency Medical Services, https://www.ems.gov/whatisems.html.
[2] Physio Control, http://www.physio-control.com/.
[3] Detroit Fire Department, https://en.wikipedia.org/wiki/Detroit_Fire_Department.
[4] National Public Safety Telecommunications Council, EMS Telemedicine Report Prehospital Use of Video Technologies, 2016.
[5] National Association of State EMS Officials (NASEMSO), Realizing the Value of EMS in Our Nations Health Care Transformation, 2016.
[6] FirstNet, http://www.firstnet.gov/about.
[7] Tracker Assist, http://trackerassist.com/.
[8] Man Down App, http://www.mandownapp.com/.
[9] Esraa I. Abou El Safa, Ghada A. El Khayat,"A Mobile Solution for Fast and Accurate Medical Emergency Reporting," in *IEEE First Conference on Connected Health: Applications, Systems and Engineering Technologies*, 2016.
[10] Twiage Medical App, http://www.twiagemed.com/.
[11] TrackEMS,http://www.track-ems.com/.
[12] Pulsara,https://www.pulsara.com/.
[13] Tucson Fire Department, Starting the 21st Century, http://www.tucsonfirefoundation.com/wp-content/uploads/2015/10/Starting-the-21st-Century.pdf, 2006.
[14] Project ETHAN, http://www.emsworld.com/video/12178910/project-ethan-reducing-ed-transports-in-houston.
[15] Sherita N. Chapman Smith, Prasanthi Govindarajan, Matthew M. Padrick, Jason M. Lippman, Timothy L. McMurry, Brian L. Resler,"A low-cost, tablet-based option for prehospital neurologic assessment: The iTREAT Study," *Neurology*, vol87(1), pp.19-26, 2016
[16] E-Bridge, http://general-devices.com/wp-content/uploads/2016/01/e-Bridge_Brochure.pdf.
[17] Rescue Net ePCR, https://www.zolldata.com/rescuenet-epcr/.
[18] SafetyPAD, http://www.safetypad.com/.
[19] Field-Ready ePCR Tablet, https://www.ems1.com/ems-products/software/974208-Field-Ready-ePCR-Tablet/.
[20] Critical Care, http://www.imagetrend.com/solutions-ems-critical-care/.
[21] MyEMSRecrods, http://www.imagetrend.com/solutions-ems-critical-care/.
[22] Basic Life Support Acquisition of 12 Lead ECGs, https://www.health.ny.gov/professionals/ems/policy/16-01.htm.
[23] Beyond Basic Training, http://www.emsworld.com/article/10686934/training-emt-basics-to-acquire-12-leads.
[24] My Medical, http://mymedicalapp.com/.
[25] G. Ozsoyoglu," Temporal and real-time databases: a survey," *IEEE Transactions on Knowledge and Data Engineering* , vol. 7, no. 4, pp. 513–532, 1995.
[26] Google FireBase, https://firebase.google.com/
[27] Equivital EQ02 LifeMonitor, http://www.equivital.co.uk/.
[28] Waze, https://www.waze.com/.
[29] Qingyang Zhang, Zhifeng Yu, Weisong Shi and Hong Zhong, "Demo Abstract: EVAPS: Edge Video Analysis for Public Safety," in *Proceedings of 1st IEEE/ACM Symposium on Edge Computing (SEC), Washington DC*, Oct 27-28, 2016.