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Integrated Safety and Efficiency in Intelligent Vehicular Networks: Issues and Novel Constructs

Gérard Le Lann[a,*]

[a]INRIA, BP105, F-78153 Le Chesnay Cedex, France

Abstract

We present the cohort and the group constructs which are aimed at reconciling safety and efficiency for intelligent vehicular networks on roads and highways, and show how platoons and vehicular ad hoc networks can be structured as cohorts and groups. Fundamental implications of safety requirements are reviewed. A rationale for on-board systems based on diversified functional redundancy is developed, illustrated with a proposal for neighbor-to-neighbor periodic beaconing based on short range unidirectional communications meant to withstand telemetry failures. Worst-case analytical results are given for safe inter-vehicle spacing in cohorts despite inaccurate vehicle space-time coordinates and failing telemetry capabilities. The group construct is based on prefixing usage of sensing-based solutions with omnidirectional communications. Benefits resulting from prefixing vehicle maneuvers with vehicle role assignments are illustrated with the on-ramp-merging safety-critical scenario.

Keywords: Safety; Dependability; Platoons; Vehicular Ad Hoc Networks; Cooperative Automated Driving; V2V Communications.

1. Introduction

An intelligent vehicular network (IVN) is an open set of automated vehicles endowed with demonstrated efficiency and safety properties. In this paper, we consider IVNs on roads and highways. Efficiency goals are significant reductions in energy consumption, pollution, and travel times. Such goals rest on reducing human reaction latencies and longitudinal spacing, as well as the durations of risk-prone lateral maneuvers. Safety goals are significant reductions in accident and injury rates, which imply large enough inter-vehicle longitudinal spacing, as well as enforcing reduced velocities in the course of risk prone maneuvers, which are thus time consuming. Clearly, efficiency and safety are antagonistic goals.

* Corresponding author. Tel.: +33 (0)1 3963 5364.
E-mail address: Gerard.Le_Lann@inria.fr.

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Platoons, which were introduced in [Caudill & Garrard 1977], and vehicular ad hoc networks (VANETs) are the most studied forms of IVNs. The high compactness requirement, which is met with platoons, is largely ignored in VANETs. In both cases, safety problems arise due to failures impacting on-board (OB) systems or radio channels. Many such problems are yet unsolved. This is a serious impediment to the deployment of IVNs. A global approach building on results that came out of national initiatives in various countries, as well as recent projects such as, e.g., eVALUE, SAFESPOT and HAVEit in Europe, can be envisioned. Limitations proper to platoons and VANETs can be circumvented by "splitting" the platoon construct in two distinct constructs – cohort and group. As a result, IVN complexity can be mastered, and safety proof obligations can be met. Table 1 summarizes the need for "augmenting" platoons and VANETs with novel constructs.

Table 1. A summarized appraisal of platoons and VANETs

Criteria	Platoons	VANETs
Compactness as a design driver	yes	no
Safety in the presence of failures	?	?
Strong features	rigorous definitions of platoons platoon is a structuring construct proofs (e.g., kinematics)	ad hoc mirrors reality communication technologies an integral part of VANETs
Limitations	complexity communication technologies are an add-on	no rigorous definitions for "clusters" lack of structuring constructs simulations, few proofs

In Section 2, we review some important implications of safety requirements. The distinction between non safety-critical and safety-critical (SC) scenarios is explored in Section 3. Cohorts and groups are introduced in Section 4. A rationale for neighbor-to-neighbor unidirectional communications in cohorts is exposed in Section 5, along with recent findings on how to keep safe inter-vehicle spacing despite failing telemetry capabilities. In Section 6, we elaborate on the open issue of time-bounded multi-access channel delays in mobile wireless networks.

2. Safety Requirements and Some Fundamental Implications

Safety is a system property which does not reduce to such properties as, e.g., reliability or availability. An instantiation of an IVN may be safe in the presence of vehicles that violate reliability requirements. Conversely, a set of vehicles, each meeting reliability requirements, may instantiate an unsafe IVN. However, a violation of a dependability property may lead to safety hazards. This has been acknowledged years ago for OB systems, as witnessed by the ISO 26262 standard, an adaptation of the IEC 61508 standard for Automotive Electric/Electronic Systems, which focuses on *functional safety of individual vehicles*. With IVNs, *functional and non-functional safety properties of vehicle networks* are at stake. Currently, there are very few solutions for IVNs that build on state-of-the-art in Dependable Computing [Avizienis et al. 2004]. Let us briefly review three major obligations that derive from safety requirements.

2.1. Diversified functional redundancy