

# A Proof-theoretic Trust and Reputation Model for VANET

Giuseppe Primiero, Franco Raimondi, Taolue Chen and Rajagopal Nagarajan

Department of Computer Science  
Middlesex University, London  
[www.cs.mdx.ac.uk/people/giuseppe-primiero/](http://www.cs.mdx.ac.uk/people/giuseppe-primiero/)



Middlesex  
University

parigi

# Vehicular Ad Hoc Networks (VANETs)

- vehicles and roadside unit networks created to enhance transportation systems
- vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications
- services include:
  - ▶ vehicle and road safety services
  - ▶ traffic efficiency and management services
  - ▶ information and entertainment services.

Trust to ensure integrity, reliability and safety of services.

- entity-centric trust [9, 4]
- data-centric [12, 8]
- combined [16].
- overview of trust in fixed and mobile ad hoc networks [17],

- [15]: offers an analysis as a characteristic of message forwarding among vehicles, drivers and other agents:
- other approaches in [3, 2].

# Current Approaches to Verification

- simulations cannot guarantee the absence of unpredictable and unsafe behaviours
- exhaustive safety control is through formal verification
- Formal approaches to VANET include
  - ▶ [6] for verification of a congestion control protocol using PRISM
  - ▶ verification of privacy and authentication using the AVISPA tool in [1];
  - ▶ verification of the TESLA authentication protocol [5] using Petri nets.
- theorem proving ignored so far

# Objectives

- ① proof-theoretic translation of the trust and reputation model for VANET given in [15]
- ② identify non-trustworthy relations through a proof-checking method
- ③ calculus formally correct through translation to a Coq library.
- ④ transitive message passing operations are guaranteed safe
- ⑤ protocols for handshaking, recipient selection and message passing based on reputation

# The Language

## Definition (Syntax of (un)SecureND)

$$\mathcal{A}^{\prec} := \{\mathcal{V}, \mathcal{R}\}$$

$$\mathcal{V} := \{v_1 \prec \dots \prec v_n\}$$

$$\mathcal{R} := \{rsu_1 \prec \dots \prec rsu_m\}$$

$$\mathcal{S} := \{S_1, \dots, S_n\}$$

$$\mathcal{C} := \{C_{\vec{n}}^{S_1}, \dots, C_{\vec{n}}^{S_n}\}$$

$$\begin{aligned} \phi_{C_j}^{\mathcal{A}_{S_i}} := & a_{C_j}^{\mathcal{A}_{S_i}} \mid \neg \phi_{i,j}^{\mathcal{A}} \mid \phi_{i,j}^{\mathcal{A}} \rightarrow \phi_{k,l}^{\mathcal{A}} \mid \phi_{i,j}^{\mathcal{A}} \wedge \phi_{k,l}^{\mathcal{A}} \\ & \mid \phi_{i,j}^{\mathcal{A}} \vee \phi_{k,l}^{\mathcal{A}} \mid \perp \mid \text{Read}(\phi_{C_j}^{\mathcal{A}_{S_i}}) \mid \\ & \text{Write}(\phi_{C_j}^{\mathcal{A}_{S_i}}) \mid \text{Trust}(\phi_{C_j}^{\mathcal{A}_{S_i}}) \end{aligned}$$

$$\Gamma^{\mathcal{A}} := \phi_{i,j}^{\mathcal{A}} \mid \phi_{i,j}^{\mathcal{A}} < \phi_{k,l}^{\mathcal{A}} \mid \Gamma^{\mathcal{A}}; \phi_{i,j}^{\mathcal{A}}$$

# Examples

*A vehicle profile  $\Gamma^{v_i}$  receives a message  $\phi_{j,k}$  about service  $S_j = \text{weather}$  and characteristic  $C_k = \text{temperature}$  stating  $\phi = (\text{temp} \geq 5^\circ \text{C})$ .*

*under the service weather,  $C_k = \text{humidity}$  and  $C_l = \text{precipitation} - \text{forecast}$ , where the former characteristic is essential to determine the latter.*



## Definition (Judgements)

A judgement  $\Gamma^{v_l} \vdash_s \phi_{i,k}^{v_j}$  states that a message  $\phi$  about service  $i$  and characteristic  $k$  signed from agent  $v_j$  is validly accessed at step  $s \geq 0$  under the profile of agent  $v_l$ .

$$\frac{\Gamma^{v_i} \vdash_s \neg \mathcal{O}(\psi_{i,l}^{v_j})}{\Gamma^{v_i} \vdash_{s+1} \mathcal{O}(\neg \psi_{i,l}^{v_j})} \quad \mathcal{O} \in \{Read, Trust, Write\}, \neg\text{-distribution}$$

$$\frac{}{\Gamma^{v_i} \vdash_s Read(\psi_{i,l}^{v_j})} \text{ read}$$

$$\frac{\Gamma^{v_i} \vdash_s Read(\psi_{i,l}^{v_j}) \quad \Gamma^{v_i}; \psi_{i,l}^{v_j} : \text{profile}}{\Gamma^{v_i} \vdash_{s+1} Trust(\psi_{i,l}^{v_j})} \text{ trust}$$

$$\frac{\Gamma^{v_i} \vdash_s Read(\psi_{i,l}^{v_j}) \quad \Gamma^{v_i} \vdash_{s'} Trust(\psi_{i,l}^{v_j})}{\Gamma^{v_i} \vdash_{s'+1} Write(\psi_{i,l}^{v_j})} \text{ write}$$

$$\frac{\Gamma^{v_i} \vdash_s Write(\psi_{i,l}^{v_j})}{\Gamma^{v_i} \vdash_{s+1} \psi_{i,l}^{v_j}} \text{ exec}$$

# Checking for inconsistent messages

$$\frac{\Gamma^{v_i} \vdash_s \text{Read}(\psi_{i,l}^{v_j}) \rightarrow \perp \quad \Gamma^{v_i} \setminus \{\neg\psi_{i,l}^{v_i}\} : \text{profile}}{\Gamma^{v_i} \setminus \{\neg\psi_{i,l}^{v_i}\} \vdash_{s+1} \neg \text{Trust}(\neg\psi_{i,l}^{v_i})} \text{MTrust-I}$$

# Accepting new (inconsistent) information

$$\frac{\Gamma^{v_i} \setminus \{\neg\psi_{i,l}^{v_i}\} \vdash_s \neg \text{Trust}(\neg\psi_{i,l}^{v_i}) \quad \Gamma^{v_k}; \psi_{i,j}^{v_j} : \text{profile}}{\Gamma^{v_i} \setminus \{\neg\psi_{i,l}^{v_i}\}; \Gamma^{v_k} \vdash_{s+1} \text{Trust}(\psi_{i,l}^{v_j})} \text{MTrust-E, } \forall v_k \prec v_j$$

# Opportunistic Forwarding

PROCEDURE OpportunisticForwarding( $v_i, v_j$ )

```
IF  $v_i$  Write(HELLO)
  THEN forall [ $v_k \in \mathcal{A} \mid v_k$  Write(HELLO)],
  SELECT  $\min(v_k, \prec)$ 
  DO Handshaking( $v_i, v_k$ )
ENDIF
```

```
IF Handshaking( $v_i, v_k$ )
  THEN  $v_i$  Write( $\phi_{i,k}$ ) AND  $v_k$  Read( $\phi_{i,k}$ )
  IF  $v_k$  Trust( $\phi_{i,k}$ )
    THEN  $v_k$  Write( $\phi_{i,k}$ )
  ELSE  $v_k \neg$ Trust( $\phi_{i,k}$ )
  ENDIFELSE
  IF forall  $v_i \prec v_k, v_i$  Trust( $\phi_{i,k}$ )
    THEN  $v_k$  Trust( $\phi_{i,k}$ )
  ELSE  $v_k \neg$ Trust( $\phi_{i,k}$ )
  ENDIFELSE
ENDIF
```

ENDPROCEDURE

## Definition (Feedback Set)

The feedback set of vehicle  $v_j$  for a message  $\phi_{i,j}^{v_i}$ , for all  $v_j, v_i \in \mathcal{A}$  is the set of formulas  $\psi_{i,k}^{v_j}$  such that they agree with  $\phi_{i,j}^{v_i}$  for the service identifier  $i$  and are obtained by a derivation construed by a *read* rule followed by a  $\rightarrow I$  rule, i.e.

$$FS^{v_j}(\phi_{i,j}^{v_i}) = \{\psi_{i,k}^{v_j} \mid \Gamma^{v_j} \vdash_s \text{Read}(\phi_{i,j}^{v_i}) \rightarrow \psi_{i,k}^{v_j}\}$$

# Assessing messages' value based on time

## Definition (Vehicle's Perception)

The perception of vehicle  $v_j$  for a message  $\phi_{i,j}^{v_i}$ , for all  $v_j, v_i \in \mathcal{A}$  is the sum of elements of the feedback set over that formula, weighted by the step of the derivation at which it is obtained:

$$AP^{v_j}(\phi_{i,j}^{v_i}) = \sum_{FS^{v_i}(\phi_{i,k}^{v_j})} (s(\psi_{i,k}^{v_j} \in FS^{v_i}(\phi_{i,k}^{v_j})))$$

# Assessing messages' set value based on time and ranking

## Definition (Vehicle's Perception of Characteristic Set)

The perception of vehicle  $v_j$  for a set of messages  $\mathcal{M}_{S_i, C_k}^A$  from other vehicles about characteristic  $C_k$  of service  $S_i$  is the sum of elements of the feedback set over the messages received about that service characteristic, weighted by the steps of the derivation at which it is obtained and further by the value  $r(C_k)$  of the rank of characteristic  $k$ :

$$AP^{v_j}(\mathcal{M}_{S_i, C_k}^A) = \sum_{FS^{v_i}(\phi_{i,k}^{v_j} \dots \phi_{i,k}^{v_n})} (1 - r(C_k)(s(\psi_{i,k}^{v_j} \in FS^{v_i}(\phi_{i,k}^{v_j} \dots \phi_{i,k}^{v_n}))))$$

where  $r$  is a ranking of characteristics valid for each vehicle  $v_i$ .



# Vehicles' reputation based on the value of their messages

## Definition (Reputation)

$$\forall v_i, v_j \in \mathcal{V}, S_i \in \mathcal{S}, v_i \prec v_j \leftrightarrow AP^{v_i}(\mathcal{M}_{S_i, C_k}^A) > AP^{v_j}(\mathcal{M}_{S_i, C_k}^A).$$

# Conclusions

- a proof-theory for trust and reputation in VANETs
- logic (un)SecureND, including an explicit *trust* function on formulas to guarantee consistency check at each retrieval step (after a *read* function), before forwarding is granted for a package (by a *write* function).
- Opportunistic Forwarding selects receivers on the basis of their reputation ranking
- Trust on forwarding guarantees correctness on transitive transmissions
- resolution protocol for restoring information after removing previously stored data.
- Protocol Validation via as a large inductive type in the Coq proof assistant <https://github.com/gprimiero/SecureNDC>.
- Future Work:
  - ▶ majority selection on opportunistic forwarding (instead of consensus)
  - ▶ separate ordering for vehicles and RSUs.

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