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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

The aim of the Decentralized Congestion Control (DCC) is to adapt the transmit parameters of the ITS station operating the ITS-G5 technology to the radio channel conditions, in order to maximize the probability of a successful reception at intended receivers.

The DCC aims to provide channel resources among neighbouring ITS-S according to their needs. The Facilities Layer DCC Entity determines priorities between different messages and informs DCC_CROSS about the available resources to control the channel load generated by each application.

In case of a road traffic emergency the ITS-S may still transmit a burst of messages during a short period of time to maintain a safe road traffic environment, even during a high network utilization period, where every ITS-S has very few resources (e.g. CAM period at 1 Hz or 2 Hz). However, this exception occurs rarely and the messages transmitted for this purpose are only those of uttermost importance.

1 Scope

The present document specifies the Facilities Layer DCC Entity of the DCC mechanism for ITS-S using the ITS-G5 technology, taking into account the available channel resources of the ITS-S from the cross-layer DCC entity and the message generation requirements from applications and services. The functional behaviour and the interfaces of the Facilities Layer DCC Entity to the DCC_CROSS component are specified as well. The present document does not address Multi-Channel Operation.

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 TS 102 636-4-2: "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".

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

[3] ETSI TS 102 723-1: "Intelligent Transport Systems (ITS); OSI cross-layer topics; Part 1: Architecture and addressing schemes".

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.

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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 EN 302 665: "Intelligent Transport Systems (ITS); Communications; Architecture".

[i.2] ETSI TS 102 687: "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part".

[i.3] ETSI EN 302 663: "Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.4] ETSI TR 103 562: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in ETSI EN 302 665 [i.1], ETSI TS 103 175 [2] and the following apply:

cross-layer DCC: cooperation mechanisms based on components distributed over several layers of the protocol stack which jointly work together to fulfil the operational requirements of DCC

decentralized congestion control: set of mechanisms for ITS-S to maintain network stability, throughput efficiency and fair resource allocation to ITS-S using ITS-G5 access technology

DCC_ACC: DCC component located at the access layer

DCC_CROSS: DCC cross-layer component located in the management plane

DCC_CROSS_Facilities: function in the DCC_CROSS entity that provides DCC control parameters to the facilities layer and to the applications

DCC_FAC: DCC component located at the facilities layer

DCC_NET: DCC component located in the networking & transport layer

ITS application: component of ITS applications layer

ITS-G5: access technology to be used in frequency bands dedicated for European Intelligent Transport Systems (ITS) as defined in ETSI EN 302 663 [i.3]

3.2 Symbols

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

ARD_i	average resource deficit for TC_i
ACR_i	maximum available channel resources for TC_i
ACR_{ij}	maximum available channel resources for application/service *j* and TC_i
CBR_a	available percentage of channel resources defined in ETSI TS 103 175 [2]
$\overline{CRE_{ij}}$	estimated channel resource for application/service *j* and TC_i
CR_a	available percentage of channel resources
CR_i	total estimated channel resources from all applications/services in TC_i
GCR_i	gross channel resource for TC_i
L_{ij}	message length for application/service *j* and TC_i (in the unit of octets)
$\overline{L_{ij}}$	average message length for application/service *j* and TC_i (in the unit of octets)
$\overline{L_{ij}^*}$	previously estimated average message length for application/service *j* and TC_i (in the unit of octets)
NCR_i	net channel resource for TC_i
PNR_i	proportional net channel resource for TC_i
R_{ij}	data rate for application/service *j* and TC_i
TC_i	traffic class with index *i*
$T_{off\ ij}$	inter-message interval for application/service *j* and TC_i (in the unit of seconds)
$\overline{T_{off\ ij}}$	average inter-message interval for application/service *j* and TC_i (in the unit of seconds)
$T_{off\ \min ij}$	proposed minimum inter-message interval for application/service *j* and TC_i (in the unit of seconds)

3.3 Abbreviations

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

CA	Cooperative Awareness
CAM	Cooperative Awareness Messages
CPM	Collective Perception Message
DCC	Decentralized Congestion Control
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
ITS	Intelligent Transport Systems
ITS-S	ITS Station
MCM	Maneuver Coordination Message
MCS	Modulation and Coding Scheme
MF-SAP	Management Facilities Service Access Point
OFDM	Orthogonal Frequency Division Multiplexing
TC	Traffic Class

4 Decentralized Congestion Control Architecture

4.1 Overview

ETSI EN 302 665 [i.1] provides the ITS reference architecture for an ITS-S and ETSI TS 103 175 [2] provides DCC architecture for ITS-G5 systems as shown in Figure 1. The present document provides details of the DCC_FAC entity residing in the facilities layer for ITS-G5 systems.

The DCC functionality, including interfaces mapped to the ITS-S architecture, is shown in Figure 1. It is distributed between the following entities:

- DCC_FAC located in the facilities layer is optional and specified in the present document;
- DCC_NET located in the networking and transport layer as specified in ETSI TS 102 636-4-2 [1];
- DCC_ACC located in the access layer as specified in ETSI TS 102 687 [i.2];
- DCC_CROSS located in the management plane as specified in ETSI TS 103 175 [2].

The components are connected through the DCC interface 1 to interface 4 as shown in Figure 1. These interfaces are compliant with ETSI TS 102 723-1 [3].

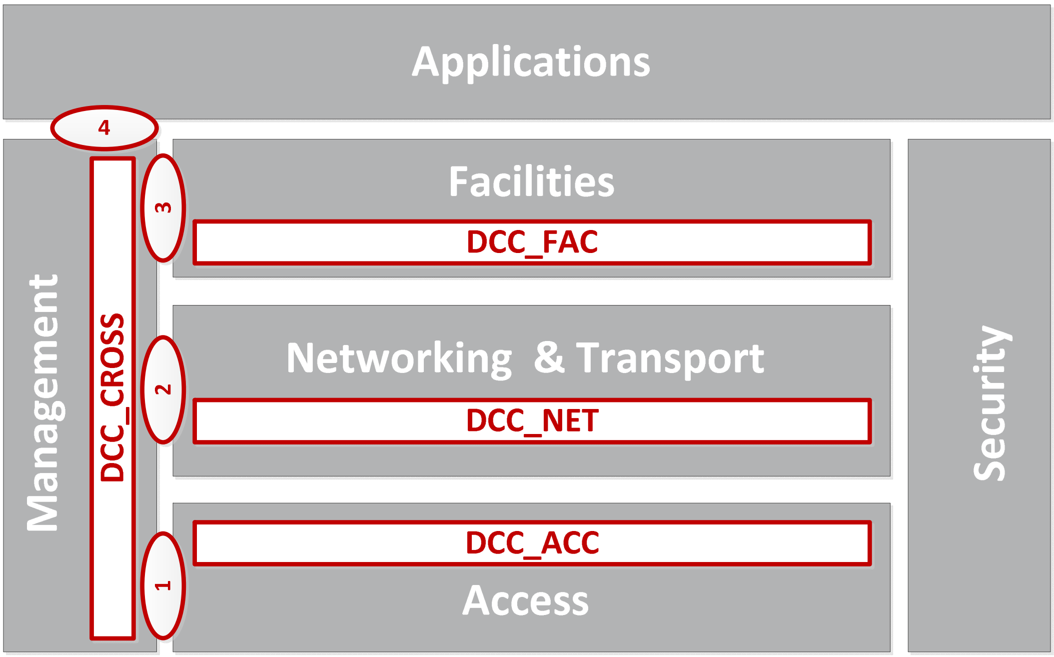

Figure 1: DCC Architecture

5 DCC Facilities Entity (DCC_FAC)

The DCC_FAC is a facilities layer entity that supports the control of the channel load generated by each application/service via DCC_CROSS by considering the available channel resources of the ITS-S from the DCC_CROSS and monitoring the message generation by applications/services. When the DCC_FAC is supported, the functional requirements of DCC_FAC are as follows:

- DCC_FAC shall provide an indication of the upper limit for the channel resource utilization, e.g. minimum of inter-message interval, maximum message size, available data rate according to MCS, etc., for each message generation per application/service.

NOTE 1: Only if the required channel resources are estimated to be higher than the available channel resources, i.e. CBR_a defined in ETSI TS 103 175 [2], will DCC_FAC have an influence on generated messages.

- DCC_FAC shall not cause an ITS-S to underutilize the available channel resources.
- The channel load control for an ITS-S supported by DCC_FAC should slightly overutilize the available channel resources.
- The channel resource utilization indicated by DCC_FAC shall take the message priority based on the traffic class as defined in ETSI TS 102 636-4-2 [1] into account.

If the DCC_FAC entity is supported, the DCC_CROSS shall implement the DCC_CROSS_Facilities function as described in ETSI TS 103 175 [2] (see Figure 2).

NOTE 2: Generated messages cannot be dropped by DCC_FAC by design.

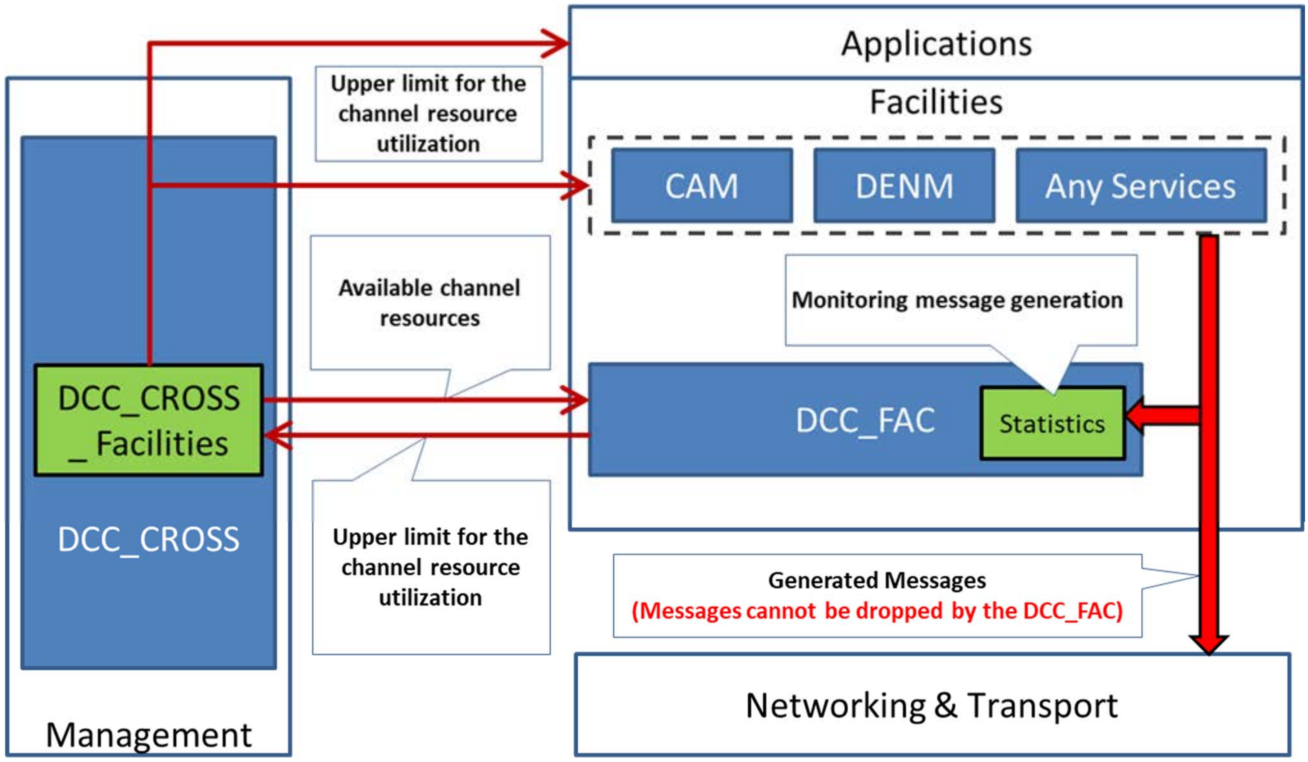

Figure 2: DCC_FAC entity in the Facilities Layer

The detailed mechanism of DCC_FAC entity is implementation specific. Possible mechanisms are described in Annex A and Annex B.

6 Interfaces for DCC_FAC

6.1 Overview

The DCC_FAC entity shall support the interfaces illustrated in Figure 2. The primitive transferred over these interfaces shall be compliant with ETSI TS 102 723-1 [3].

6.2 Interface with DCC_CROSS (MF-SAP)

6.2.1 MF-GET.request

6.2.1.1 Function

This primitive allows retrieving of a parameter in the management entity, as described in clause 5, and Annex A and Annex B.

6.2.1.2 Semantics

The parameters of the management service primitive MF-GET.request shall be as follows:

```
MF-GET.request    (
                  FAC-ID,
                  CommandRef,
                  Sequence of M-Param
                  )
```

Table 1: Parameters of the service primitive MF-GET.request

Name	ASN.1 type	Valid range	Description
MN-ID	INTEGER	Integer number	Unique identifier of the Management Interface
CommandRef	INTEGER	Integer number	Unique cyclic reference number of request
	INTEGER	0 to 255	Number of subsequent M-Param elements
M-Param.No	CHOICE	0 to 255	See Table 5
M-Param.Value		Depends on M-Param.No	

6.2.2 MF-GET.confirm

6.2.2.1 Function

This primitive reports the result of a previous MF-GET.request.

6.2.2.2 Semantics

The parameters of the management service primitive MF-GET.confirm shall be as follows:

```
MF-GET.confirm (
               FAC-ID,
               CommandRef,
               Sequence of Errors OPTIONAL
               )
```

Table 2: Parameters of the service primitive MF-GET.confirm

Name	ASN.1 type	Valid range	Description
MN-ID	INTEGER	Integer number	Unique identifier of the Management Interface
CommandRef	INTEGER	0 to 255	Unique cyclic reference number of request
	INTEGER	0 to 255	Number of subsequent Errors elements
Errors. M-paramNo	INTEGER	See Table 5	See Table 5
Errors.ErrStatus	ENUMERATED	Specified in ETSI TS 102 723-1 [3].	Indicates error status of request.

6.2.3 MF-SET.request

6.2.3.1 Function

This primitive allows setting of a parameter in the management entity, as described in clause 5, and Annex A and Annex B.

6.2.3.2 Semantics

The parameters of the management service primitive MF-SET.request shall be as follows:

```
MI-SET.request (
               MAC-ID,
               CommandRef,
               Sequence of M-Param
               )
```

Table 3: Parameters of the service primitive MF-SET.request

Name	ASN.1 type	Valid range	Description
MN-ID	INTEGER	Integer number	Unique identifier of the Management Interface
CommandRef	INTEGER	Integer number	Unique cyclic reference number of request
	INTEGER	0 to 255	Number of subsequent M-Param elements
M-Param.No	CHOICE	0 to 255	See Table 5
M-Param.Value		Depends on M-Param.No	

6.2.4 MF-SET.confirm

6.2.4.1 Function

This primitive reports the result of a previous MF-SET.request.

6.2.4.2 Semantics

The parameters of the management service primitive MF-SET.confirm shall be as follows:

```
MF-SET.confirm    (
                  MAC-ID,
                  CommandRef,
                  Sequence of Errors OPTIONAL
                  )
```

Table 4: Parameters of the service primitive MF-SET.confirm

Name	ASN.1 type	Valid range	Description
MN-ID	INTEGER	Integer number	Unique identifier of the Management Interface
CommandRef	INTEGER	0 to 255	Unique cyclic reference number of request
	INTEGER	0 to 255	Number of subsequent Errors elements
Errors. M-paramNo	INTEGER	See Table 5	See Table 5
Errors.ErrStatus	ENUMERATED	Specified in ETSI TS 102 723-1 [3]	Indicates error status of request

6.2.5 DCC Parameter at the MF-SAP

Table 5: List of M-Param for DCC interface at MF-SAP

M-Param.No	Name of M-Param	Access	Format	Description
0	Access Layer Identifier	W/R	1 octet 0 … ITS-G5 (Other values are reserved for future updates)	Indicates the Intended access layer technology for which the DCC parameters are retrieved
1	Channel Number	W/R	1 octet, Range from 1 to 7	Identifies the radio channel number for which the DCC parameters are retrieved
2	MCS	W/R	2 octets	MCS for which the DCC parameters are retrieved

M-Param.No	Name of M-Param	Access	Format	Description
3	Available resources	R	2 octets, mapped to reciprocal value of the available percentage of channel resources CR_a	Available percentage of channel resources CR_a for the ITS-S on the selected channel, provided by the DCC algorithm in relation to the total available channel resources available to all ITS-S. See the example below.
4	Application identifier	W/R		Locally unique application ID corresponding to the application index *i* for which the DCC parameters are written.
5	TC	W/R	1 octet	Traffic class corresponding to the index *j* for which the DCC parameters are written.
6	Average message size	W/R	1 octet, granularity is 1 OFDM symbol length = 8 µs	Average message size $\overline{T_{on\,ij}}$ for the application with index *i* and the traffic class with index *j*.
7	Minimum inter-message interval	W/R	2 octets, in ms	proposed minimum inter-message interval $T_{off\,\min ij}$ for the application/service with index *i* and the traffic class with index *j*.

EXAMPLE: For ITS-G5 CR_a is the percentage of time the radio channel is idle in relation to the total averaging time. It is called CBR_a in ETSI TS 103 175 [2].

Annex A (informative): Traffic class based DCC_FAC algorithm

A.1 Overview

The DCC_FAC entity is illustrated in Figure A.1. Its purpose is to support controlling the channel load generated by each application/service at the generation time. The left part illustrates the DCC_CROSS entity in the management plane. As described in ETSI TS 103 175 [2], the DCC_CROSS optionally introduces a DCC_CROSS_Facilities function interfacing with the DCC_FAC entity. For simplification of the figure, other functionalities located in DCC_CROSS are not depicted here.

The DCC_FAC obtains the available percentage of channel resources CR_a per radio channel from the DCC_CROSS. CR_a is provided by the DCC algorithm based on information provided by DCC_ACC.

DCC_FAC analyses the average length (number of octets) of the message and the average inter-message interval for each application and service by monitoring their behaviour, to calculate from the data rate for the used MCS the proposed minimum inter-message interval $T_{off\ \min ij}$ for each application/service with index *j* and traffic class with index *i*.

Based on this analysis, a table in the management plane can provide for each application/service, each used MCS, and each traffic class the proposed minimum inter-message interval and average message size per radio channel.

NOTE: Messages cannot be dropped directly by the DCC_FAC. When implemented, the DCC_FAC controls the message rates and message size indirectly through DCC_CROSS. The DCC_FAC implements a statistics function DCC_FAC_Statistics to monitor data behaviour from applications and services.

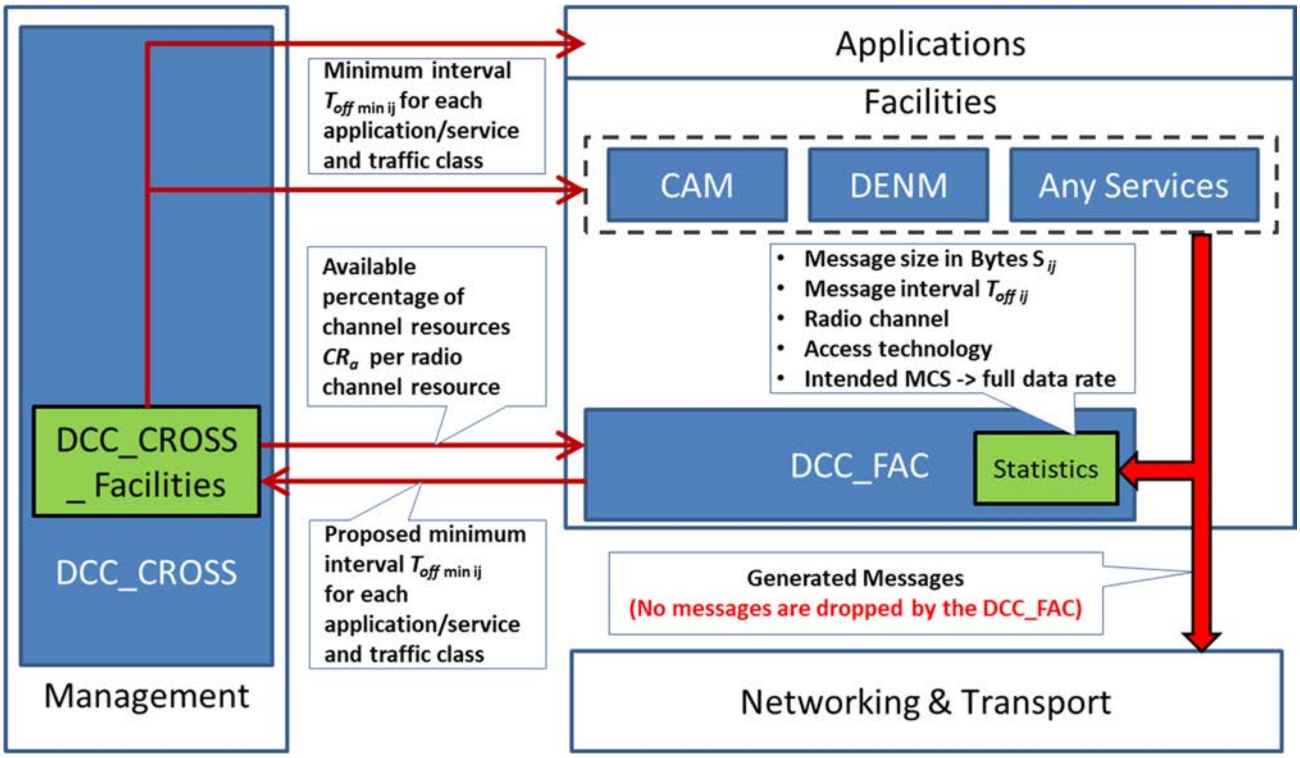

Figure A.1: DCC_FAC entity in the Facilities Layer of Traffic class based DCC_FAC algorithm

A.2 Details of Traffic class based DCC_FAC algorithm

The DCC_FAC entity performs the following steps for each radio channel at every time when the facilities layer generates a message:

1) When the facilities service entity generates a message for application/service *j* and TC_i, DCC_FAC analyses the message length L_{ij} of the recently generated message and the inter-message time interval $T_{off\ ij}$ between last two recently generated messages for application/service *j* and traffic class with index *i*, referred to as TC_i from the facilities service entity.

2) DCC_FAC estimates the average message length $\overline{L_{ij}}$ and the average inter-message interval $\overline{T_{off\ ij}}$ for application/service *j* and TC_i:

$$\overline{L_{ij}} = w \times L_{ij} + (1 - w) \times \overline{L_{ij}^{*}} \quad \text{(A.1)}$$

$$\overline{T_{off\ ij}} = w \times T_{off\ ij} + (1 - w) \times \overline{T_{off\ ij}^{*}} \quad \text{(A.2)}$$

Where $\overline{L_{ij}^{*}}$ is the previously estimated average message length for application/service *j* and TC_i. If $\overline{L_{ij}^{*}}$ is not available due to no previously generated message, $\overline{L_{ij}}$ is set to L_{ij}. The weight coefficient w is set to 0,1 for the examples in clause A.3.

And $\overline{T_{off\ ij}^{*}}$ is the previously estimated average inter-message interval for application/service *j* and TC_i. If $\overline{T_{off\ ij}^{*}}$ is not available due to no previously generated message, $\overline{T_{off\ ij}}$ is set to $T_{off\ ij}$.

NOTE 1: $T_{off\ ij}$ and $\overline{T_{off\ ij}}$ will be available as soon as the 2nd message for each application/service *j* and TC_i is generated.

3) Calculate the estimated channel resource $\overline{CRE_{ij}}$ for each application/service *j* and TC_i for the used MCS data rate R_{ij}:

$$\overline{CRE_{ij}} = \frac{\overline{L_{ij}}}{\overline{L_{ij}} + R_{ij} \times \overline{T_{off\ ij}}} \quad \text{(A.3)}$$

If $\overline{T_{off\ ij}}$ is not available due to no previously generated message, $\overline{CRE_{ij}}$ is set to 0.

4) Calculate the total estimated channel resources $\overline{CR_i}$ from all applications/services in one traffic class TC_i:

$$\overline{CR_i} = \sum_j \overline{CRE_{ij}} \quad \text{(A.4)}$$

5) Obtain the available channel resources CR_a from DCC_CROSS.

6) Set the available channel resources ACR_0 for traffic class TC_0.

$$ACR_0 = max(CR_{0min}, CR_a). \quad \text{(A.5)}$$

NOTE 2: CR_{0min} is set to 0,001 for the examples in clause A.3. $CR_{0min} > 0$ indicates the ITS-S to have an opportunity to send some messages at least every 4 seconds but typically one message every second.

7) Set the maximum available channel resources ACR_i for traffic class TC_i.

$$ACR_i = max\left(CR_{imin}, ACR_{(i-1)} - \overline{CR_{(i-1)}}\right) for\ i \geq 1 \quad \text{(A.6)}$$

NOTE 3: CR_{imin} is set to 0,001 for the examples in clause A.3.

8) Divide the available channel resources ACR_i between the application with index *j* and traffic class with index *i*:

$$ACR_{ij} = \frac{\overline{CRE_{ij}}}{\overline{CR_i}} \times ACR_i \quad \text{(A.7)}$$

9) Put the minimum inter- message interval $T_{off\ \min ij}$ into a table in the DCC_CROSS in the management plane:

$$T_{off\ \min ij} = \frac{\overline{L_{ij}}}{R_{ij}} \times \frac{1-ACR_{ij}}{ACR_{ij}} \quad \text{(A.8)}$$

Parameters

- External interface from DCC_CROSS (MF-SAP): available percentage of channel resources per radio channel CR_a (Message generation parameters shown in Figure A.1).
- External interface to DCC_CROSS (MF-SAP): the proposed minimum inter-message interval $T_{off\ \min ij}$ for each application/service with index *j* and traffic class with index *i*.
- Monitoring the applications and facilities services (e.g. CA basic service, DEN basic service, etc.): message length L_{ij} and inter-message interval $T_{off\ ij}$ of each application/service with index *j* and traffic class with index *i*.

A.3 Examples

Table A.1 shows a case that the available channel resource is sufficient for all application/services and traffic classes. Note that the message size for each application/service are fixed in this example but the method is applied to fixed and variable message sizes.

Table A.1: Example of Sufficient Channel Resources ($CR_a = 0,005, T_{on\ ij} = \frac{L_{ij}}{R_{ij}} = 0,001\ s$)

TC_i	ACR_i (ACR_{ij})	$T_{off\ ij}$	CR_i ($\overline{CRE_{ij}}$)	$T_{off\ \min ij}$
TC_1	0,005	0,499 s	0,002	0,199 s
TC_2	0,003	0,799 s	0,00125	0,332 s
TC_3	0,00175	0,999 s	0,001	0,570 s

Table A.2 shows a case when the available channel resource is insufficient due to the reduction of the inter-message interval of TC_1 from 0,499 s to 0,249 s. In this case, the minimum inter-message interval of TC_2 exceeds the expected inter-message interval of TC2 (i.e. 0,999 s > 0,799 s) and the generation of messages for TC_3 will be temporarily restricted to 1 Hz message rate.

Table A.2: Example of insufficient Channel Resources ($CR_a = 0,005, T_{on\ ij} = \frac{L_{ij}}{R_{ij}} = 0,001\ s$)

TC_i	ACR_i (ACR_{ij})	$T_{off\ ij}$	CR_i ($\overline{CRE_{ij}}$)	$T_{off\ \min ij}$
TC_1	0,005	0,249 s	0,004	0,199 s
TC_2	0,001	0,799 s	0,00125	0,999 s
TC_3	0	0,999 s	0,001	1,001 s

Annex B (informative): Transmission Demand and Deficit based DCC_FAC algorithm

B.1 Overview

Prioritizing messages using only static and fixed TCs may bring resource allocation challenges in future as the type of messages, such as High priority DENM, Normal DENM, CAM, CPM, MCM, multi-hop DENM, etc. continues to grow. According to ETSI TS 102 636-4-2 [1], there are 4 TCs, i.e. TC_0, …, TC_3, but the types of V2X safety messages are larger than 4.

Strict prioritization using static TCs is used by DCC_ACC for queuing and flow control as specified for DCC_CROSS according to ETSI TS 103 175 [2], which may lead to starvation of lower priority services during insufficient channel resources as described in ETSI TR 103 562 [i.4]. Such a starvation at DCC_CROSS and DCC_ACC may not be prevented, unless some resource is transferred at the DCC_FAC from a higher priority TC to a lower priority TC once in a while, while total resource consumption at DCC_FAC remains within the CR_a.

In this Annex, resource allocation is presented using an additional factor, i.e. resource deficit in addition to prioritization via TC, demonstrating the feasibility for flexible channel resource allocation using DCC_FAC on top of DCC_ACC, which may not be possible by DCC_ACC alone, thus presenting an additional benefit of DCC_FAC.

B.2 Operation of Channel Resource Calculation

As described in Annex A, DCC_FAC implements a statistics function DCC_FAC_Statistics to monitor data behaviour based on time series analysis from applications and services. This function monitors and keeps a history of the average message length $\overline{L_{ij}}$ of the generated messages and the average inter-message interval requested $\overline{T_{off\,ij}}$ and the minimum inter-message interval suggested by DCC_FAC, i.e. $T_{offmin\,ij}$.

In addition, DCC_FAC_Statistics monitors the average estimated channel resource demand $\overline{CR_i}$ by each TC_i and the maximum available channel resource ACR_i for each TC_i. Finally, for the starvation mitigation functionality as proposed in this Annex, DCC_FAC_Statistics stores the average resource deficit for each TC_i as:

$$\boldsymbol{ARD_i} = \mathbf{min}(\mathbf{0}, \boldsymbol{ACR_i} - \overline{\boldsymbol{CR_i}}) \qquad \text{(B.1)}$$

The estimated channel resource CR_i and available channel resource ACR_i are calculated in the same manner as detailed in Annex A. The gross channel resource GCR_i for each TC is calculated as a sum of the minimum between the maximum available channel resource and the available and estimated channel demand reduced by the average resource deficit ARD_i:

$$\boldsymbol{GCR_i} = \mathbf{min}(\boldsymbol{ACR_i}, \overline{\boldsymbol{CR_i}}) + \mathbf{x}_i * \boldsymbol{ARD_i} \qquad \text{(B.2)}$$

The coefficient x_i is used to give higher emphasis to a resource deficit of a higher priority TC, i.e. $x_{TC_1} > x_{TC_2} > x_{TC_3} > x_{TC_4}$. The values of x_i can be in the range of 0 to 1 such as: $x_{TC_1} = 1$; x_{TC_2} 0,5; $x_{TC_3} = 0{,}25$; $x_{TC_4} = 0{,}125$ respectively, denoting the deficit of each TC as twice important as the deficit of following lower priority TC. If x_i is set to 0 for all TC, then the allocation will be solely based on absolute prioity of each TC similar to Annex A.

This gross channel resource of each TC is adjusted proportionately as a function of the resource demand and resource deficit by other TCs to obtain the proportional net resource PNR_i:

$$\boldsymbol{PNR_i} = \frac{\boldsymbol{GCR_i}}{\sum_1^N \boldsymbol{GCR_k}} \qquad \text{(B.3)}$$

The net channel resource NCR_i for TC_i, is calculated as:

$$\boldsymbol{NCR_i} = \boldsymbol{PNR_i} \times \boldsymbol{CR_a} \qquad \text{(B.4)}$$

The NCR_i of each TC_i, is divided proportionately among its services in a similar manner as Annex A:

$$\boldsymbol{ACR_{ij}} = \frac{\overline{\boldsymbol{CRE_{ij}}}}{\overline{\boldsymbol{CR_i}}} \times \boldsymbol{NCR_i} \qquad \text{(B.5)}$$

Similarly, the inter message interval of each service *j* belonging to each TC_i is calculated as, and updated in the DCC_CROSS and DCC_FAC_Statistics:

$$\boldsymbol{T_{off\,\min ij}} = \frac{\overline{\boldsymbol{L_{ij}}}}{\boldsymbol{R_{ij}}} \times \frac{\boldsymbol{1-ACR_{ij}}}{\boldsymbol{ACR_{ij}}} \qquad \text{(B.6)}$$

B.3 Examples

Table B.1 shows the same example of insufficient channel resource as shown in Annex A, where TC_1 is allocated its resource demand of 0,004 while TC_3 is allocated no resource at all. CBR_a = 0,005, $T_{on\ ij} = \frac{\overline{L_{ij}}}{R_{ij}}$= 0,001 s.

Table B.1: Example of insufficient channel resources and first resource allocation

TC_i	$T_{off\ ij}$	CRE_i	CR_i	$T_{off\,\min ij}$
TC_1	0,249 s	0,004	0,004	0,199 s
TC_2	0,799 s	0,00125	0,001	0,999 s
TC_3	0,999 s	0,001	0	∞

Table B.2 shows the resource allocation at the next update considering the average resource deficit of each TC, with x_{TC_1} = 1; x_{TC_2}= 0,5 and x_{TC_3} = 0,25. On average, TC_1 sacrifices 0,018 s (18 ms) of inter message interval, to allow TC_3 messages once every 4 seconds, instead of completely blocking TC_3.

Table B.2: Example of insufficient channel resources and updated resource allocation

TC_i	$T_{off\ ij}$	CRE_i	CR_i	ARD_i	NCR_i	$T_{off\,\min ij}$
TC_1	0,249 s	0,004	0,004	0	0,00372	0,26775 s
TC_2	0,799 s	0,00125	0,001	0,00025	0,00105	0,954556 s
TC_3	0,999 s	0,001	0	0,001	0,00023	4,299 s

Table B.3 shows the resource allocation at the tenth update, considering the average of each parameter during the ten previous instances.

Table B.3: Example of insufficient channel resources and tenth updated resource allocation

TC_i	$T_{off\ ij}$	CRE_i	CR_i	ARD_i	NCR_i	$T_{off\,\min ij}$
TC_1	0,249 s	0,004	0,00382	0,00014	0,00362	0,275298 s
TC_2	0,799 s	0,00125	0,00102	0,00023	0,00104	0,960179 s
TC_3	0,999 s	0,001	0,00015	0,00088	0,00034	2,937318 s

History

Document history		
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