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Requirement Analysis and Implementation of Smart Emergency Medical Services

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ABSTRACT Emergency medical service (EMS) occurs in a high-pressure and error-prone environment, where paramedics must provide prompt decisions in care while recording information with limited time, incomplete data, restricted resources, and competing priorities. The EMS requires cooperative workflows between patients or caregivers, paramedics and medical centers in the community. In a conventional EMS, they have difficulties in obtaining causes of emergencies and personal medical histories, which are important for a rapid and proper response. We analyzed the requirement of a smart EMS (SEMS) system and derived the key components in connected care environments leveraging information and communication technology. A survey of paramedics (n=113) revealed that a SEMS system using IoT technology should integrate personal lifelogs, electronic medical records, and patient monitoring in ambulances into pre-hospital care recording systems. It also addressed context-awareness in the EMS accelerates first responder's activities, while supporting personalized care not only at the scene of the emergency but also during the entire hospital stay. Based on requirement analysis, we designed and implemented SEMS using health information standards to provide interoperability between devices and systems. As an application of SEMS, an example service is introduced: lifelog-connected EMS for stroke patients with a real-time location service for managing timeline of treatment.

INDEX TERMS Internet of Things, emergency services, health information management, sensor systems, medical information systems.

I. INTRODUCTION

A quality of EMS must comply with limits on service times, despite restricted resources. Paramedics and medical staff in emergency departments (EDs) may not receive necessary information, including the patient's medical history and the conditions at the scene of the emergency. The importance of disseminating the available information of emergency increases in regionalized EMS to provide the appropriate response and patient transport [1], [2]. Information and communication technology (ICT) can provide a significant improvement in the timeliness of treatment for acute symptoms in emergency. Thus, regional EMSs have been early adopters of new communications technology, medical and non-medical devices, and software into integrated workflows [1], [3].

Internet of Things (IoT) technology can enable round-the-clock monitoring of medical conditions and provide that to an EMS information. Wireless technology allows acquisition of remote monitoring of pulse oximetry data, blood pressure readings, ECG traces, and the monitoring of patients' movements. Consequently, IoT-supported EMS connects this daily healthcare information to in-hospital care, as shown in Fig. 1.

In the daily healthcare phase, information is collected about an individual's health conditions and medical history, lifestyle, and environment. In the pre-hospital EMS phase, emergency service providers obtain information about events at the scene and in the ambulance in the form of electronic-Patient Care Reports (ePCRs). These ePCRs provide hospital staff with collated information: from bystanders, first responders, and paramedics at the scene; the clinical history

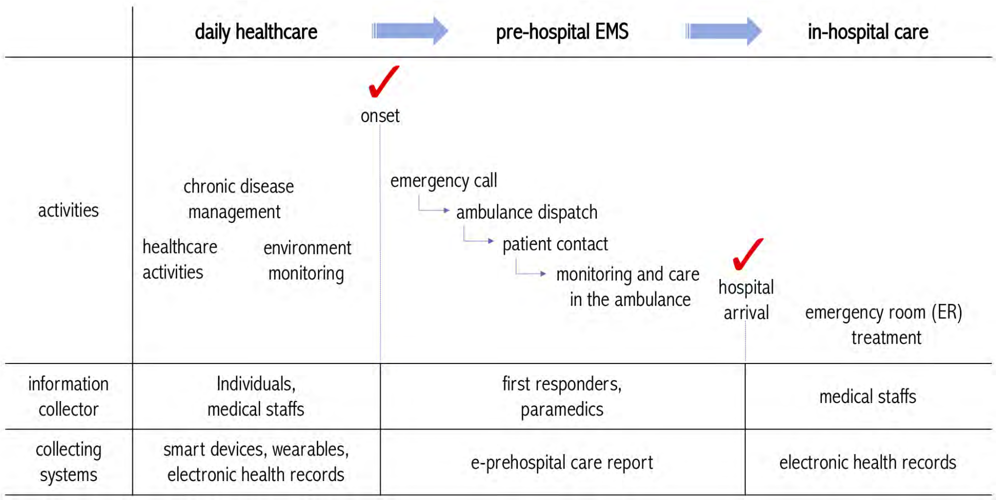

FIGURE 1. Personalized EMS environment for connected healthcare.

of the patient; and pre-hospital treatments administered. The information in ePCRs can be shown to benefit care in the emergency room (ER) and eventual outcomes [3]. As the use of mobile devices and communications technologies improve and become more affordable, new ways of using these technologies will be discovered in the EMS infrastructure that evolve from conventional EMS to patient-centered emergency care.

Providing a smart and personalized EMS requires more than the application of technology to EMS, with its emphasis on workflow with limited time and personnel, in a resource-constrained environment. In this article, we specify requirement of enhanced EMS systems in connected healthcare environment through the analysis of propositions from paramedics. Reflecting the result of analysis, we introduce the SEMS system, which integrates information about the current emergency with the medical history of patients, and delivers them directly to the appropriate ER and national or regional administration. The SEMS links electronic medical records (EMRs), lifelog and signals from monitoring devices in ambulance vehicles to EMS by a variety of telecommunication methods. We employed a health information standard, integrated health enterprise (IHE), to verify the integration and interoperability of SEMS components. We also discuss example applications of SEMS with a lifelog application for stroke patients and a pathway tracking in a protocol for acute disease.

II. METHOD FOR REQUIREMENT ANALYSIS

A survey was conducted to decide on the key functionalities that should be provide by SEMS and to ensure their validity. An online survey was completed by 113 paramedics located in 5 fire-stations: 91 were male and 22 were female, with an average length of experience of 4.6 years (a distribution is shown in Table 1). Experience of unintended event that occurs in the course of work is also summarized in Table 1.

TABLE 1. Participants characteristics.

Participant characteristics	Participants (n = 113)
Age	
range	24 – 46
mean(sd)	31 (± 4.7)
Gender	
female	22
male	91
Job experience in emergency service (years)	
range	1 – 20
mean(sd)	4 (± 3.6)
Experience of work-related accidents (times)	
None	61
1 – 5	49
6 – 10	2
11 – 15	0
≥16	1

The survey contained 24 propositions (or questionnaires) based on the demand of technologies concerning the current emergency environment (Table 2). Responses were sought on a five-point scale, with higher scores indicating greater agreement with the proposition and the positive score represents scale 4 (agree) and 5 (strongly agree).

III. RESULTS AND DISCUSSION TO IDENTIFY CHALLENGES FOR SMART EMS

We used the results from the survey to identify both perceived obstacles to efficient emergency services and attitude toward use of technology in EMS. In this section, we summarized the challenges for SEMS based on surveyed results and literatures.

TABLE 2. Proposition code and results of ems requirement analysis.

Code	Proposition	Scale					Mean(SD)	Positive scores (%)
		1	2	3	4	5		
P1	I have often been aware that EMS data is not being recorded accurately.	4	31	45	29	4	3.0(±0.9)	29.2
P2	I am frequently concerned about the reliability of EMS records.	8	43	42	16	4	2.7(±0.9)	17.7
P3	The use of an ePCR system can be a positive factor.	3	3	36	57	14	3.7(±0.8)	62.8
P4	We need a system that records and reports field conditions in real time.	5	12	54	35	7	3.2(±0.8)	37.2
P5	The address of patients is often unclear, delaying arrival of the ambulance.	0	9	29	62	13	3.7(±0.7)	66.4
P6	The patient or a caregiver needs to cooperate in promptly identification of the patient.	1	0	7	47	58	4.4(±0.6)	92.9
P7	More convenient methods of accessing patient information including health records is required.	1	0	7	47	58	4.4(±0.6)	92.9
P8	Infection is frequently a concern due to the lack of prior information about infected patients.	2	3	35	53	20	3.8(±0.8)	64.6
P9	More equipment should be provided in the ambulances for intensive care.	2	6	36	53	16	3.7(±0.8)	61.1
P10	A patient's medical history is needed if appropriate care is to be provided.	1	1	22	69	20	3.9(±0.6)	78.8
P11	There are limitations in providing intensive care that can be provided at the scene.	1	3	35	60	14	3.7(±0.7)	65.5
P12	Medical guidance is essential for on-site first aid.	5	15	53	37	3	3.2(±0.9)	35.4
P13	Good communication with the control station is necessary to obtain information about the patient quickly.	2	2	34	47	28	3.9(±0.9)	66.4
P14	It is difficult to communicate with the control station at a disaster scene where there are many casualties.	2	14	55	33	9	3.3(±0.9)	37.2
P15	Patients are frequently redirected to a different hospital due to the refusal of admission or other circumstances.	1	4	8	77	23	4.0(±0.7)	88.5
P16	It is difficult to determine the best hospital from the patient's condition.	1	27	48	31	6	3.1(±0.9)	32.7
P17	To transport patients efficiently, it is necessary to refer the available capacity of several hospitals.	0	2	18	61	32	4.1(±0.7)	82.3
P18	Patients and caregivers often ask to transfer to specific hospital on their convenience.	0	0	9	48	56	4.4(±0.6)	92.0
P19	Direct transmitted information about patients' transport and their severities to hospitals will improve emergency response.	2	8	44	40	19	3.6(±0.9)	52.2
P20	There is a need for an effective system for sharing information between first-aid teams in the field.	0	3	50	41	19	3.7(±0.8)	53.1
P21	Patient data obtained by medical devices in an ambulance should be recorded and also transmitted directly to the control center and hospitals.	4	10	52	34	13	3.4(±0.9)	41.6
P22	Information of people who need to use 119 (911) services frequently should be identified.	0	0	21	35	57	4.3(±0.7)	81.4
P23	The feedback of patient outcomes is necessary to improve the quality of an EMS.	1	9	34	53	16	3.7(±0.8)	61.1
P24	It is difficult to score the severity of patients at a disaster scene where there are many casualties.	1	8	49	47	8	3.5(±0.7)	48.7

A. ACCURATE REPORTING IN EMS ACTIVITIES

Paramedics transfer information at the scene including their procedures and medications into emergency department of hospitals [4]. In the conventional EMS, paramedics recorded paper care charts, which had certain disadvantages of errors in writing and frequent misplacement [5]. Propositions in our requirement analysis addressed the inaccuracy in reporting information during EMS activities. The experience of insufficient or incorrect information recording was answered by 29.2 percent of respondents (P1), and 60.6 percent of them concerned the reliability of EMS records (P2). Recently, ePCRs using tablet devices have been incorporated into pre-hospital care, to conveniently connect EMS information to hospitals [6], [7]. Paramedics' acceptance and preference to the use of ePCR was investigated in P3 in the survey with the positive agreement of 62.8%. In the research of electronic ambulance call recording (eACR), ER physicians also have agreed the usability of eACR [8].

Information and communication techniques can provide mechanisms to enhance EMS data, to solve the problem of inaccuracy in data collection. Biomedical signals from patient monitoring devices in ambulances are recorded in ePCRs through direct access using RS-232 interfaces or wireless connections [9]. Recent ECG monitors and defibrillators are capable of transmitting cardiac signals to hospitals ahead of the patient's arrival using transmission protocols that configure ePCRs and collection servers for real-time and reliable ECG transmission [10], [11]. In addition, pulse oximetry, end-tidal carbon dioxide, blood pressure, ventilators, regional perfusion, invasive arterial, and intracranial pressure information can be uploaded to current EMS systems. It is also surveyed that more than 37 percent of respondents addressed the necessity of automatic recording of field conditions (P4).

B. REFERENCING RELIABLE MEDICAL RECORDS

EMRs have the potential to improve the quality of EMS records and the real-time handoff information. Zorab et al. noted that patients' pre-existing medical conditions, recent treatments, and health information are difficult to obtain in an ambulance, although access to this information is essential for the most appropriate care by paramedics [12]. Our requirement analysis also revealed that most paramedics require more convenient methods to access patient's health information (P7, 92.9%). For interoperation between EMS and medical history of patients, a study introduced techniques to retrospectively link data in EMRs with EMS records using machine learning classifiers [5]. Unclear information of demographic or identification are also main obstacles in EMS activities as investigated in our survey (62.8 percent of agreement in P5, 92.9 percent of agreement in P6). However, the real-time integration has been impeded due to the lack of a reliable method to automatically link a patient's data in the EMS system and the corresponding data in EMRs. The linking of the patient's records across different data sources requires emergency medical identification and a broker system [7]. Having accurate record linkage can serve many important functions for quality assurance, increased survival rate, and clinical data analysis, since EMS systems can detail the clinical trajectory of the patient. This reduces the burden of manual recording and possible misinformation in ePCRs. Having the wrong patient linked could result in a patient receiving medications that they are allergic to, or withholding medications because of a perceived allergy or prior administration. Especially, paramedics need information of patient medical history to correspond infections as shown in the results of P8 (64.6%) and to provide appropriate care based on the medical history (P10, 78.8%). Providers could also assume that the patient received treatment that was never administered in EMS.

Besides the utility during EMS activities, referencing EMRs also provide qualified feedback information of hospital outcomes to EMS providers after patient delivery, which especially promotes advancements in the care of patients with acute symptoms including cardiac arrest, stroke, and trauma care. Previously, it was difficult for EMS providers to receive contemporaneous feedback about individual patient outcomes. In the proposition P23 in our survey, total of 61.1 percent of respondents answered they need feedback of patient outcome to improve quality of EMS. Having discharge diagnosis and information linked to an ePCR would allow EMS administration and individual providers to continuously improve their practice, target educational interventions, and automatically monitor key performance metrics.

C. REAL-TIME DATA COMMUNICATION FROM SCENES TO HOSPITALS AND CONTROL CENTERS

The effective management of patients and EMS events at the emergency scene and in ambulance settings will impact other parts of the health service, including emergency departments and primary care. The importance of communication protocol that delivers the prehospital information to hospitals was addressed in [4]. Direct transmitted information about patients and field condition is addressed in P19 and P21 in our survey, because medical staff in hospitals can refer to vital signs of patients or interventions provided in the field, such as ECG acquisition or pain medication. EMS telemedicine studies have addressed this issue and solutions through streaming data derived from the emergency field to hospitals by various mobile network.

D. TRIAGING AND PATIENT TRACKING

In disaster scenes with mass casualties, EMS should prioritize the dispatch of patients and ambulances based on the triage, casualty information, and available facilities. In the survey, paramedics expressed difficulty in triaging especially in a disaster scene (48.7 percent of agreement in P24) and this severity scoring is important for determining the best hospital. In P16, paramedics experienced difficulty in determining best hospital to deliver patients. Decision support systems can apply algorithms that match patients' condition to an index of symptom severities [13]. Technology for triage tagging utilizes beacon sensors, radio-frequency identification (RFID) tags, or barcode stripes to send triage data from the scene to EMS managers and hospitals [14]. The dispatching algorithm then schedules the delivery of patients to the appropriate receiving facilities. The necessity of intelligent dispatching algorithm utilizing information of patient condition, capacity of hospitals and mass casualties in the disaster was also investigated in our survey (82.3 percent agreement in P17 and 92 percent agreement in P18). Therefore, the management system for disaster or contagious diseases must provide an efficient method to track each patient and ambulance. Without tracking capabilities, a broad area or the entire hospital can be blocked when a patient is infected by a contagious disease. Such tracking also enables adjustment of care pathways and workflows efficiently [15], even in the hospital, because scheduling multiple patients to the restricted ER facilities is a complex decision that should consider each patient's triage, suggested golden time, available facilities, and expected waiting time [16].

E. LIFE MONITORING IN EMS

IoT-supported healthcare empowers people with value-based solutions to deliver effective care and manage the health of individuals with optimized performance. Lifelogging is also a major part of patient-centered medicine, by connecting heterogeneous medical devices or wearable devices into an IoT platform and analyzing patterns in daily healthcare. Researchers investigated the use of healthcare devices to monitor human physiological changes, by recording daily measurements during various activities and diagnosing personalized circadian differences based on the analysis of logged data [17]. In [18], a resource-based data-accessing method was introduced to acquire and process IoT data ubiquitously, which provided support to EMS.

Life monitoring for EMS includes not only recording physiological signals using medical equipment or wearable devices, but also monitoring circumstances. The utility of such life monitoring extends beyond EMS to the entire care process, which can be elaborated if paramedics and medical staff have information about the patient's home situation, the safety of the surroundings, and other contributing factors [5].

IV. IMPLEMENTATION OF SMART EMERGENCY MEDICAL SERVICES

We designed and implemented key functions of EMS as a National Fire Agency-funded smart emergency medical service (SEMS) system, which provides supportive EMS information management in connected care environments. We applied the concept described in the previous section to the SEMS with the following features as shown in Fig.2: (1) integration of current emergency information (EMS monitoring broker in Fig.2); (2) easy access to health trajectories (health trajectory broker in Fig.2); (3) real-time information sharing (real-time EMS sharing broker in Fig.2); and (4) standardized device-to- device communications.

A. INFORMATION COLLECTION AND SHARING WITH INTEGRATION BROKERS

For collecting current emergency information, SEMS provides an event-tracking service and bio-signal monitoring.

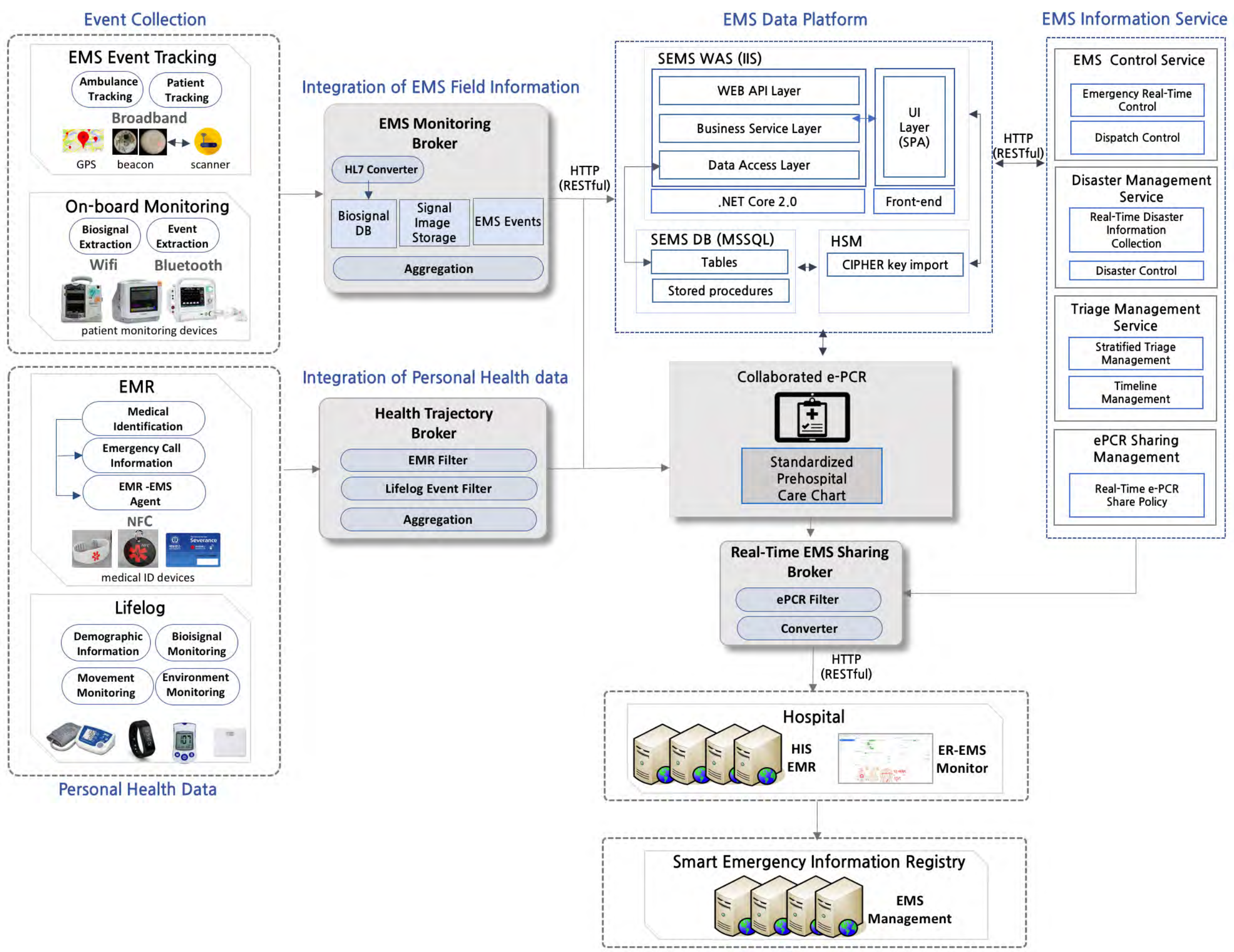

FIGURE 2. SEMS architecture.

EMS event tracking collects signals from beacon sensors embedded in triage tags or attached on ambulances. The bio-signal integration broker converts signals from various onboard monitoring devices to the HL7 (Health Level 7) standard format, then aggregates the converted data with signal images for delivery into ePCRs.

Medical trajectories include EMR and lifelog information, which refers to historical health condition. First, SEMS utilizes a tagging tool, Lifetag, that acts as emergency medical identification, to provide a personal EMR profile for emergency from the hospital information system of Severance Hospital, Yonsei Medical Center [19]. Lifetag facilitates the information management of paramedics, by referring the current health status of people in need through the NFC communication between paramedics' smartphones and medical identification, which is embedded in name cards, necklaces, wristbands, and sticker-type attachments to smartphones. This invented medical emergency ID devices extract major EMR information, including allergies, medication, surgery history, cancer, cerebrovascular disease, cardiac disease, and tuberculosis. The information is updated midnight daily to maintain the EMR for emergencies. The ePCR integration broker aggregates this EMR information and lifelog data into ePCR records as standardized pre-hospital care information.

The third broker facilitates real-time sharing of EMS information with hospitals and national emergency agencies. The ER-EMS monitor provides access to filtered information of SEMS ePCR data essential for fast initiation of treatment, which includes initial triage and measurement of vital signs.

TABLE 3. Overview of ihe pcd domain profiles.

Profiles	Description
[DEC]	Device Enterprise Communication: Publication of information acquired from point-of-care medical devices to applications using a consistent messaging format and device semantic content
[ACM]	Alert Communication Management: Remote communication of point-of-care medical device alert conditions
[DEC-SPD]	Subscribe to Patient Data: Filtering mechanism using a publish / subscribe to negotiate what device data they receive based on a set of client-specified predicates
[IDCO]	Implantable Device Cardiac Observation: Specification of creation, transmission, and processing of discrete data elements and report attachments associated with cardiac observations
[IPEC]	Infusion Pump Event Communication: Infusion system with logging of the whole history of an infusion operation.
[PIV]	Point-of-care Infusion Verification: Communication of validated medication delivery / infusion order
[POI]	Pulse Oximetry Integration: Usage the existing DEC and PCD-01 transaction to exchange pulse oximetry observation sets with clinical information systems
[RDQ]	Retrospective Data Query: Patient specific, user-initiated queries of retrospective data stores of clinical data (i.e., retrospective data)

B. INTEROPERABILITY FOR DEVICE-TO-DEVICE COMMUNICATION BROKERS

SEMS records are composed from the cooperation of several heterogeneous distributed systems. To validate the connection between SEMS components in Fig. 2, we utilized Integrated Health Enterprise (IHE) architecture infrastructure which helps ensure semantic and functional interoperability between distributed systems [20]. A specification created by the IHE development process shows methods to apply existing standards including HL7 and DICOM to a particular clinical information management. Integration profiles specifies requirements and use cases in each domain by actors and transactions. We built SEMS to allow interoperation between devices and systems which can be described by IHE Patient Care Device (PCD) domain's activities that are profiled shown in Table 3. We demonstrated SEMS interoperability by IHE PCD test in IHE connectathon [21], and Fig. 3 shows its message flow from patient monitoring devices to HIS.

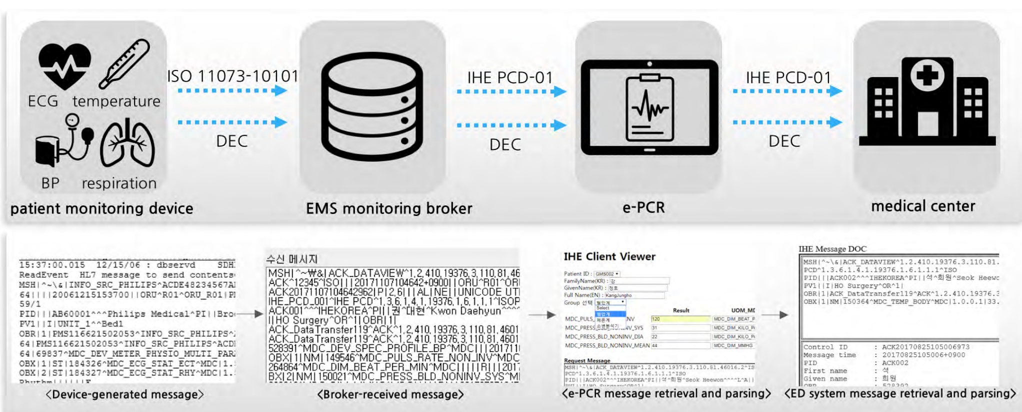

FIGURE 3. IHE test of interoperability of SEMS.

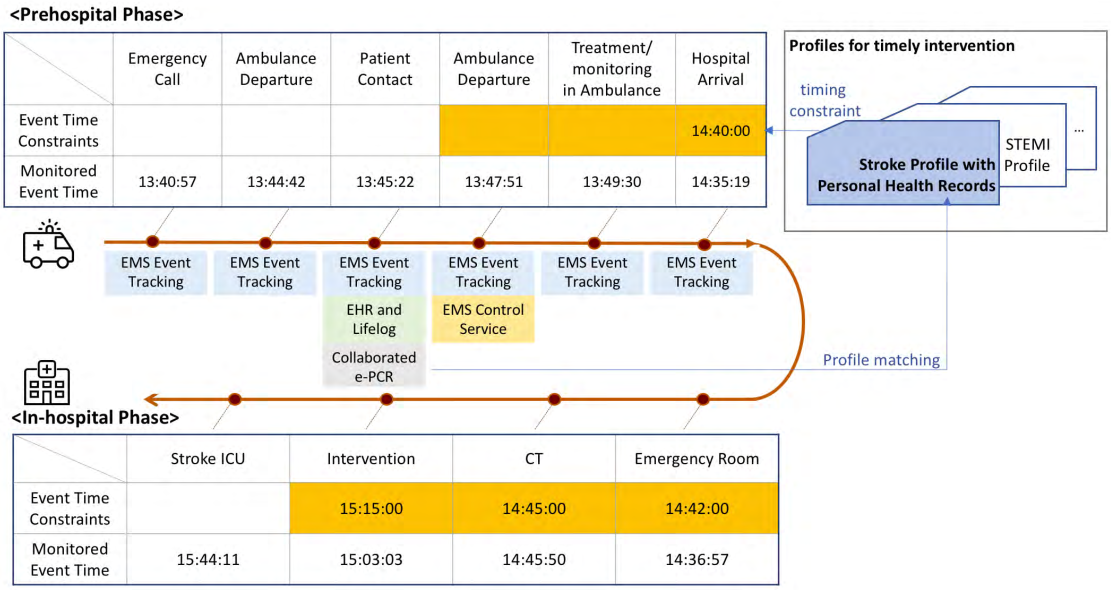

FIGURE 4. Event schedule of time-critical treatment for stroke patients in SEMS.

C. USE CASE: MONITORING STROKE PATIENTS AND CONNECTED EMS MANAGEMENT

Time-dependent treatments include percutaneous cardiac intervention (PCI) for cardiac events and thrombolytic treatment for acute stroke patients are beneficial only when performed in golden time that is known as 3 or 4 hours after onset. This timing constraint motivates pervasive monitoring to rapidly detect symptoms. Therefore, we developed a smartphone application that aids stroke patients to monitor their arm weakness [22]. The accelerator embedded smart phones or wristband can detect unintentional arm drift and the screening tool can initiate emergency procedure with symptom information [23]. As an activation protocol for stroke, FAST (Facial palsy, Arm weakness, Speech deficiency, and Time) is known as a de facto standard to initiate personal emergency procedure. Therefore, monitoring of abnormal movement captured by mobile devices can be transferred to EMS system and may also decrease hospital arrival time. The information of symptoms on face, arm, and speech can be automatically delivered to e- PCR with onset time through health trajectory broker which aggregates and filter for ePCR recording. These devices are the virtual medical point of contact and must be able to rapidly and accurately identify stroke and transport these patients to the appropriate facilities for treatment. There are many conditions that have similar presentations to stroke and can be mistakenly identified as potential strokes, thereby affecting the initial prehospital triage and transport to appropriate health care facility [24]. Thus, SEMS requires more credible data than a general user-reported data, and this data is almost identical to the primary information in a hospital's EMR system. For example, if a patient who has lifetag that is an EMR-referencing device in SEMS [19], the triage supporter can provide helpful information that 'possible recurrent stroke patient', utilizing his medical history and smart lifelogging tool [22]. Then, SEMS dynamically adjusts the timeline for the EMS activity and patient treatment as stroke profile described, and finally contributes to 'onset-to-door' time and 'onset-to-needle' time that are QoS (quality of service) factors in EMS (Fig. 4).

In the personalized timeline management in SEMS, monitored event time is recorded by patient tracking process utilizing beacon sensors and scanners. The patient tracking is efficient not only for personalized care but also in disaster management or infection control in the hospital. Disaster scene or hospital ED is crowded with diversely triaged patients. SEMS can support ER management to control crowding in each area by collecting and analyzing broadcasted beacon signals. This functionality of personalized tracking with area management is also essential to prevent the spread of infectious disease.

V. CONCLUSION

Life monitoring and connected care environment accelerate smart EMS by leveraging information of current patient condition and medical trajectory. Fast improving technology has facilitated seamless interoperation and integration between sensors, medical records, patient monitoring devices and heterogeneous systems in EMS and hospitals. Observing requirement in EMS, we implemented a smart EMS system integrating contexts in emergency fields into connected care environments reflecting demands of paramedics who proposed to utilize technology to reduce burden of recording and transmitting information. Autonomous collecting, integrating and sharing EMS based on personal profiles enhance emergency activities of paramedics on emergency scene and clinicians in ER, resulting in increased survival rate. We plan to investigate the effect of such composition of personal health records and continuous monitoring in prehospital stage on precision medicine for personalized treatment, especially for predicting treatment outcomes of emergency patients.

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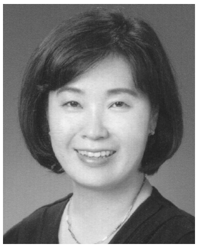

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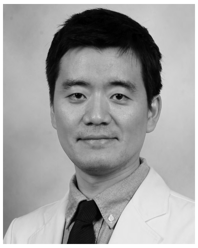

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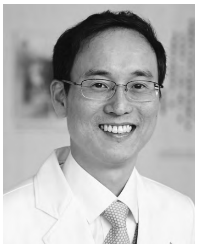

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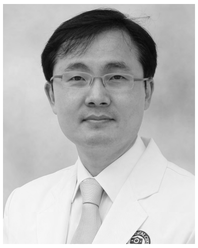

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