Towards improving situation awareness during emergency transportation through Ambulance-2-X communication and semantic stream reasoning

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Abstract— **With the recent introduction of the eCall system, the cars involved in accidents exchange relevant information directly with the emergency healthcare services. For road safety, Vehicular Ad-hoc Networks can be used to exchange safety information between cars and ambulances, via vehicle-2-x communication. In this paper, we exploit recent advances in vehicle-2-x communication and the advantages of knowledge representation and reasoning in order to deploy cooperative communication for medical emergency services. The developed system continuously matches data retrieved from inter-vehicular communication with structured knowledge from vehicular ontologies and open street maps.**

Keywords— **emergency medical services, Car-2-X communication, stream reasoning, semantic web**

I. Introduction

With the adoption by the European Commission of the directive ensuring that, by October 2015, cars will automatically call emergency services in case of serious accident. The "eCall" system automatically dials 112 and communicates the vehicle's location to emergency services. From the technical viewpoint, the eCall system introduces some challenges, but also many opportunities to employ emerging technologies (like vehicular communication) for emergency healthcare services.

Vehicular Ad-hoc Networks (VANETs) use vehicles as mobile nodes able to self-configure in order to create a communication network. In VANETs, cars are able to employ secure and reliable communication to ensure innovative intelligent transport systems. For emergency services and road safety, VANETS can be used to exchange safety information between cars and ambulances, via vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, without being restricted by weather conditions or distance [1].

Vehicle-2-X technology has just solved low level aspects with respect to ad-hoc networks or regulatory norms and standards. Thus, much work remains at the application layer, to seamlessly integrate the newly developed services. In this paper we exploit the advances in *knowledge representation and reasoning* to deploy cooperative communication for medical emergency services. Our solution aims to increase situation awareness of the vehicles closed to the ambulance, thus increasing safeness during medical emergency services. The emergency vehicle moving to a crash site will take advantage of the VANET infrastructure to establish the fastest route, to communicate with the vehicles in the path to ensure a clear route, and also to maintain a permanent connection with the hospital and the damaged vehicle.

II. Enacted technologies

A. Description logics

In the description logic $\mathcal{ALC}$, concepts are built using the set of constructors formed by negation, conjunction, disjunction, value restriction, and existential restriction [2], as shown in table 1. Here, C and D represent concept descriptions, while r is a role name. The semantics is defined based on an interpretation $I = (\Delta^I, \cdot^I)$, where the domain Δ^I of I contains a non-empty set of individuals, and the interpretation function $\cdot^I$ maps each concept name C to a set of individuals $C^I \in \Delta^I$ and each role r to a binary relation $r^I \in \Delta^I \times \Delta^I$. The last column of table 1 shows the extension of $\cdot^I$ for non-atomic concepts.

Definition 1. *A concept C is satisfied if there exists an interpretation I such that $C^I \neq \emptyset$. The concept D subsumes the concept C, represented by (implies C D) if $C^I \subseteq D^I$ for all interpretations I.*

Definition 2. *An assertional box ABox is a finite set of concept assertions (instance a C) or role assertions (re-*

Constructor	Syntax	Semantics
negation	(not C)	$\Delta^I \setminus C^I$
conjunction	(and C D)	$C^I \cap D^I$
disjunction	(or C D)	$C^I \cup D^I$
existential restriction	(some r C)	$\{x \in \Delta^I \mid \exists y : (x,y) \in r^I \wedge y \in C^I\}$
value restriction	(all r C)	$\{x \in \Delta^I \mid \forall y : (x,y) \in r^I \rightarrow y \in C^I\}$
individual assertion	(instance a C)	$\{a\} \in C^I$

Table 1: KRSS syntax and semantics of $\mathcal{ALC}$.

lated a b r), where C *designates a concept,* r *a role, and* a *and* b *are two individuals. Usually, the unique name assumption holds within the same* $ABox$*. A terminology* $TBox$ *is a finite set of terminological axioms of the forms (equiv C D) or (implies C D).*

Constraints on concepts (i.e. *disjoint*) or on roles (*domain*, *range*, *inverse* role, or *transitive* properties) can be specified in more expressive description logics[1].

B. Vehicle-2-X communication

Communication among vehicles relies on the Wireless Access in Vehicular Environments (WAVE) protocol and the IEEE 802.11p wireless standard. The WAVE architecture provides interoperable wireless V2V and V2Infrastructure (V2I) services. The IEEE 1609.1 details the management activities required for the proper operation of the applications, while IEEE 1609.3 describes the considerations to be taken into account for communication security. Two main message types are used to enable V2X communication [4]: periodic messages and event-driven messages. A vehicle advertises its current status to other vehicles, for example, vehicle position, speed, direction of travel by sending periodic messages in the network. Event-driven messages are described as emergency messages sent to other vehicles if hazardous situations are detected.

Geocast ad hoc routing protocol is introduced as the core networking protocol for vehicular communication based on IEEE 802.11 technology promoted by the Car-to-Car Communication Consortium (C2C-CC) in Europe [5]. Geocast protocol presumes that vehicles have information regarding their geographic location position by use of GPS or other positioning system. The three key components of Geocast protocol are beaconing, location service and forwarding. Beaconing allows nodes to continuously and periodically broadcast information to all neighbors in the reception range, to permit cooperative awareness. The location service can map a node's ID to its geographical position. Forwarding enables relaying data through VANET network to a certain destination, using GeoUnicast - provides data delivery between two nodes via multiple wireless hops, or GeoBroadcast - distributes data packets by flooding, where nodes rebroadcast the packets if they are located in the geographical region determined by the packets.

[1]We provide only some basic terminologies of description logics in this paper to make it self-contained. For a detailed explanation about families of description logics, the reader is referred to [3].

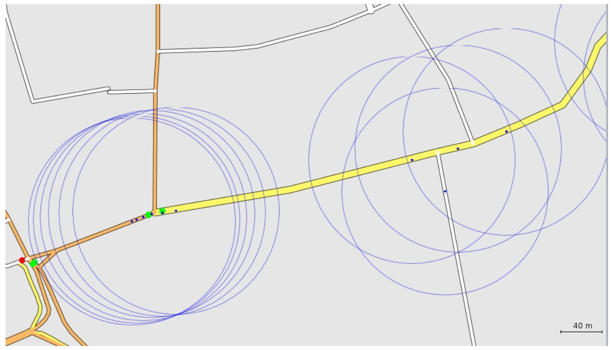

Fig. 1: Simulating an eCall on Ion Creanga street.

III. Event recognition

Our illustrative scenario simulates an eCall triggered by a car accident that took place on the IonCreanga street in Cluj-Napoca, with the ambulance approaching from the Republicii street (see Fig. 1. The vehicles communicate within a range of 200 meters. The following subsections describe: i) how the communication between vehicles was designed; ii) how domain knowledge is represented within the emergency vehicle; iii) how the emergency vehicle continuously reason on the data available to recognize traffic events; respectively iv) which queries can be performed to increase situation awareness.

A. Communication protocol

For communication between vehicles, we employ reasoning in description logic on top of the above Geocast protocol to determine the location and status of the vehicles situated in the geographic area where the accident took place. By complementing the location table and the information from the periodically beaconing messages with domain knowledge, a vehicle is able to infer a wide range of information about an approaching ambulance:

(i) based on the node ID and the speed entries in the location table, the system can infer if the ambulance is moving or it is stationary;

(ii) based on the node ID, the geographical position, speed and heading entries in the location table compared to vehicle data, the system infers if an ambulance is approaching or it is in the rear/front, or if the ambulance is traveling from the opposite direction;

(iii) if the beaconing signal includes lane information, than the system is able to detect lane-changing of the moving ambulance.

When the ambulance is approaching an accident, it sends GeoBroadcast signals enhanced with intended path/route information. The messages sent by the emergency vehicle are selected accordingly to the current situation and running events:

Stop	*Ambulance vehicle crossing!*
Drive right	*Ambulance vehicle in oncoming traffic!*
Drive right	*Ambulance vehicle overtaking!*
Form corridor	*Ambulance vehicle approaching!*

B. Domain knowledge

To facilitate situation awareness, we empower the vehicular agents with several knowledge sources.

Firstly, they rely on various *vehicular ontologies*, as the one exemplified in Fig. 2. The ontology consists of the tbox *emergency-vehicles* (line 1), which defines the main concepts and relationships among them. The relationship *on-same-street* has the inverse role *on-same-street*. Both roles relate individuals of type vehicle with instances of the same type. Buses and emergency vehicles are subsumed by the more generic concept *vehicle* (lines 3 and 4). If a vehicle is identified as a *bus*, it cannot be interpreted as a emergency-vehicle in future instances of time, constrained by the disjoint property in line 6. In the abox *emergency-vehicles-cluj*, the ontology contains assertions about a particular situation, in which the bus $b1$ is in front of ambulance $a1$ (line 10). Based on axiom 2, both vehicular agents can deduce that $a1$ is on the same street with $b1$. Note that the domain and range restrictions of the *on-same-street* role are satisfied, because the system is aware that $b1$ and $a1$ are vehicles (from axioms 3, 4, and 5).

Secondly, street topology data was obtained using *OpenStreetMap*, which gives to vehicular agents the possibility to choose an area by its coordinates and to export it in RDF format.The RDF tuples include knowledge about the selected traffic area: the location of semaphores, number of lines, one way street, etc.

```
1.  (in-tbox emergency-vehicles)
2.  (define-primitive-role on-same-street
      :inverse om-same-street :domain vehicle :range vehicle)
3.  (implies bus vehicle)
4.  (implies emergency-vehicle vehicle)
5.  (implies ambulance emergency-vehicle)
6.  (disjoint bus emergency-vehicle)
7.  (in-abox emergency-vehicles-cluj)
8.  (instance a1 ambulance)
9.  (instance b1 bus)
10. (related b1 a1 on-same-street)
```

Fig. 2: Sample of the ontology in the emergency-vehicle domain.

Temporal predicate	Informal semantics
((move ?o) t_{start} t_{end}*)*	object *?o* is known to be moving between time t_{start} and time t_{end}
((approach ?o1 ?o2) t_{start} t_{end}*)*	*?o1* is approaching object *?o2* during the time interval $[t_{start}, t_{end}]$
((behind ?o1 ?o2) t_{start} t_{end}*)*	*?o1* is behind object *?o2* during the time interval $[t_{start}, t_{end}]$
((beside ?o1 ?o2) t_{start} t_{end}*)*	*?o1* is beside object *?o2* during the time interval $[t_{start}, t_{end}]$
((in-front-of ?o1 ?o2) t_{start} t_{end}*)*	*?o1* is beside object *?o2* during the time interval $[t_{start}, t_{end}]$

Table 2: Temporal predicates in vehicular streams.

C. Event recognition

Stream data received from the vehicular network triggers rules that assert volatile facts about the current situation. Assertions about vehicles are valid only within a certain time interval. The vehicles have to decide: i) if the ambulance approaces or not; or ii) if the ambulance comes from front or behind. The temporal assertions in table 2 have been used in model the above specifications.

The reasoning engine combines contiguous facts in a single temporal assertion. Given two assertions *((behind ?o1 ?o2* t_0 t_k*)* and *((behind ?o1 ?o2)* t_{k+1} t_n*)*, the merged information is stored as *((behind ?o1 ?o2)* t_0 t_n*)*. Assume the assertions in Fig. 3 have been stored. Ambulance $a1$ is moving between instance 5 and 60 (line 11), while bus $b1$ between 1 and 50 (line 12). Between time-steps 10 and 20, ambulance is approaching the bus (line 13). Both vehicular agents are aware that the $a1$ is approaching

```
11. (define-event-assertion ((move a1) 5 60))
12. (define-event-assertion ((move b1) 1 50))
13. (define-event-assertion ((approach a1 b1) 10 20))
14. (define-event-assertion ((behind a1 b1) 10 20))
15. (define-event-assertion ((beside a1 b1) 20 30))
16. (define-event-assertion ((in-front-of a1 b1) 30 60))
17. (define-event-assertion ((recede a1 b1) 30 40))
```

Fig. 3: Asserting primitive events from vehicular communication about the ambulance $a1$ and the bus $b1$.

```
21. (define-event-rule ((overtake ?obj1 ?obj2) ?t1 ?t2)
22.       ((?obj1 ambulance) ?t0 ?tn)
23.       ((?obj1 ?obj2 on-same-street) ?t0 ?tn)
24.       ((move ?obj1) ?t0 ?t2)
25.       ((move ?obj2) ?t1 ?t2)
26.       ((approach ?obj1 ?obj2) ?t1 ?t3)
27.       ((behind ?obj1 ?obj2) ?t1 ?t3)
28.       ((beside ?obj1 ?obj2) ?t3 ?t4)
29.       ((in-front-of ?obj1 ?obj2) ?t4 ?t2))
```

Fig. 4: Complex event recognition: identifying when the ambulance overtakes a vehicle.

```
select * {GEO SUBTYPE
          <prefix:/spherical/degrees/-180.0/180.0/-90.0/90.0/5.0>
          POLYGON (RESOURCE x:w7934417 ){?a ex:location ?b.}
          Where{}}
ORDER BY <prefix:/fn/haversineKilometers>(?o,POINT(23.58,46.76))
```

Fig. 5: SPARQL query for retrieving the vehicles on the street.

from behind of the bus (line 14). Between 20 and 30, the vehicles are beside each other, as identified in line 15. After time 30, ambulance is in front of the bus (line 16), while between 30 and 40 ambulance is moving away from b1 (line 40). These assertions are obtained reasoning on the data obtained from vehicular communication.

Rules on top of description logic are enacted to recognize complex events, as car overtaking event [6] in fig. 4. Here, primitive volatile facts from table 2 represent premises of the event rule.

D. Querying the vehicular network

To retrieve all the vehicles in the same street with the ambulance, the query in Fig. 5 is enacted. Here the street is modeled as a polygon. The role *on-same-street* is used to store the obtained answers (recall line 10 in Fig. 2). To check if the ambulance $a1$ overtakes the bus $b1$, the query q_1 is used: q_1: *(timenet-retrieve ((overtake a1 ?v) ?t1 ?t2))* From axiom 8 in Fig. 2, $a1$ satisfies precondition 22 of the overtaking rule. The precondition 23 is satisfied by the answers obtained from query in figure 5. The preconditions 24 to 29 are satisfied by the assertions in figure 3. Hence, the obtained answer *(((?obj2 b1) (?t1 (10 19)) (?t2 (31 50))))* confirms that the event overtake took place between the ambulance a1 and the identified vehicle $b1$. For time variables *?t1* and *?t2* an interval for the lower and upper-bound is returned [6]. The overtaking starts at t1=10 at the earliest and 19 at the latest. It ends at t2=29 at the earliest and 50 at the latest.

IV. Discussion and Related Work

Several studies in mobile telemedicine has concluded that patient survival during a health emergency situation [7] depends on the effective pre-hospital healthcare [8]. In order to achieve a complete system that covers all telemedicine elements, VANETs are seen as the missing link. V2V and V2I communication capabilities of VANET added to existing mobile telemedicine systems can ensure rapid intervention and thus patient survival. Combining V2X technology, communication, and semantic stream reasoning, we proposed an efficient method for telemedicine services. By facilitating different communication channels during ambulance transportation, we aimed at minimizing collision hazards and decreasing intervention time by inter-vehicular collaboration.

V. Conclusion

We proposed a method to increase situation awareness during emergency transportation of patients. Our approach combines semantic reasoning with the emerging Car-2-X technology. We employed reasoning in description logic on top of data collected continuously from vehicular communication. The developed system performs temporal reasoning on real topological maps imported from OpenStreetMap. Our approach is a step towards minimizing hazards during medical emergency services.

Conflict of Interest

The authors have no conflict of interest.

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