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TECHNICAL SPECIFICATION

Intelligent Transport Systems (ITS);
Decentralized Congestion Control Mechanisms for
Intelligent Transport Systems operating in the 5 GHz range;
Access layer part

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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 Specification (TS) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

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Introduction

Decentralized congestion control (DCC) is a necessity in *ad hoc* networks where the number of communicating stations varies and is not known in advance. Vehicular *ad hoc* network (VANET) presents a challenge because in a few seconds a very high density of vehicles can be in radio range of each other due to for example an accident. A DCC algorithm needs to cope with few as well as many communicating stations within radio range. The medium access control (MAC) algorithm schedules transmissions to avoid interference between communicating stations. The wireless channel is a finite resource and when the number of required resources exceeds available resources, the DCC algorithm needs to shape the data traffic injected by each communicating station to avoid channel congestion. All MAC schemes applied in an *ad hoc* setting such as the high-speed vehicular environment need to have DCC. However, DCC cannot solely operate on the MAC layer since the MAC layer is not aware of the applications running in the station. DCC is a cross-layer functionality and applications need to be aware of the current channel activity to prioritize between different internal data traffic sources once DCC will restrict transmissions.

In infrastructure based networks (i.e. networks containing a centralized network controller such as an access point or base station) when the required resources exceed available resources, the centralized network controller can for example decide to not grant access to the network or run certain links with reduced quality of service. But for a VANET, communicating stations are responsible for a graceful degradation of applications, where some might be temporarily shut down while others can continue without disruption when the DCC is active.

DCC is also a way to divide the resources among the communicating stations and to restrict that some stations operate using all resources. ETSI EN 302 571 [1] put up upper limits on the DCC by using duty cycle requirements.

1 Scope

The present document describes the means of controlling the data traffic injected to a frequency channel from the access layer perspective. The outlined algorithms are only applicable to ITS-G5 [i.4].

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 referenced document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

[1] ETSI EN 302 571 (V2.1.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[2] ETSI TS 103 175 (V1.1.1): "Intelligent Transport Systems (ITS); Cross layer DCC management entity for operation in the ITS G5A and ITS G5B medium".

2.2 Informative 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 referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

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 102 636-4-2 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 2: Media-dependent functionalities for ITS-G5".

[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] G. Bansal, J. B. Kenney, and C. E. Rohrs: "LIMERIC: A Linear Message Rate Control Algorithm for DSRC Congestion Control," in IEEE Transactions on Vehicular Technology, vol. 62, no. 9, pp. 4182-4197, July 2013.

[i.4] ETSI EN 302 663 (V1.2.1): "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

channel busy ratio (CBR): time-dependent value between zero and one representing the fraction of time that a single radio channel is busy with transmissions

duty cycle: defined as the ratio, expressed as a percentage of the transmitter total "on" time on one carrier frequency, relative to 1 second period

3.2 Symbols

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

CBR_L_0_Hop	Local channel busy ratio for a specific frequency channel for ego ITS station
CBR_G	Global channel busy ratio for a specific frequency channel
CBR_L_0_Hop_Previous	the second most recent CBR_L_0_Hop
CBR_G_Previous	the second most recent CBR_G
CBR_{ITS-S}	moving average of measured CBR values
CBR_{target}	control parameter
G_{max}^{+}	control parameter
G_{max}^{-}	control parameter
T_{CBR}	period of time
T_{on}	duration of a transmission
T_{on_pp}	duration of the previous transmission
T_{off}	minimum time between two transmissions
δ	$T_{on} /(T_{on} + T_{off})$
α	control parameter
β	control parameter
δ_{max}	maximum value of δ
δ_{min}	minimum value of δ
δ_{offset}	offset value of δ
t	current system time
t_{go}	time when gate keeper opens
t_{pg}	time when the gate keeper closes

3.3 Abbreviations

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

CBR	Channel Busy Ratio
DCC	Decentralized Congestion Control
DCC_ACC	DCC component of the ACCess layer
DCC_FAC	DCC component of the FACilities layer
DCC_NET	DCC component of the NETwork layer
ITS	Intelligent Transport Systems
ITS-S	ITS Station
MAC	Medium Access Control
TDC	Transmit Datarate Control
TPC	Transmit Power Control
TRC	Transmit Rate Control
UTC	Coordinated Universal Time
VANET	Vehicular Ad Hoc NETworks

4 Overview

4.1 Introduction

The objective of the present document is to describe the decentralized congestion control (DCC) algorithms fulfilling the requirements described in clause 4.2.10 of ETSI EN 302 571 [1] and in clause 7.2 of ETSI TS 103 175 [2]. In order to conform to the present document either the algorithm specified in clause 5.3 or the algorithm specified in clause 5.4 shall be implemented.

4.2 Architecture

The DCC architecture is shown in Figure 1. It consists of the following DCC components:

- DCC_ACC located in the access layer;
- DCC_NET [i.1] located in the networking & transport layer;
- DCC_FAC [2] located in the facilities layer; and
- DCC_CROSS [2] located in the management layer.

The DCC_ACC component is specified in the present document and belongs to a DCC framework covering all parts of the architecture.

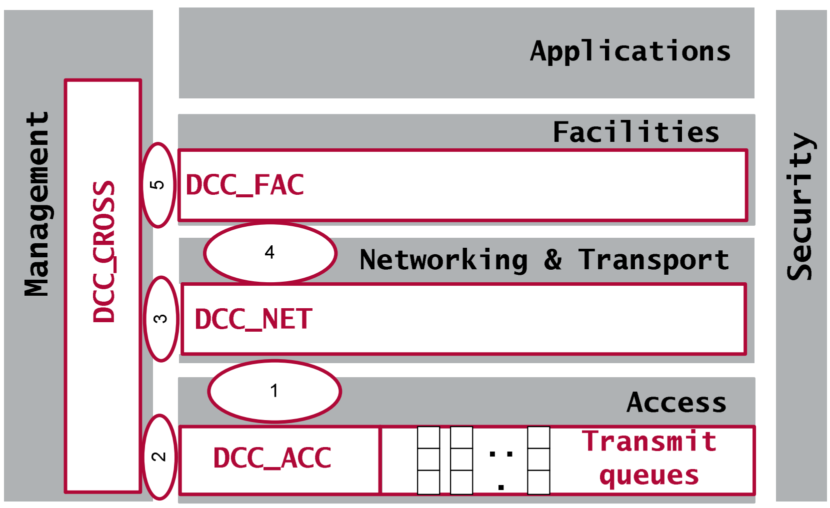

Figure 1: DCC Architecture

4.3 DCC_ACC component

The DCC_ACC component provides the local channel busy ratio (CBR) value to the DCC algorithm. If information sharing for DCC is supported through ETSI TS 102 636-4-2 [i.1], then the global CBR, *CBR_G*, value shall be used.

NOTE: The global CBR value can be received from the GeoNetworking header if ETSI TS 102 636-4-2 [i.1] is supported.

5 Algorithms

5.1 Introduction

Different techniques exist for controlling the network load:

- Transmit power control (TPC)
- Transmit rate control (TRC)
- Transmit datarate control (TDC)

One or several techniques combined can be used by the DCC algorithm for controlling the network load. In Table 1, the different techniques are briefly described.

Table 1: Different DCC access mechanisms described.

Technique	Description
TPC	In TPC, the output power is altered to adjust the current channel load. For example, during high utilization periods the ITS-S can reduce its output power and thereby, is a reduction in interference range achieved. This results in that ITS-Ss further away will experience a reduced CBR.
TRC	TRC regulates the time between two consecutive packets from an ITS-S. During high utilization periods, the TRC increases the time between two packets for the ITS-S, T_{off} time.
TDC	TDC is a mechanism that can be used by wireless systems offering several transfer rate options. During high utilization periods and depending on application, a higher transfer rate can be used to decreased the T_{on} time.

An introduction to reactive and adaptive DCC algorithms is provided in Annex C of ETSI TS 103 175 [2] and Annex A of ETSI TR 101 612 [i.2].

5.2 Requirements

The DCC algorithm is subject to the following requirements:

- The algorithm shall run on each frequency channel specified in ETSI EN 302 571 [1] independently.
- The algorithm shall run in an infinite loop.
- The algorithm shall be activated at least every 200 ms.
- The algorithm shall not exceed the limits provided in clause 4.2.10 in ETSI EN 302 571 [1] and in clause 7.2 in ETSI TS 103 175 [2].
- The CBR assessment shall be according to clause 4.2.10 in ETSI EN 302 571 [1].

5.3 Reactive approach

The reactive approach consists of several states reached depending on the current CBR. The evaluation of state is performed every T_{CBR}. Every state can control the network load using one or a combination of the techniques described in clause 5.1. One state can only be reached by a neighbouring state. For example, the "Active 1" state in Figure 2 can only be reached by the "Relaxed" state and the "Active 2" state.

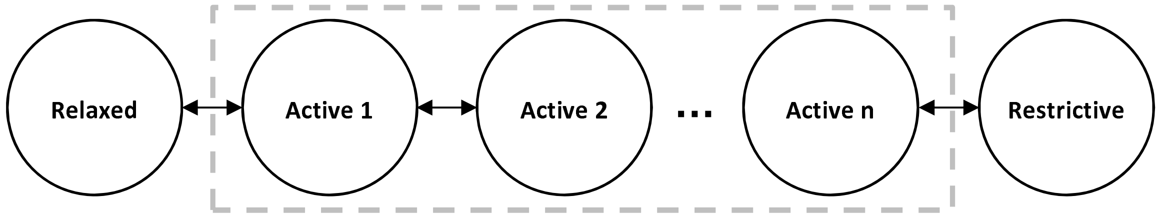

Figure 2: A generic outline of the reactive approach

Increased CBR value implies higher network utilization resulting in fewer transmission opportunities for the ITS-S with possible less output power and similar. Restrictive state is the most stringent in terms of transmission opportunities and relaxed state can in essence be restricted by the limits in ETSI EN 302 571 [1].

NOTE: In Annex A, configurations of the reactive approach for two different T_{on} values are provided.

5.4 Adaptive approach

In the adaptive approach, at every time when UTC modulo 200 ms is zero the following steps shall be executed:

Step 1: $CBR_{ITS-S} = 0,5 \times CBR_{ITS-S} + 0, \times ((CBR\_L\_0\_Hop + CBR\_L\_0\_Hop\_Previous)/2)$ (1)

NOTE 1: If information sharing is supported via ETSI TS 102 636-4-2 [i.1], then *CBR_G* is substituted for *CBR_L_0_Hop* is exchanged with. *CBR_G_Previous* is substituted for *CBR_L_0_Hop_Previous*.

Step 2: **If** sign($CBR_{target} - CBR_{ITS-S}$) is positive **then** $\delta_{offset} = \min(\beta \times (CBR_{target} - CBR_{ITS-S}), G^{+}_{max})$; (2)

Else $\delta_{offset} = \max(\beta \times (CBR_{target} - CBR_{ITS-S}), G^{-}_{max})$ (3)

Step 3: $\delta = (1-\alpha) \times \delta + \delta_{offset}$ (4)

Step 4: **If** $\delta > \delta_{max}$, $\delta = \delta_{max}$ (5)

Step 5: **If** $\delta < \delta_{min}$, $\delta = \delta_{min}$ (6)

The parameter δ is a unitless value that represents the maximum fraction of time that this ITS-S is allowed to transmit on the wireless medium, over any given interval. For example, if δ = 0,01, the aggregate of all transmissions from this ITS-S are allowed to occupy the medium up to 1 % of the time. When considering an interval of one second, δ represents an upper bound on the permitted duty cycle.

NOTE 2: In Annex B, a proposal of how packet handling using the parameter δ is found.

In Table 3, the basic parameter setting of the adaptive approach is provided.

Table 3: Parameter values of adaptive approach

Parameter	Value	Description
α	0,016	Algorithm parameter.
β	0,0012	Algorithm parameter.
CBR_{target}	0,68	The adaptive approach updates δ so that CBR adapts to this target.
δ_{max}	0,03	Upper bound on allowed fraction of medium usage, specified in ETSI EN 302 571 [1].
δ_{min}	0,0006	Lower bound on allowed fraction of medium usage, to prevent starvation under high CBR.
G^{+}_{max}	0,0005	Algorithm parameter.
G^{-}_{max}	-0,00025	Algorithm parameter.
T_{CBR}	100 ms	Interval over which CBR is measured. δ is updated at twice this interval.

NOTE 3: Detailed analysis and rationale for algorithm parameters for the adaptive approach is found in [i.3].

Annex A (informative): Parameter setting of reactive approach

This annex provides a possible parameter setting for the reactive approach described in clause 5.3 depending on the T_{on} time. The proposed parameter setting contains 5 states, where three are so-called active states. Table A.1 outlines the number of transmission opportunities when T_{on} < 1 milliseconds and Table A.2 provides values for when the T_{on} < 500 microseconds.

Table A.1: Mapping of CBR values to state and the currently allowed transmission opportunities per second when T_{on} is max 1 ms

State	CBR	Packet rate	T_{off}
Relaxed	< 30 %	10 Hz	100 ms
Active 1	30 % to 39 %	5 Hz	200 ms
Active 2	40 % to 49 %	2,5 Hz	400 ms
Active 3	50 % to 60 %	2 Hz	500 ms
Restrictive	> 60 %	1 Hz	1 000 ms

Table A.2: Mapping of CBR values to state and the currently allowed transmission opportunities per second when T_{on} is max 500 μs

State	CBR	Packet rate	T_{off}
Relaxed	< 30 %	20 Hz	50 ms
Active 1	30 % to 39 %	10 Hz	100 ms
Active 2	40 % to 49 %	5 Hz	200 ms
Active 3	50 % to 65 %	4 Hz	250 ms
Restrictive	> 65 %	1 Hz	1 000 ms

Annex B (informative): Packet handling to meet channel occupancy limit δ

The adaptive approach works for variable packet sizes. Given that an ITS-S transmission occupies the channel continuously during a packet transmission, it is only possible to satisfy the δ occupancy limit over longer intervals. Conceptually, the Access layer enforces an occupancy limit with a "gate keeping" function at the interface to the Network & Transport layer. The gate keeper state is "open" when the Access layer will accept a packet from the Network & Transport layer for enqueuing in a transmit queue (see Figure 1), and is "closed" when the Access layer will not accept a packet due to the occupancy limit. The present document describes a simple gate keeping function that ensures that the ITS-S's channel occupancy never exceeds δ. More complex gate keepers are also possible, for example to use a leaky bucket to allow a constrained amount of transmission burst. The actual implementation of the gate keeping function is outside the scope of the present document. This description assumes that a packet is transmitted if and only if it is admitted to the Access layer by the gate keeper.

The main task of the gate keeper is to compute the next time that the gate will open. This gate-opening time is based on the recent transmission activity of this ITS-S and the occupancy limit δ computed in the adaptive approach. The gate closes when one packet crosses the interface to the Access layer. This could be immediately after opening, if a packet is waiting at the interface, or it could be later. Note that the movement of packets across the internal Access layer interface is modelled as instantaneous, regardless of the duration of that packet's eventual transmission on the air.

It is denoted the time when the gate closes as t_{pg}. If at time t a packet of (eventual) transmit duration T_{on_pp} passes through the open gate into an Access layer queue, the gate closes, $t_{pg} = t$, and the gate keeper computes the gate-opening time t_{go} as:

$$t_{go} = t_{pg} + \min\left(\max\left(\frac{T_{on_{pp}}}{\delta}, 25\ ms\right), 1\ s\right) \qquad \text{(B.1)}$$

This equation reflects constraints from ETSI EN 302 571 [1], such that the ITS-S does not transmit at intervals shorter than 25 ms, and is never required to wait longer than one second between transmissions. Note that the minimum interval is directly proportional to the duration of the packet (T_{on_pp}), and inversely proportional to the occupancy limit (δ).

When δ is updated (see steps 1 to 5 in clause 5.4), it is recommended to also update the earliest gate-opening time, t_{go}, to reflect the new occupancy limit if the gate is currently closed. Update equation (B.2) preserves the order in which ITS-Ss reach their respective gate-opening times. This method avoids synchronizing the gate-opening time across ITS-Ss, which could lead to elevated contention-based packet loss. Note that simply re-applying equation (B.1) with the updated δ could result in synchronized gate-opening times for ITS-Ss nearing the end of their gate-closed interval, and is not recommended. The variable t_{go} on the right hand side of equation (B.2) is the t_{go} computed from equation (B.1) or (B.2), whichever was executed most recently.

$$t_{go} = t_{pg} + \min(\max(\frac{T_{on\_pp}}{\delta} \times \frac{t_{go} - t}{t_{go} - t_{pg}} + t - t_{pg}, 25\ ms), 1\ s) \qquad \text{(B.2)}$$

Annex C (informative): Bibliography

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- A. Rostami, B. Cheng, G. Bansal, K. Sjöberg, M. Gruteser, and J. B. Kenney, "Stability challenges and enhancements for vehicular congestion control approaches," in IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 10, April 2016, pp. 2935-2948.

Annex D (informative): Change History

date	Version	Information about changes
July 2011	V1.1.1	First publication of the TS
April 2018	V1.2.1	Update of reactive DCC algorithm (Clause 5.3) and addition of an adaptive DCC algorithm (clause 5.4). Parametrization of reactive DCC algorithm in Annex A and proposal of packet handling for adaptive DCC algorithm in Annex B.

History

Document history		
V1.1.1	July 2011	Publication
V1.2.1	April 2018	Publication