Towards a Robust Exchange of Imperfect Information in Inter-Vehicle Ad-Hoc Networks using Belief Functions

Mira Bou Farah*, David Mercier**, Éric Lefèvre** and François Delmotte**

***Abstract*— This paper introduces a system for exchanging and managing imperfect information about events in vehicular networks (VANET). Using belief functions, this model is developed through an application using smartphones.**

I. INTRODUCTION

In a world where vehicles are getting more and more predominant, safety issues are a major concern for public authorities and manufacturers. On the other hand, the integration of technology within the vehicles is skyrocketing. From break assistance to traffic information, the inter-vehicle communication becomes affordable.

The ad-hoc networks are able to get organized without infrastructure. Instead of communicating via a central access point, the ad-hoc networks are formed of wireless nodes communicating to exchange information. In mobility context, the ad-hoc networks are called Mobile Ad-Hoc Networks (MANET) [4]. Introduced by Hong [13] and Royer [19], a comparison between different algorithms is presented by Boukerche [1].

Vehicular Ad-Hoc Networks (VANET) are branch of MANET applied to Inter-Vehicle Communication (IVC) where nodes are highly dynamic. Two modes of communication are known in IVC: Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V). The present work concerns V2V communication where information are decentralized and vehicles build their own information assembly.

Many projects have been developed to make inter-vehicle communication theory possible in real life. In relation to network protocols, FleetNet (2000-2003) [11], [12] and CarTalk (2001-2004) [16], [18] projects use geographical positions for inter-vehicle communication, CarTalk project using no existing infrastructure. Focusing on data dissemination, TrafficView [17] is a road data dissemination system using V2V communication. It allows continuous exchange between vehicles of position and speed information, to inform drivers about road situation (traffic, weather, quickest way, ...). Concerning data management, Mobi-Dik [27], [28] project has the objective to build a low-bandwidth MANET database which self-manages. It consists on sort resources, choose and store only the most relevant information, and reduce propagation of information to a limited spatial zone and limited time interval.

In inter-vehicle networks, VESPA (Vehicular Event Sharing with a mobile P2P Architecture) [2], [5], [6] is a system that allows vehicles to share different types of information such as accidents or emergency brakings. It also guides in particular drivers to find a parking place or to get traffic information.

Drivers are usually unsure of the information they are communicating, in this case they either do not send the event or decide to send it in spite of its uncertainty. Besides, drivers can receive certain and uncertain pieces of information and treat them in the same way. To allow drivers to deal with imperfect information about events, a system using belief functions is presented in this paper.

Introduced by Dempster [8] and Shafer [21], belief functions constitute a rich and flexible framework to deal with uncertain and imprecise information. They have been already used in many domains [20] including real-life applications, for instance to identify automatically postal addresses [14] or to evaluate risk in water treatment [7].

In [3], Cherfaoui et al. have already introduced belief functions to manage uncertainties in vehicular networks but their work is limited to simulations. The model proposed in this paper is different and has been implemented and tested using Hong-Ta Corporation (HTC) smartphones. It mainly differs by the fact that vehicles are considered as being only equipped with communication systems, there are no common road maps shared by vehicles. In particular, unlike Cherfaoui's model, the proposed model allows events of the same type to be present on the same road segment, for instance: different accidents, different parking space, ... This choice implies the necessity to assure a procedure to determine identical events. Another different consideration lies in the choice of the events dissemination strategy. In the present application, each vehicle sends new events or repeats received one. A choice has been undertaken to keep combinations of messages in each vehicle and to not diffuse it, each driver making its own overview of the situation, the environment being not overloaded with partial fused messages.

This paper is organized as follows. Needed basic concepts on belief functions are recalled in Section II. A system for exchanging and managing imperfect information about events is introduced in Section III. An application using smartphones is then presented in Section IV. Finally, Section V concludes this paper.

II. BELIEF FUNCTIONS: BASIC CONCEPTS

In this paper, belief functions are handled with Smets' semantic approach: the Transferable Belief Model (TBM)

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[22], [24], where belief functions are interpreted as weighted opinions with no underlying probabilistic measure.

Two levels are distinguished in the TBM:

- the credal level, where available pieces of information are represented by belief functions, and manipulated;
- the pignistic or decision level, where belief functions are transformed into probability measures when a decision has to be made, and the expected utility is maximized.

A. Representing Information

Let us consider $\Omega = \{\omega_1, \omega_2, ..., \omega_k\}$, called *frame of discernment*, a finite set of possible answers to a given question of interest.

The knowledge regarding the answer to the question can be quantified by a basic belief assignment (BBA), also called a mass function, denoted m and verifying:

$$\begin{array}{rcccl} m & : & 2^\Omega & \rightarrow & [0,1] \\ & & A & \mapsto & m(A) \ , \end{array} \tag{1}$$

where 2^Ω is the set of all possible subsets of Ω, and such that the sum of the masses is equal to 1:

$$\sum_{A \subseteq \Omega} m(A) = 1 \ . \tag{2}$$

The quantity $m(A)$ represents the part of the belief allocated to the fact that the true answer to the question of interest belongs to A, in particular $m(\Omega)$ represents the degree of ignorance of the source which has provided information m.

Let us note that the mass on the empty set may be strictly positive. It represents a conflict, an alarm. Discussions on this point can be found in [26] and [15, Section 5].

Each subset A of Ω such that $m(A) > 0$ is called a *focal element* of m.

B. Manipulating Information

1) Discounting: When receiving information, represented by a mass function m, it is always possible to have some doubt regarding the reliability of the source which has provided this BBA. Such a metaknowledge can be taken into account by using the discounting operation [21, page 252] defined by:

$$\left\{ \begin{array}{rcl} {}^\alpha m(A) & = & (1-\alpha) m(A), \quad \forall A \subset \Omega, \\ {}^\alpha m(\Omega) & = & (1-\alpha) m(\Omega) + \alpha \ , \end{array} \right. \tag{3}$$

where $\alpha \in [0,1]$ is called the discount rate; coefficient $\beta = (1-\alpha)$ represents the degree of reliability regarding the information provided.

2) Conjunctive rule of combination: Two mass functions m_1 and m_2 obtained from distinct and reliable sources, can be combined using the conjunctive rule of combination noted $\bigcirc\!\!\!\!\cap$ and defined by:

$$\begin{aligned} m_1 \bigcirc\!\!\!\!\cap\, m_2(A) &= m_{1 \bigcirc\!\!\!\!\cap 2}(A) \\ &= \sum_{B \cap C = A} m_1(B) \cdot m_2(C) \ , \forall A \subseteq \Omega \ . \end{aligned} \tag{4}$$

With this combination, masses are transferred to focal elements intersections.

C. Making a decision

At this level, the mass function m defined on Ω which represents the available information regarding the answer to the question of interest (and resulting in practice from a fusion process) has then to be transformed into a probability measure. A solution [9] consists in computing the *pignistic probability* [25] defined by:

$$BetP^\Omega(\{\omega\}) = \sum_{\{A \subseteq \Omega, \omega \in A\}} \frac{m(A)}{|A| \ (1 - m(\emptyset))}, \quad \forall \omega \in \Omega. \tag{5}$$

III. A System For Exchanging and Managing Imperfect Information about Events

When vehicles detect an event on the road, the method proposed in this paper allows them to disseminate it with a certain confidence degree.

Different types of events can be considered such as accident, parking place, traffic-jam, fog blanket, animals on the road, accident, working area, dangerous vehicle, etc.

Vehicles are assumed equipped with Global Positioning System (GPS). Location and date of events are generated automatically once a driver source decides to broadcast a perceived event.

A. Exchanged Messages Representation

Vehicles exchange messages about events which can occurred on the road, each message giving information regarding one event.

A message M is represented as a 5-tuple (S, t, d, ℓ, m) described in Table I.

TABLE I
MESSAGE ATTRIBUTES

Attribute	Description
S	Source which has perceived the event
t	Type of the event
d	Date and Time when S has detected the event
ℓ	Location where S has detected the event
m	Mass function representing the confidence of S regarding the fact that the event is present

Consequently:

- $M.S$ designates the source of information S which have perceived the event. It is not necessarily the source which have transferred the message M.
- $M.t$ indicates the type t of the event reported by message M.
- $M.d$ points out the date d when S has detected the event. It is generally not the date at which message M has been received.
- $M.\ell$ indicates the location l of the event reported by message M.
- At last, $M.m$ denotes mass function m, held by vehicle source S, which is defined on the frame of discernment $\Omega = \{ev, \neg ev\}$ where:

- ev stands for "the event, which is of type t, is present at time d at location ℓ."
- and $\neg ev$ means "the event, which is of type t, is not present at time d at location ℓ."

B. Sending messages

As illustrated in Fig. 1, each vehicle V sends two kinds of message:

- new messages, the source of which being vehicle V. New messages are generated by the driver;
- and existing messages repeated by vehicle V; the source of these messages being vehicle V or another vehicle. Repeated messages are automatically broadcast without the intervention of the driver.

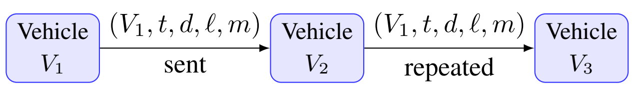

Fig. 1. Vehicle V_1 sending a new message repeated by vehicle V_2. Vehicles being on the move, vehicle V_1 may also receives the repeated message which is broadcast.

C. Determining an update

New messages concern either a new event, or an update of an event previously reported.

To determine updated messages, Algorithm 1 is used. Updates correspond to messages where the same source has broadcast the same event many times with only a different confidence, which means a different mass function m.

Algorithm 1 Determining an update

Require: Two messages $M_1 = (S_1, t_1, d_1, \ell_1, m_1)$ and $M_2 = (S_2, t_2, d_2, \ell_2, m_2)$. A distance Δ. A constant ϵ_t depending on the type t of event.
Ensure: True if M_1 refers to an update of message M_2, False otherwise.
begin
if $S_1 = S_2$ and $t_1 = t_2$ and $\Delta(\ell_1, \ell_2) < \epsilon_{t_1}$ and $d_1 > d_2$ **then**
  {The message M_1 is an update of M_2.}
  Return True
else
  Return False
end if
end

Vehicle takes into consideration only the newest version of received messages as exposed in the next section.

D. Grouping Messages associated with the Same Event

All messages received by a vehicle are stored in tables according to the event they concern.

Let us note M_i^j, each message M_i on event j. Table on event j is then noted M^j and contains messages M_i^j.

The proposed procedure to manage new received messages is defined by Algorithm 2. This procedure can be sum up in the following manner:

- First, it is checked if the received message is a new message or an update of a stored message;
- If not, the received message is introduced in the table of an event j such that it has the nearest particularities regarding the type, date and location (same type, close location, close date). Let us note that each table M^j concerns messages M_i^j of the same type t and corresponding to the same event j.
- If no stored message looks like the message received, a new table is created.

Algorithm 2 New Message Management

Require: A received message $M = (S, t, d, \ell, m)$.
Require: **(internal system)** Distances Δ, Δ'. Constants λ_t, λ'_t depending on the type t of event. A threshold ϵ_t also depending on the type t of event. Messages M_i^j.
Ensure: Treatment of M: either it is not considered, it replaces another message or it is inserted in an existing or a new event table M^j.
begin
if M is already present in one of the tables M^j **then**
  Do not consider M.
else if M is an update of a message M_i^j **then**
  Replace M_i^j by M.
else
  {Even if M is not found in any event table M^j, it can concern an event j already created. To verify this: find M_i^j having the same type of M and being the closest to location and date of M. If the distance d_i^j is sufficiently low, M corresponds to the event M^j.}
  $d_i^j \leftarrow min_{M^j.t=t}(\lambda_t \cdot \Delta(d, M_i^j.d) + \lambda'_t \cdot \Delta'(\ell, M_i^j.\ell))$
  if $d_i^j < \epsilon_t$ **then**
    Insert M in table M^j.
  else
    {A new event has been detected.}
    Create a new table $M^{j'}$ containing M.
  end if
end if
end

E. Deleting Useless Messages

With the time, all messages stored in tables are not necessarily useful: some of them become obsolete, others situated too far from the driver are no more useful for him/her.

Then, in parallel with the new messages treatment, a procedure allows the system to take into account the utility to keep messages.

This procedure consists in deleting too old messages and events located too far from the vehicle. Formally, it suppresses all messages M_i^j such that:

$$\lambda_{M_i^j.t} \cdot \Delta(d, M_i^j.d) + \lambda'_{M_i^j.t} \cdot \Delta'(\ell, M_i^j.\ell) > \gamma_t \qquad (6)$$

where d is the current date, ℓ is the current location of the vehicle, Δ and Δ' are distances, and λ_t, λ'_t and γ_t are constants depending on the type t of the event.

F. Data Fusion: giving an overview of the situation to the driver

With the use of belief functions, an overview of the situation regarding each event can be given to the driver such that each event is associated with a degree of confidence.

The degree of confidence on each event j is obtained from each message present in table M^j, more precisely, from each mass function of each message M_i^j, mass functions of each message M_i^j being combined in the following manner.

- First, each mass function $M_i^j.m$ is discounted with a discount rate $\alpha_i = \lambda_{M_i^j.t} \cdot \Delta(d, M_i^j.d)$ to take into account the ageing of the message. The older the message is, the more discounted it is. Let us recall that too old messages have been already discarded by the process exposed in Section III-E.
- Then, for each event j, discounted mass functions ${}^{\alpha_i}M_i^j.m$ are conjunctively combined using (4).
- At last, pignistic probabilities (5) regarding each event presence are given.

An overview of the whole proposed system is given in Fig. 2.

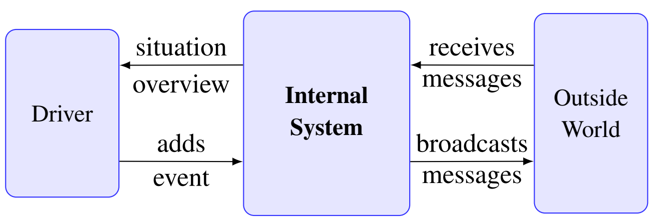

Fig. 2. General flowchart of the model. The internal system manages new messages, repeats messages which have still an interest, deletes useless one, and offers an overview at driver's request.

IV. APPLICATION

The model exposed in this paper has been implemented and tested using Hong-Ta Corporation (HTC) smartphones.

HTC is a Taiwan-based manufacturer making smartphones based primarily on Microsoft's Windows Mobile, Android or Microsoft's Windows Phone 7 operating systems.

The implementation of the model has been realized by extending a VESPA [2], [5], [6] platform, an application which consists in sending and receiving two types of events: parking place and working area, only one event being received at the same time.

VESPA application is developed and embarked in HTC Touch Diamond mobiles, also known as HTC P3700. It is portable to every other Windows Mobile 6.1-powered Pocket PC device, communicating via Wi-Fi in ad-hoc network mode, and equipped with GPS in order to communicate their locations.

The proposed application homepage, illustrated in Fig. 3, allows users to send messages (S,t,d,ℓ,m) as follows.

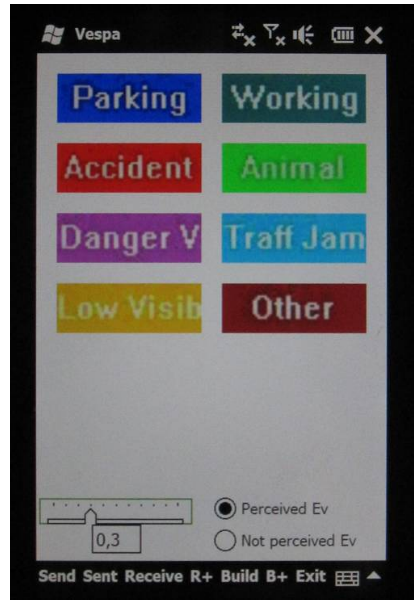

Fig. 3. Application Homepage

- Source S is the International Mobile Equipment Identity (IMEI), a unique mobile identifier automatically generated by the program.
- Type t of the event is chosen by the user. Eight different types of events are proposed: parking place, accident, animal on the road, working area, dangerous vehicle, traffic jam, low visibility, other.
- Date d is generated automatically when the user sends the message.
- Location ℓ is generated automatically using user's GPS coordinates when the user sends the message.
- Using the cursor, illustrated in Fig. 3, the user can fill in the ignorance degree $m(\Omega)$. As the two possible answers are ev and $\neg ev$, by the use of a radio button user chooses ev if he perceived the event, or $\neg ev$ if he wants to point out there is not an event. The mass function is then computed as follows:
  - if the user chooses ev, the obtained mass function is defined as $m(\{ev\}) = 1 - m(\Omega)$;
  - else, the user chooses $\neg ev$, and $m(\{\neg ev\}) = 1 - m(\Omega)$.

Messages sent are broadcast to all other HTC connected to the same Wi-Fi ad-hoc network.

At any time users can ask for an overview of the events using a *build* button present at the bottom of the homepage (Fig. 3).

Hereinafter, an example using major features of the proposed method and showing its interest is detailed.

A user S_1 sends a message M_1 informing the others about an accident event (Fig. 3):

- He/she perceives the accident, so he/she chooses ev by use of a radio button in the graphical user interface;
- He/she assigns an ignorance degree of 0.3 to the message by use of a track bar;

- He/she chooses the $accident$ type and sends the message.

Three other users S_2, S_3, and S_4 perceive an accident in the same area at the same time period. They send information (messages M_2, M_3, and M_4 respectively) assigning an ignorance degree of 0.4, 0.5 and 0.2 respectively.

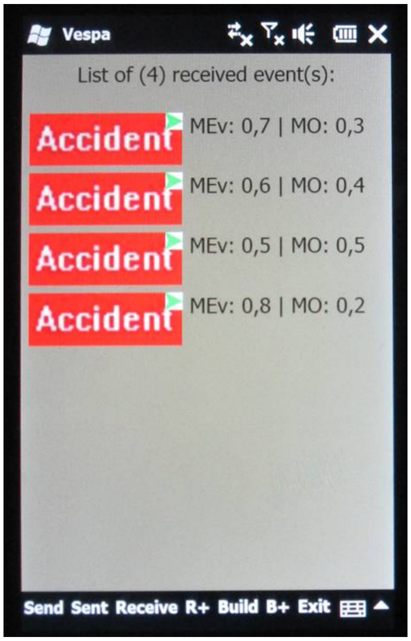

Fig. 4. Reception of messages M_1, M_2, M_3 and M_4. MEv being the mass on the event, MO the mass on Omega.

Fig. 5. Fusion of messages M_1, M_2, M_3 and M_4. MEv being the mass supporting the presence of the event, $MNEv$ the mass on the fact that the events is not present, MO the mass on the ignorance.

TABLE II
COMBINATION OF MASS FUNCTIONS m_i FROM MESSAGES M_i, $i \in \{1, 2, 3, 4\}$

	m_1	m_2	m_3	m_4	$m_{1 \bigcirc\!\!\!\!\cap\, 2 \bigcirc\!\!\!\!\cap\, 3 \bigcirc\!\!\!\!\cap\, 4}$	$BetP$
$\emptyset$	0	0	0	0	0	
$\{ev\}$	0.7	0.6	0.5	0.8	0.988	0.994
$\{\neg ev\}$	0	0	0	0	0	0.006
Ω	0.3	0.4	0.5	0.2	0.012	

Receivers of messages M_i, $i \in \{1, 2, 3, 4\}$, (Fig. 4) can reach to build information (Fig. 5) computed by the program. Following Algorithm 2, messages have been identified as referring to the same accident event, then their mass functions have been combined using the conjunctive rule of combination (cf Section III-F). Results of this combination is exposed in Table II. Receivers obtain a mass function with a high confidence degree of 0.988 in the event, and a low ignorance degree, with no conflict.

Few minutes later, user S_1 does not see the accident event any more. He reaches his disseminated messages, chooses $\neg ev$ instead of ev, assigns a new ignorance degree of 0.2, and sends the event information again. The new message, noted M_1', contains the same attributes of M_1 except the mass function m.

TABLE III
COMBINATION OF MASS FUNCTIONS m_i FROM MESSAGES M_i, $i \in \{1', 2, 3, 4\}$.

	$m_{1'}$	${}^{\alpha_2}m_2$	${}^{\alpha_3}m_3$	${}^{\alpha_4}m_4$	$m_{1' \bigcirc\!\!\!\!\cap\, 2 \bigcirc\!\!\!\!\cap\, 3 \bigcirc\!\!\!\!\cap\, 4}$	$BetP$
$\emptyset$	0	0	0	0	0.862	
$\{ev\}$	0	0.48	0.4	0.64	0.026	0.268
$\{\neg ev\}$	0.8	0	0	0	0.090	0.732
Ω	0.2	0.52	0.6	0.36	0.022	

HTC mobiles receiving both messages M_1 and M_1' take only the new message M_1' into consideration which has the latest transmission date, message M_1 being deleted (cf Algorithm 1 and Algorithm 2). As exposed in Section III-F, messages M_2, M_3 and M_4 being now older, their mass functions are more discounted, let us consider a 80% discounting for each message. Table III exposes the combination result of these messages mass functions. Receivers obtain a mass function with a greater confidence degree in $\neg ev$, the conflict reflecting the contradiction between messages. In this situation, a bet in favour of $\neg ev$ is recommended as expressed by the pignistic probability $BetP$.

V. CONCLUSIONS AND FUTURE WORKS

In this paper, a method has been proposed to manage uncertain events in vehicular ad-hoc networks. It considers messages corresponding to the same event, and helps drivers making a decision by combining received information using belief functions.

This method has been developed in a mobile application considering different types of events. Mobile can be fixed in vehicle using mount kit, to allow drivers to share road events such as accidents or traffic jam. It can also be used by pedestrians to share other kind of events such as bag snatcher or long entrance queue. Numerous developments remain, however this application has already demonstrated its interest.

Uncertainty of events grows with event oldness and distance separating vehicle from event. The proposed system specifies a threshold above which the event is no longer considered.

Besides, an event can generate another type of event, for example an accident can generate a traffic jam. In future work, the link between events has to be taken into consideration.

Likewise the presence or not of an event can be too restrictive. For example, a traffic jam can either be red, orange or green. Then it might be interesting to consider more than two states in the frame of discernment for some types of event.

At last, this developed application is still at the prototype stage. The main purpose of this work is to consider a model for managing the imperfection of the events; a marketable application deserves of course to be developed, the graphical interface having in particular to be improved to better meet users' requirements. Camera or sensors might also be installed in vehicles in such a way to automatically detect events, without driver assistance.

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