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Intelligent Transport Systems (ITS);
Cross Layer DCC Management Entity
for operation in the ITS G5A and ITS G5B medium;
Validation set-up and results

Reference

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Keywords

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650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

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Executive summary

The documented simulations prove that there are functional methods to manage channel load.

Different metrics have been selected to compare the effectiveness and fairness of different methods, and also possible coexistence of adaptive and reactive algorithms has been demonstrated in simulations.

Despite currently defined methods and individual parameters, in future even more complex methods and algorithms for managing channel load can be expected to evolve.

1 Scope

The present document covers the overall validation of the cross layer DCC functionality of the ETSI ITS architecture. It considers the cross layer DCC specification developed in ETSI TS 103 175 [i.1] and the cross layer concept described in ETSI TR 101 612 [i.2] and all other relevant DCC components in the communication stack.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TS 103 175: "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium".

[i.2] ETSI TR 101 612: "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium; Report on Cross layer DCC algorithms and performance evaluation".

[i.3] IEEE 802.11-2012: "IEEE Standard for Information technology -- Telecommunications and information exchange between systems Local and metropolitan area networks -- Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.4] ETSI EN 302 663: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.5] ETSI TS 102 687 (V1.1.1): "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part".

[i.6] ETSI EN 302 637-2: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.7] Oyunchimeg Shagdar: "Evaluation of Synchronous and Asynchronous Reactive Distributed Congestion Control Algorithms for the ITS G5 Vehicular Systems", Technical Report 462, INRIA Paris-Rocquencourt. 2015. <hal-01168043>.

[i.8] ns-2, network simulator, http://www.isi.edu/nsnam/ns/, https://en.wikipedia.org/wiki/Ns-(simulator).

[i.9] ns-3, network simulator, http://www.nsnam.org, https://en.wikipedia.org/wiki/Ns_(simulator).

[i.10] SUMO, Simulation of Urban mobility, http://www.dlr.de/ts/en/desktopdefault.aspx/, http://sumo-sim.org/.

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[i.19] G. Bansal, B. Cheng, A. Rostami, K. Sjoberg, J. Kenney, and M. Gruteser: "Comparing LIMERIC and DCC approaches for VANET channel congestion control", Wireless Vehicular Communications (WiVeC), 2014 IEEE 6th International Symposium on, pp. 1-7, 2014.

[i.20] B. Aygun, M. Boban, A. Wyglinski: "ECPR: Environment-aware Combined Power and Rate Distributed Congestion Control for Vehicular Communication", arXiv preprint arXiv:1502.00054: http://arxiv-web3.library.cornell.edu/abs/1502.00054.

[i.21] M. Boban, J. Barros, and O. K. Tonguz: "Geometry-Based Vehicle-to-Vehicle Channel Modeling for Large-Scale Simulation", IEEE Transactions on Vehicular Technology, Vol. 63, No. 9, pp. 4146-4164, Nov. 2014.

[i.22] Open Street Map, topological data base, http://www.openstreetmap.org/.

[i.23] M. Boban and P. d'Orey: "Measurement-based evaluation of cooperative awareness for V2V and V2I communication", IEEE Vehicular Networking Conference (VNC 2014), December 2014, pp. 1-8.

[i.24] Claudia Campolo, Antonella Molinaro, Riccardo Scopigno: "Vehicular ad hoc Networks, Standards, Solutions, and Research", ISBN: 978-3-319-15496-1 (Print), 978-3-319-15497-8 (Online).

[i.25] "Highway Capacity Manual", Transportation Research Board, Washington, D.C. 2010. ISBN 978-0-309-16077-3.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in ETSI TS 103 175 [i.1], ETSI TR 101 612 [i.2] and the following apply:

NAV: busy flag defined in [i.3]

ns-3: discrete-event network simulator for Internet systems, targeted primarily for research and educational use.

NOTE: ns-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

α	Adaption parameter that control the DCC algorithm
β	Adaption parameter that control the DCC algorithm
δ	Default packet length for the simulations
CBP_{Target}	Target channel load
CBR_n	CBR measured at the nth monitoring interval
CL_n	Channel load calculated upon measurement of CBR_n
N_GenCam	Maximum number of consecutive CAM generations due to the elapsed time since the last CAM generation
NDL_maxChannelLoad	The channel is considered to be overloaded if the CBP is larger than this value
NDL_minChannelLoad	The channel is considered to be mainly free if the CBP is smaller than this value
NDL_TimeDown	controls how fast DCC reacts to channel load decrease
NDL_TimeUp	controls how fast DCC reacts to channel load increase
r_j	Message rate of ITS-S j
T_{BUSY}, T_{busy}	Total time during which the channel is indicated as busy during T_{mon}
T_GenCam	Currently valid upper limit of the CAM generation interval
T_CheckCamGen	Time period for checking the generation of a new safety message
T_GenCam_Dcc	Initial CAM generation time interval.
T_GenCamMin	No CAM can be generated with an interval smaller than this variable
T_GenCamMax	No CAM can be generated with an interval greater than this variable
$T_{monitor}$, T_{mon}	CBR monitoring interval

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

A-DCC	Adaptive DCC
AIFS	Arbitration Inter Frame Space
BSM	Basic Safety Message
BTP	Basic Transport Protocol
CAM	Cooperative Awareness Message
CBP	Channel Busy Percentage
CBR	Channel Busy Ratio
CCA	Clear Channel Assessment
CCH	Control Channel
CL	Channel Load
DCC	Decentralized Congestion Control
DENM	Decentralized Environmental Notification Message
ECPR	Environment- and Context-aware Combined Power and Rate distributed congestion control
EDCA	Enhanced Distributed Channel Access
FIR	Finite Impulse Response

GPS Global Positioning System
iCS iTetris Control System
IP Internet Protocol
IPG Inter-Packet Gap
ITS Intelligent Transportation System
ITS-G5 Radio interface, collectively known as the 5 GHz ITS frequency band
ITS-S ITS Station
LIMERIC LInear MEssage Rate Integrated Control
LOS Line Of Sight
LOS-C stable flow Level-of-Service of traffic conditions

NOTE: As defined in [i.25].

LOS-F fully saturated (breakdown flow) Level-of-Service of traffic conditions

NOTE: As defined in [i.25].

MAC Medium Access Control
NAR Neighborhood Awareness Ratio
PDR Packet Delivery Ratio
PER Packet Error Rate
PHY Physical Layer
PIR Packet Inter-Reception time
QPSK Quadrature Phase-Shift Keying
R-DCC Reactive DCC
RNAR Ratio of Neighbors Above Range
SINR Signal to Interference and Noise Ratio
SUMO Simulation of Urban MObility
TA Target Awareness
TC Traffic Class
TCP/IP Transmission Control Protocol/Internet Protocol
T-DCC DCC with solely CAM triggering conditions
TX Transmit
UDP User Datagram Protocol
UDP/IP User Datagram Protocol/Internet Protocol
UK United Kingdom
US United States
WAVE Wireless Access in Vehicular Environments
WLAN Wireless Local Area Network

4 DCC theory

The aim of DCC is to avoid overloading the ITS-G5 radio channel. This can be done by different means as specified in ETSI TS 102 687 [i.5].

It has been shown recently that a pure message rate control can effectively limit the channel load [i.24], therefore most of the simulation results presented in the present document focus on this type of DCC. Clause 5.3 gives an outlook of how DCC can be even further improved to not only avoid channel overload, but also maximise the awareness about other vehicles in the vicinity.

When designing a message rate DCC algorithm the following key fundamentals are important:

- Convergence to a single message rate by all network nodes
- Bounded stability in the sense that message rate changes over time should be within small bounds

Further details about convergence and stability are summarised in [i.24].

5 Simulation results

5.1 Characteristics of common algorithms

5.1.1 Reactive table based algorithm

5.1.1.1 Simulator 1: Conclusions

Using Simulator 1, the following issues targeting reactive dynamic DCC algorithm are studied.

- DCC synchronization
- Channel load characterization
- Non-identical receiver parameters

The following conclusions are drawn:

- It is very important to provide a solution to avoid the synchronization of DCC behaviour among ITS-S. If a careful attention is given on this issue, the simple reactive DCC algorithm can perform better than having no DCC (hereunder called DccOff). In the case of rate adaptation, introducing a random message generation rate offset seems to be a good solution, but is not further investigated in the present document.
- If the road traffic is sparse, the reactive DCC algorithm tends to show poorer performance than DccOff.
- Resetting the message generation timer based on the actual CBR value is not advantageous.
- If the ITS-S transmits unsynchronized, the current CBR is a good indicator of the channel load. However, if the transmissions are synchronized, it is necessary to pay attention on CBR for a longer interval.
- If the system consists of ITS-S with heterogeneous channel sensing capability, non-negligible negative impact can be expected in terms of communications range and fairness.
- The fairness issue caused by non-identical sensing capabilities is more significant for DCC-enabled system.

5.1.1.2 Simulator 1: Introduction

The results of simulator 1 are detailed in paper [i.7], using a simulation tool combining ns-3 (network simulator) and SUMO (Simulation of urban mobility). Simulator 1 implemented the reactive DCC algorithm, controlling the message rate following a parameter look-up table (shown in table 2).

Following simulations are performed with simulator 1:

- Simulation 1.1: Study on the synchronization issue of the DCC.
- Simulation 1.2: Study on channel load characterization.
- Simulation 1.3: Study on non-identical sensing capabilities.

Simulation 1.1 investigates the handling of the channel busy ratio (CBR), which is the ratio of the time when the channel is perceived as busy to the monitoring interval. It is the commonly agreed metric used to characterize channel load. Since the wireless channel is shared by ITS-S that are in the vicinity of each other, the CBR monitored at such ITS-S takes similar values. As a consequence, the ITS-S may take synchronized reactions to the channel load, e.g. the ITS-S reduce/increase the transmission rate at around the same time. Simulation 1.1 studies such a synchronized DCC behaviour observed in reactive DCC algorithm. The following different possible reactions of the CAM generator, which is responsible for adjusting the message generation rate as a means to perform DCC, were studied:

- *Timer handling*: In general, a transmission of a CAM is triggered by a timer, which is set to the CAM interval. Hence, upon being informed with a new CBR value (at an arbitrary point of time), the CAM generator may:

  1) wait the expiration of the on-going timer and set the timer to the new CAM interval; or

2) cancel the on-going timer and set it to the new CAM interval. The former and latter behaviours are respectively named *Wait-and-Go* and *Cancel-and-Go*.

- *Interval setting*: As mentioned above, the CBR measured for the shared channel may lead to the situation where the nearby ITS-S increase/decrease the CAM interval at around the same time. This is especially true for the reactive DCC algorithm, which controls the rate following a parameter look-up table. Therefore, one can think of avoiding such a synchronized behaviour by applying random intervals. Hence, two possible behaviours can be envisioned: upon determination of a new CBR value, in the simulation the CAM generator sets the message generation interval to:

  1) the value (say *new_CAM_interval*) provided by the table; or

  2) a random value (e.g. taken from the range [0, *new_CAM_interval*]) for the first packet and then follows the table.

  The former and latter behaviours are respectively named *Synchronized* and *Unsynchronized*. In practice, synchronization could happen when the CAM transmissions are triggered based on the common GPS clock.

Considering the above-mentioned behaviours of the CAM generator, the following four different versions of Reactive DCC are simulated:

- DccReactive-1: Wait-and-Go & Synchronized
- DccReactive-2: Cancel-and-Go & Synchronized
- DccReactive-3: Wait-and-Go & Unsynchronized
- DccReactive-4: Cancel-and-Go & Unsynchronized

Simulation 1.1 studies and compares the performances of these different versions of reactive DCC to understand the synchronization issue and their underlying reasons.

Simulation 1.2 investigates the optimum time interval for the channel load characterization. While it is commonly agreed that CBR should be monitored over a certain interval (e.g. 100 ms), it is not clear whether the channel load should be characterized only by the current value of CBR or whether it should also consider the past CBR values. To evaluate this aspect, channel load (CL) is defined as follows.

$$CL_n = (1 - \alpha) \times CL_{n-1} + \alpha \times CBR_n \qquad (1)$$

In equation 1, CBR_n is the CBR measured at the n^{th} monitoring interval and CL_n is the channel load calculated upon measurement of CBR_n. The weight factor α defines whether the channel load considers only the last CBR or also takes its history into account by applying a discrete time first order low pass filtering to the CBR. Obviously, by choosing $\alpha = 1$, the channel load is characterized by the "current" channel condition only. In simulation 1.2 the performances of a reactive DCC algorithm for different values of α is evaluated.

Simulation 1.3 studies the DCC performance in heterogeneous road systems, made of ITS-S with different levels of sensing capability. Specifically, it is considered that different ITS-S sense the wireless channel at different threshold levels; as a consequence CL is measured differently, what leads to different reactions of each ITS-S. To perform this study, the ITS-S in the simulations are provided with random sensitivity offset values in the range of [-6, +6] dBm.

5.1.1.3 Simulator 1: Tools and setup

Simulator 1 uses the open discrete event simulation environment ns-3 (version 3.21) [i.9], combined with the traffic simulator SUMO (version 0.22) [i.10]. The key simulation modules, which are relevant to simulator 1, are illustrated in figure 1, where the modules highlighted in red are newly developed extensions to ns-3.

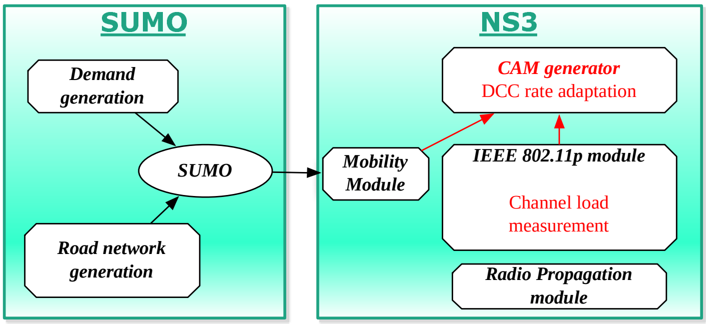

Figure 1: Simulators and the key modules relevant to the work

The latest stable version of ns-3, ns-3.21, is used as basis for simulator 1. Among a number of new functionalities, it includes the WAVE system [i.14], which supports the vehicular functionalities of IEEE 802.11 [i.3] similar to ITS-G5 [i.4]. The system follows the TCP/IP communication architecture. The key software components used in simulator 1 are a CAM generator, UDP/IP, the vehicular functionalities of IEEE 802.11 MAC, radio propagation, and mobility modules.

The CAM generator is a newly developed module, which receives position and mobility information from the mobility module and periodically generates CAMs. The module is implemented with DCC rate adaptation algorithms. Simulator 1 focuses on the reactive DCC algorithm as described in ETSI TS 102 687 [i.5]. When the reactive DCC module is provided with a CL value (see equation 1), it adjusts the CAM generation interval following the parameter lookup table shown in table 2.

The messages generated by the CAM generator are processed by the UDP and IP modules, and received at the MAC. Even though the protocols standardized in ETSI are BTP/GeoNetworking, utilizing UDP/IP is equivalent regarding the objective of studying channel congestion caused by 1-hop broadcast messages (CAM). It should be noted that since the header lengths of UDP/IP and BTP/GeoNetworking are different, the necessary message length adjustment is made at the CAM generator such that the length of the frames transmitted on the wireless channel have the same length as when using BTP/GeoNetworking.

The PHY layer of ns-3 is extended with a CBR monitoring functionality, which monitors the channel activities and calculates the CL. Since ns-3 is an event-based simulator, the CBR monitoring module exploits the event notifications installed in ns-3. In addition, the module holds a timer and calculates the CBR value at every $T_{monitor}$ interval following equation 2. It should be mentioned that the timer setting is made independently at each ITS-S, and hence the CL notifications to the CAM generator are not synchronized among the individual ITS-S.

$$CBR = \frac{\sum T_{busy}}{T_{monitor}} \qquad (2)$$

The ns-3 mobility module is responsible for handling the mobility of ITS-S and is the interface of ns-3 with the SUMO traffic simulator. The SUMO traffic simulator is used to generate road network and traffic following user-specified scenarios. The outputs of the traffic simulator are converted in a file format readable by the mobility module of the ns-3 simulator.

Unless otherwise noted, the communication and road parameters used by simulator 1 are listed in table 1.

Table 1: Default simulation parameters of simulator 1

Parameters	Value
Communication	
CAM default TX rate	10 Hz
CAM message size	400 Bytes
TX Power	23 dBm
$ED^{threshold}$	-95 dBm
EDCA Queue/TC	1 DENM/3 CAM
Modulation scheme	QPSK ½ 6 Mbits/s
Antenna pattern	Omnidirectional, gain = 1 dBi
Access technology	ITS G5A
ITS G5 Channel	CCA
Fading model	LogDistance, exponent 2
Road network	
Lane width	3 m
Lanes in-flow	3
Lanes contra-flow	3
DCC parameters	
CBR monitor interval ($T_{monitor}$)	100 ms
α (see (1))	1

The parameter table of the reactive DCC algorithm is shown in table 2.

Table 2: Reactive DCC parameter lookup table used in simulator 1

States	CL (%)	T_{off}
Relaxed	0 % ≤ CL < 19 %	60
Active_1	19 % ≤ CL < 27 %	100
Active_2	27 % ≤ CL < 35 %	180
Active_3	35 % ≤ CL < 43 %	260
Active_4	43 % ≤ CL < 51 %	340
Active_5	51 % ≤ CL < 59 %	420
Restricted	CL ≥ 59 %	460

The simulations are carried out for homogenous highway scenarios. Table 3 provides the road configuration. As shown in table 3 and illustrated in figure 2, the roadside ITS-S are installed every 100 m in the road centre (i.e. the separation between the two centre lanes).

The scenario consists of sparse, medium, dense, and extreme dense traffic. The density parameters are listed in table 4.

Table 3: Simulator 1 road configuration

Class	Inter-vehicle distance
Highway length	1 000 m
Lanes/Directions	3 lanes/2 directions
Roadside ITS-S inter-location	100 m
Vehicle size	2 m x 5 m

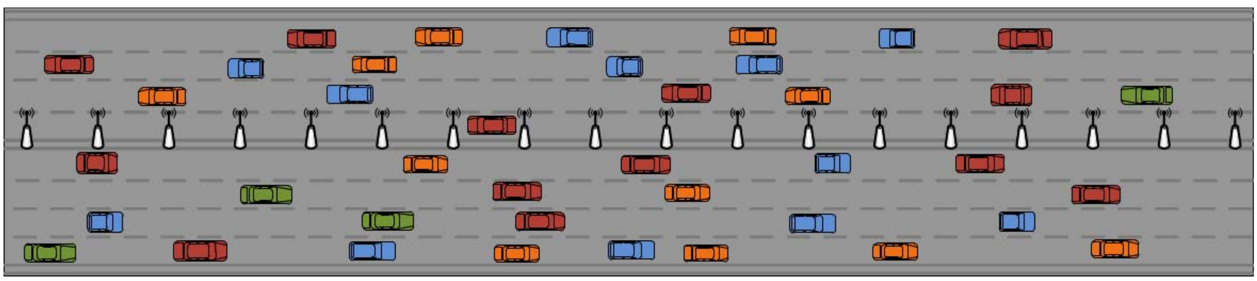

Figure 2: Illustration of a homogenous highway scenario used by simulator 1