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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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Foreword

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

1 Scope

ITS road safety and traffic efficiency systems include both vehicle to vehicle communications and related vehicle to roadside communication in highly dynamic vehicular ad hoc networks. These systems (ITS stations) are based on a set of protocols and parameters called ITS-G5 as specified in the European profile standard on the physical and medium access layer of 5 GHz ITS [2].

Many applications and services in ITS rely on the cooperative behavior of the vehicles and roadsides units which form a vehicular ad hoc network (VANET). The VANET enable the time critical road safety applications where fast information exchange is necessary to timely warn and support the driver. Special care should be taken to ensure proper functioning of the VANET and this includes decentralized congestion control (DCC) for the channels of ITS-G5.

DCC is a cross layer function, i.e. it has functions located on several layers of the ITS station reference architecture. Therefore the present document defines which DCC components are located on which layer of the ITS station communication architecture [5]. Furthermore the present document specifies the DCC mechanisms on the *access layer* (DCC_access) including transmit power control (TPC) per packet, transmit rate control (TRC) and transmit datarate control (TDC). The latter two control functions modify the average transmit power by modifying the duty cycle of the ITS station, i.e. the fraction of time that the ITS station is in "transmit" state. Additionally, DCC sensitivity control (DSC) adapts the clear channel assessment to resolve local channel congestion. Packets with higher priority are handled less restrictive introducing a transmit queueing concept and transmit access control (TAC).

The DCC mechanisms rely on knowledge about the channel. The channel state information is gained using channel probing. Channel probing measures are defined that enable the DCC methods TPC, TRC and TDC. The measures are on receive signal level thresholds or preamble information of detected packets.

The present document does not define the mechanisms at other layers than the access layer nor defines management aspects. These other mechanisms and the management aspects are necessary in order to make DCC work properly. The present document is primarily intended for trial use and may need to be updated after validation in field trials and/or other projects.

2 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.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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

2.1 Normative references

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

[1] IEEE 802.11-2007: "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".

[2] ETSI ES 202 663: "Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band".

[3] ETSI EN 302 571: "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[4] ETSI TS 102 868-1: "Intelligent Transport Systems (ITS); Testing; Conformance test specification for Co-operative Awareness Messages (CAM); Part 1: Test requirements and Protocol Implementation Conformance Statement (PICS) proforma".

[5] ETSI EN 302 665: "Intelligent Transport Systems (ITS); Communications Architecture".

[6] IEEE 802.2-1998: "Standard for Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements -- Part 2: Logical Link Control", (ISO/IEC 8802-2:1998).

2.2 Informative references

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 102 724: "Intelligent Transport Systems (ITS); Harmonized Channel Specifications for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.2] ETSI TS 102 723-3: "Intelligent Transport Systems; OSI cross-layer topics; Part 3: Interface between management entity and access layer".

[i.3] ETSI TS 102 723-10: "Intelligent Transport Systems; OSI cross-layer topics; Part 10: Interface between access layer and network and transport layers".

[i.4] ETSI TS 102 723-1: "Intelligent Transport Systems; OSI cross-layer topics; Part 1: Architecture and addressing schemes".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in [1], [2], [3], [5] and the following apply:

DCC component: part of the DCC, located in one layer, e.g. DCC_access

DCC_access mechanism: functionality of DCC_access usually using several DCC_access components

NDL database: database that contains DCC_access configuration parameters, input parameters and output parameters

reference parameter: parameter controlled by a control loop

3.2 Symbols

For the purposes of the present document, the symbols given in [1], [2], [3], [5] and the following apply:

acPrio access priority

NOTE: Provided by network layer or derived as specified in [1].

dB(x) decibel function: $10 \cdot \log_{10}(x)$
cl variable for channel load
cs variable for carrier sense threshold
ds variable for DCC sensitivity
$MIN(x_1; \ldots; x_N)$ minimum function, returns its lowest argument
$minCL(\Delta t)$ minimum channel load for time time period Δt
$MAX(x_1; \ldots; x_N)$ maximum function, returns its largest argument
$maxCL(\Delta t)$ maximum channel load for time time period Δt
M_{pkt} measured number of packets
N_p number of probes

N_{PR}	number of OFDM symbols in the preamble
N_{DPMS}	data bits per OFDM symbol
$pow(p, x)$	exponentiation: x^p
S	signal power level
S_{th}	signal level threshold
T_{AIR}	packet air time
T_{CA}	average time for channel access
T_m	measuring interval
T_p	probing interval
txQ	number of DCC_access transmit queues

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in [1], [2], [3], [5] and the following apply:

DCC	Decentralized Congestion Control
DCC_access	DCC component of the access layer
DCC_app	DCC component of the facility layer
DCC_mgmt	DCC component of the management layer
DCC_net	DCC component of the network layer
D-CCA	CCA sensitivity for DCC
DPSK	Digital Phase Shift Keying
DSC	DCC sensitivity control
NDL	Network Design Limits
SM	State Machine
SNR	Signal to Noise Ratio
TAC	Transmit Access Control
TDC	Transmit Datarate Control
TPC	Transmit Power Control
TRC	Transmit Rate Control
VANET	Vehicular Ad-hoc NETwork

4 Decentralized congestion control overview

4.1 DCC operational requirements

"Decentralized congestion control" (DCC) is a mandatory component of ITS-G5 stations operating in ITS-G5A and ITS-G5B frequency bands to maintain network stability, throughput efficiency and fair resource allocation to ITS-G5 stations. DCC requires components on several layers of the protocol stack and these components jointly work together to fulfil the following operational requirements:

- Provide fair allocation of resources and fair channel access among all ITS stations in the same communication zone.
- Keep channel load caused by periodic messages below pre-defined thresholds.
- Reserve communication resources for the dissemination of event driven high priority messages.
- Provide fast adoption to a changing environment (busy / free radio channel).
- Keep oscillations in the control loops within well-defined limits.
- Comply to specific system requirements, e.g. reliability.

4.2 DCC architecture

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

- ***DCC_access*** located in the access layer;
- ***DCC_net*** located in the networking and transport layer;
- ***DCC_app*** located in the facility layer;
- ***DCC_mgmt*** located in the management layer.

The components are connected through the DCC interfaces 1 to 5 as shown in Figure 1. These interfaces are mapped to the corresponding cross layer interfaces as described in TS 102 723 [i.2], [i.3], [i.4] and the present document.

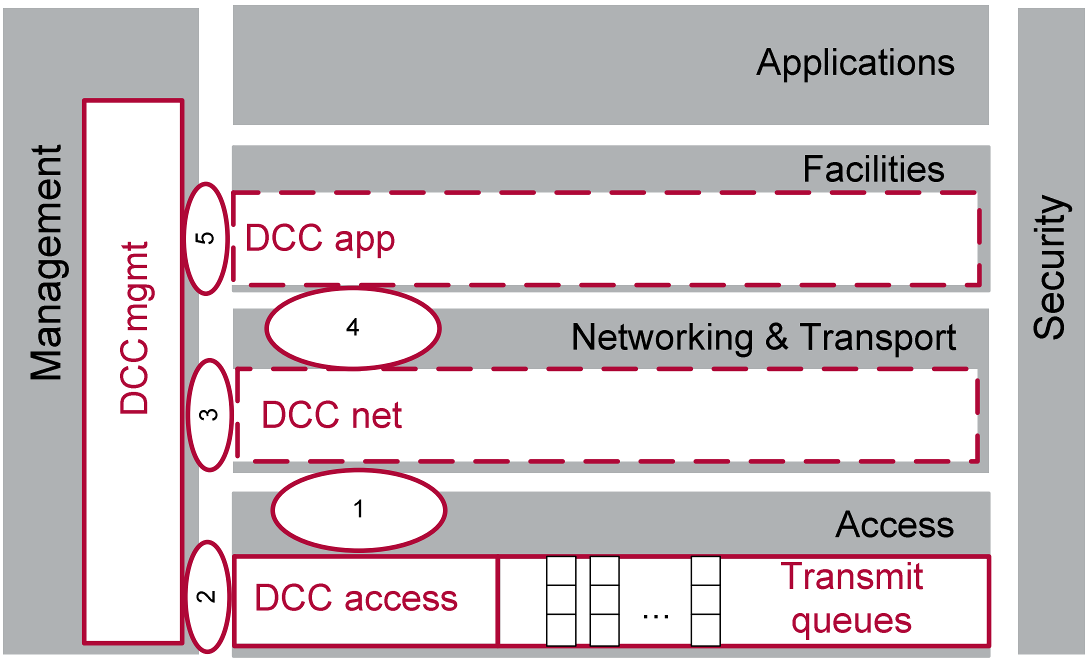

Figure 1: DCC Architecture

The present document specifies DCC_access, which comprises the DCC mechanisms *transmit power control* (TPC), *DCC sensitivity control* (DSC), *transmit rate control* (TRC) *transmit datarate control* (TDC) and DCC access control (TAC)

Additionally DCC_access services are specified that are offered to other DCC components using interface 1 [i.3] and interface 2 [i.2]. These services are a transmit model (Clause 5.6), a receive model (Clause 5.7) and channel probing (Clause 6.2) and transmit packet statistics (Clause 6.3).

NOTE: The term *packet* is used on the access layer and the network layer to indicate that usually the same payload is transported.

4.3 Network design limits (NDL)

An operational requirement of DCC is to keep the actual channel load below predefined limits that are part of the *Network Design Limits* (NDL, Clause A.4). The NDL are used to configure DCC_access. The NDL are stored in the *NDL database* that contains all relevant information used by DCC_access, i.e. configuration parameters, controlled parameters and DCC status information.

The NDL database is part of DCC_mgmt, i.e. the management layer is responsible for maintaining the information (configuration parameters). Data exchange between DCC_mgmt (including NDL database) and the other layers is described in the corresponding interface documents (TS 102 723 [i.2], [i.3], [i.4]).

The NDL database includes:

- ranges of the controlled parameters (minimum and maximum values);
- design limits, i.e. default and target values of the controlled parameters;
- regulatory limits and device dependent parameters (e.g. max. transmit power);
- model parameters, e.g. parameters of the transmit model, channel model and receive model;
- internal control loop parameters, e.g. signal level thresholds and time constants.

The controlled parameters and the measured parameters are written to the NDL database, especially:

- reference values, i.e. the average target value used by DCC_access transmit queuing for per packet control;
- channel load measures.

4.4 DCC_access functional view

Figure 2 shows the functional view of DCC_access with the building blocks:

- *transmit queuing* (Clause 6.1), which enhance the standard 802.11 queues by DCC mechanisms;
- *channel probing* (Clause 6.2) to collect statistics on the communication channel;
- *transmit statistics* (Clause 6.3) to observe the behavior of the own ITS station;
- *control loop* (Clause 6.4) that adapt the behavior of the own ITS station to the actual channel load.

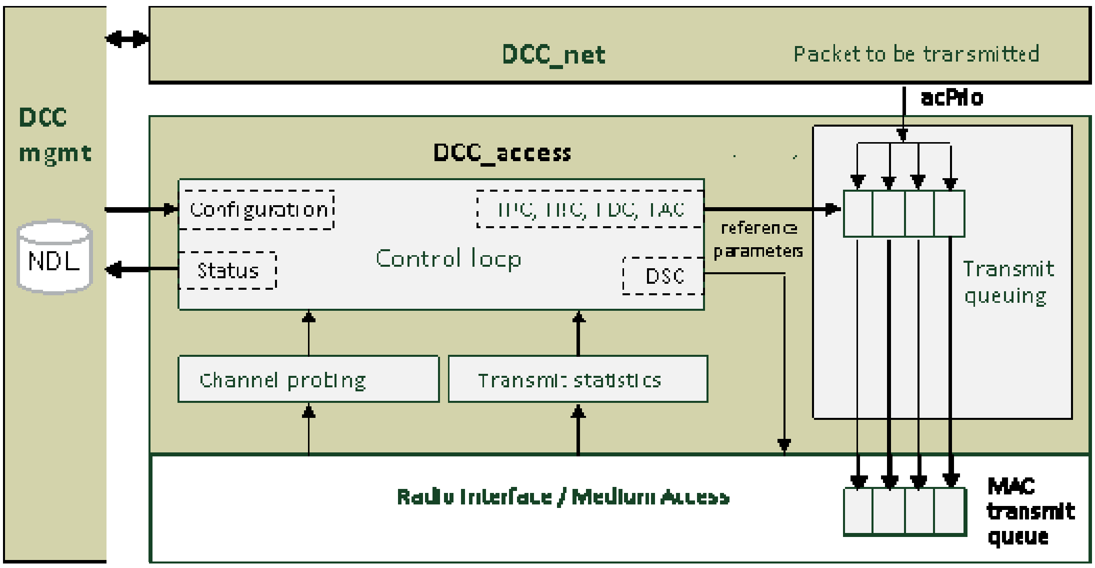

Figure 2: DCC_access functional view

DCC_access relies on measured values for the channel load (*Channel probing*) and on statistics about transmitted packets (*Transmit statistics*).

The transmit statistics of DCC_access shall take into account all packets that are transmitted, including packet repetitions, RTS, CTS and ACK packets.

The *Control loop* manages reference parameters according to the DCC_access mechanisms TPC, TRC, TDC and DSC. The reference parameters are:

- TPC → reference transmit power: *NDL_refTxPower*
- TRC → reference packet interval: *NDL_refPacketInterval*

- TDC → reference datarate: *NDL_refDatarate*
- DSC → reference D-CCA sensitivity: *NDL_refCarrierSense*
- TAC → reference queue status *NDL_refQueue*

Their usage is specified in Clause 5.

Packets are classified at network layer, which provides the access priority (acPrio) per packet via interface 1 (see Figure 1). Additionally each packet that arrives from the network layer has a preset value of transmit power and datarate.

The block *Transmit queuing* in Figure 2 assigns the packets to the corresponding MAC transmit queue (see [1]).

Enqueuing a packet to the MAC transmit queue shall not occur more frequently than specified by TRC.

On enqueuing a packet to its MAC transmit queue the preset values are compared with the current reference values of TPC, TRC and TDC and modified if necessary (see Clause [4]).

The DSC reference parameter *NDL_refCarrierSense* is used to control the CCA (see [1]).

DCC_app and DCC_net are out of scope of the present document. They may affect DCC_access indirectly by dynamically modifying the NDL database (Clause 4.3), i.e. the control loop configuration parameters. DCC_access provides a set of status parameters to these upper layers via the NDL database.

5 DCC access mechanisms

5.1 Transmit power control

5.1.1 TPC parameters

"Transmit power control" (TPC) is based on transmit power thresholds listed in Table 1.

The signal power thresholds depend on the selected channel from ITS-G5A or ITS-G5B and the selected transmit queue.

These thresholds are part of the NDL and shall be maintained by DCC_mgmt (Clause 4.2).

All transmit signal power thresholds shall be of type *ndlType_txPower* as specified in Table A.1.

Table 1: Transmit power thresholds

Transmit power thresholds	Definition
NDL_minTxPower	minimum transmit power (e.i.r.p.)
NDL_maxTxPower	maximum transmit power (e.i.r.p.)
NDL_defTxPower(acPrio)	default transmit power (e.i.r.p.)
NDL_refTxPower(acPrio)	reference transmit power (e.i.r.p.)

NDL_minTxPower is the minimum transmit signal power that can be selected by DCC_access.

NDL_maxTxPower is the maximum transmit signal power that can be selected by DCC_access, considering the maximum possible power and the maximum power allowed by regulation. Thus this value depends on the selected channel.

NDL_defTxPower is the default value for *NDL_refTxPower*, i.e. the transmit power that is used if no preset value is available.

NDL_refTxPower is the reference parameter set by the DCC_access mechanism TPC.

The NDL transmit signal power thresholds shall fulfil the following relations:

EQ 1: *NDL_minTxPower* ≤ *NDL_refTxPower* ≤ *NDL_maxTxPower*

EQ 2: *NDL_minTxPower* ≤ *NDL_defTxPower* ≤ *NDL_maxTxPower*

5.1.2 TPC Operation

The transmit power (*effTxPower*) of a packet can be set per-MSDU as described in [2]. This presetting of the network layer is modified by TPC according to the following rules:

- On reception via DCC interface 1 the packet is assigned to the corresponding transmit queue defined by the per-MSDU priority (*acPrio*).
- The preset per-MSDU value of effTxPower is corrected according to the following relation:

EQ 3: *effTxPower* = MIN(*NDL_refTxPower*(*acPrio*), *effTxPower*)

5.2 Transmit rate control

5.2.1 TRC parameters

"Transmit Rate Control" (TRC) is based on packet timing thresholds listed in Table 2.

The packet timing thresholds depend on the selected channel from ITS-G5A or ITS-G5B and the selected transmit queue. Timing thresholds are divided into packet *duration* thresholds and packet *interval* thresholds.

Packet duration thresholds shall be of type *ndlType_packetDuration* as specified in Table A.1. Packet interval thresholds shall be of type *ndlType_packetInterval* as specified in Table A.1. The thresholds are part of the NDL and shall be maintained by DCC_mgmt (Clause 4.2).

Table 2: Packet timing thresholds

Packet timing thresholds	Definition
Packet duration thresholds	
NDL_maxPacketDuration(*acPrio*)	maximum duration (air time) of a packet
Packet interval thresholds	
NDL_minPacketInterval	minimum interval between packets
NDL_maxPacketInterval	maximum interval between packets
NDL_defPacketInterval(*acPrio*)	default interval between packets
NDL_refPacketInterval(*acPrio*)	reference interval between packets

NDL_maxPacketDuration is the maximum allowed air time of a packet (T_{AIR}).
T_{AIR} is derived from the preamble duration and the number of data bits per OFDM symbol N_{DBPS} (see note 1):

EQ 4: $N_{PR} = (T_{PREAMBLE} + T_{SIGNAL}) / T_{SYMBOL}$

EQ 5: $T_{AIR} = (N_{PR} + N_{SYMBOL}) * T_{SYMBOL}$

with $T_{PREAMBLE}$, T_{SIGNAL}, T_{SYMBOL} and N_{SYMBOL} as specified in [1].

NOTE 1: $N_{SYMBOL} \approx 8 * packetLength / N_{DBPS}$ with *packetLength* as the number of bytes of the packet as encoded in the SIGNAL field of the PPDU (see [1]). N_{DPSK} is the number of data bits in an OFDM symbol dependent on MCS.

NOTE 2: $N_{PR} = 5$

NOTE 3: $T_{SYMBOL} = 8$ µs for 10 MHz channels.

NDL_maxPacketDuration shall be of type *ndlType_packetDuration* as specified in Table A.1.

NDL_minPacketInterval is the minimum packet interval that can be selected by DCC_access.

NDL_maxPacketInterval is the maximum packet interval that can be selected by DCC_access.

NDL_defPacketInterval is the default value for *NDL_refPacketInterval*, i.e. the packet interval that is used if TRC is inactive.

NDL_refPacketInterval is the reference parameter set by the DCC_access mechanism TRC.

The packet timing thresholds shall fulfil the following relations:

EQ 6: $NDL\_minPacketInterval \leq NDL\_refPacketInterval \leq NDL\_maxPacketInterval$

EQ 7: $NDL\_minPacketInterval \leq NDL\_defPacketInterval \leq NDL\_maxPacketInterval$

The packet intervals shall be measured between subsequent starts of packets.

NDL_maxPacketDuration shall be small compared to *NDL_minPacketInterval* (see [i.1]).

The packet intervals are of type *ndlType_packetInterval* as specified in Table A.1.

5.2.2 TRC Operation

The packet air time of a packet (T_{AIR}) is derived from the packet length according Clause 5.2.1.

- On reception via DCC Interface 1 the packet is assigned to the corresponding transmit queue defined by the per-MSDU priority (*acPrio*).
- In case that T_{AIR} exceeds *NDL_maxPacketDuration* the packet shall be dropped.

NOTE 1: TDC could be used to decrease T_{AIR} and avoid packet drops (Clause 5.3.2).

- If *NDL_refPacketInterval(acPrio) > 0* the configured packet interval shall be ensured.

Ensuring the packet interval means that there shall be a time interval of at least *NDL_refPacketInterval(acPrio*) between the transmission start of the current packet (from *queue acPrio*) and the transmission start of the previous packet.

NOTE 2: Transmissions of the previous packet also includes packet repetitions, RTS, CTS or ACK packets.

NOTE 3: The time for arbitration can be neglected.

5.3 Transmit datarate control

5.3.1 TDC parameters

"Transmit Datarate Control" (TDC) is based on datarate thresholds listed in Table 3.

The datarate thresholds depend on the selected channel from ITS-G5A or ITS-G5B and the selected priority.

All datarate thresholds shall be of type *ndlType_dataRate* as specified in Table A.1. They shall be maintained by DCC_mgmt (Clause 4.2).

Table 3: Packet datarate thresholds

Packet datarate thresholds	Definition
NDL_minDatarate	minimum datarate
NDL_maxDatarate	maximum datarate
NDL_defDatarate(*acPrio*)	default datarate
NDL_refDatarate(*acPrio*)	reference datarate

NDL_minDatarate is the minimum datarate that can be selected by DCC_access.

NDL_maxDatarate is the maximum datarate that can be selected by DCC_access.

NDL_defDatarate is the default value of *NDL_refDatarate*, i.e. the value that is used if TDC is inactive.

NDL_refDatarate is the reference parameter set by the DCC_access mechanism TDC.

The datarate parameters are specified via the MCS value as specified in [2].

The datarate parameters shall fulfil the following relations:

EQ 8: $NDL\_minDatarate \leq NDL\_refDatarate \leq NDL\_maxDatarate$

EQ 9: $NDL\_minDatarate \leq NDL\_defDatarate \leq NDL\_maxDatarate$

5.3.2 TDC Operation

The transmit datarate (*effTxDatarate*) of a packet can be set on a per-MSDU basis as described in [2]. This reference setting is modified by DCC_access according the following rules:

- On reception via Interface 1 the packet is assigned to the corresponding transmit queue defined by the per-MSDU priority (*acPrio*).
- The preset per-MSDU value *effTxDatarate* is corrected according to the following relation:

EQ 10: $effTxDatarate = \mathrm{MAX}(NDL\_refDatarate(acPrio), effTxDatarate)$

Furthermore the following TDC functionality shall be provided

- While the air time T_{AIR} of a packet exceeds *NDL_maxPacketDuration* the datarate *effTxDatarate* shall be increased, but not above *NDL_maxDatarate*.

5.4 DCC Sensitivity control

5.4.1 DSC parameters

"DCC Sensitivity Control" DSC is based on sensitivity thresholds listed in Table 4. All sensitivity thresholds shall be of type *ndlType_rxPower* as specified in Table A.1. They shall be maintained by DCC_mgmt (Clause 4.2).

The sensitivity thresholds are used to determine whether the transmitter is clear to send or not (Table 4). They depend on the selected channel from ITS-G5A or ITS-G5B (see [i.1]).

Table 4: DCC sensitivity thresholds

Receive signal thresholds	Definition
NDL_minCarrierSense	minimum D-CCA sensitivity
NDL_maxCarrierSense	maximum D-CCA sensitivity for DCC
NDL_defCarrierSense	default D-CCA sensitivity
NDL_refCarrierSense	reference D-CCA sensitivity

The "Clear Channel Assessment for DCC" (D-CCA) shall indicate a busy channel during a reception of a packet with receive level greater than *NDL_refCarrierSense*. In case that the preamble portion was missed, the D-CCA shall hold the carrier sense signal busy for any signal above *NDL_refCarrierSense.*

NDL_minCarrierSense is the minimum D-CCA sensitivity that can be selected by DCC_access.

NDL_maxCarrierSense is the maximum D-CCA sensitivity that can be selected by DCC_access.

NDL_defCarrierSense is the default value of *NDL_refCarrierSense*, i.e. the value that is used if DSC is inactive.

NDL_refCarrierSense is the reference parameter set by DCC_access mechanism DSC.

The thresholds for D-CCA sensitivity shall fulfil the following relations:

EQ 11: $NDL\_minCarrierSense \leq NDL\_refCarrierSense \leq NDL\_maxCarrierSense$

5.4.2 DSC operation

DSC has an impact on CCA by applying the reference parameters *NDL_refCarrierSense* instead of the installed receiver sensitivity and the -65 dBm carrier sense threshold defined in [1]. This modified version of CCA is called D-CCA.

NOTE 1: The receiver sensitivity is not modified, only the thresholds for CCA. This provides the same chance for channel access to ITS stations with high sensitive receivers. The transmitter is allowed to transmit although a far distant transmitter might be active at the same time.

Whenever the DCC_acces control loop changes its state (Clause 6.4.2) the D-CCA reference parameter *NDL_refCarrierSense* is modified accordingly (Clause 6.4.4).

NOTE 2: DSC gives priority in channel access to higher priority messages by setting a higher D-CCA sensitivity threshold *NDL_refCarrierSense* for the "priority" transmit queues and DCC prevents channel congestion resulting from external interference blocking the transmitter due to a too sensitive carrier sensing.

5.5 Transmit access control

5.5.1 TAC parameters

"Transmit access control" (TAC) is the DCC_access mechanism that support the operational requirement of fair channel access. In case of high channel load the TAC is more restrictive to ITS-stations that transmit many packets. This is done using the DCC_access transmit queueing (Clause 6.1).

The DCC_mgmt shall maintain the queueing parameters as shown in Table 6 (Clause 4.2). The parameters shall be maintained per channel.

Table 5: Queueing parameters

Receive signal thresholds	Definition
NDL_numQueue	Number of transmit queues in DCC_access
NDL_refQueueStatus(acPrio)	Status of transmit queue

NDL_numQueue is the number of available transmit queues (Clause 6.1).

NDL_refQueueStatus(*acPrio*) is the reference parameter set by the DCC_access mechanism TAC. It is an array of length *NDL_numQueue.* An array element *NDL_refQueueStatus*(*acPrio*) indicates the status of the transmit queue with priority *acPrio*.

5.5.2 TAC operation

The transmit queues are ordered according the priority such that the highest priority queue has priority index $q = 0$. The actual transmit statistics (A.2) are compared with the statistics of the DCC transmit model (Clause 5.6).

If too many packets are sent with priority index less or equal q the corresponding queue is marked as closed, i.e.:

EQ 12: $$NDL\_refQueueStatus(q) = \text{CLOSED} \;\; \text{if} \;\; txChannelUse(q) \geq NDL\_tmChannelUse(q)$$

otherwise the queue is OPEN, i.e.:

EQ 13: $$NDL\_refQueueStatus(q) = \text{OPEN} \;\; \text{if} \;\; txChannelUse(q) < NDL\_tmChannelUse(q)$$

Packets with priority *acPrio* that arrives at a closed transmit queue (*NDL_refQueueStatus*(*acPrio*) = CLOSED) shall be dropped.

NOTE: Packet drops can be avoided by the network layer by checking the queue status before sending a packet to the access layer.

The time interval between subsequent checks of the rules above shall be not greater than *NDL_minDccSampling* (Table 14).

5.6 DCC Transmit model

DCC_access relies on a transmit model that approximates the expected channel use of an ITS station. DCC_access compares the statistics of the own transmissions with the transmit model.

The DCC_mgmt shall maintain the transmit model parameters as shown in Table 6 (Clause 4.2). The parameters shall be maintained per channel.

Table 6: Transmit model parameters

Transmit model parameters	Definition
NDL_tmPacketArrivalRate(acPrio)	expected transmit packet arrival rate
NDL_tmPacketAvgDuration(acPrio)	expected average transmit packet duration
NDL_tmPacketAvgPower(acPrio)	expected average transmit power
NDL_tmChannelUse(acPrio)	expected cumulative channel use
NDL_maxChannelUse	maximum channel use

NDL_tmPacketArrivalRate(acPrio) is specified as the expected arrival rate of all packets transmitted by the ITS-station with priority *acPrio.*

EXAMPLE: *NDL_tmPacketArrivalRate*(AC_BE) = 3 packet/s means that not more than 3 packets/s are expected with priority AC_BE.

NDL_tmPacketAvgDuration(*acPrio*) is specified as the expected average duration of all packets transmitted with priority *acPrio.*

NDL_tmPacketAvgPower(acPrio) is specified as the expected average signal power of all packets arriving from the network layer with priority *acPrio, considering the* preset per-MSDU values *effTxPower* (Clause 5.1.2) and *effTxDatarate* (Clause 5.3.2).

The cumulative transmit channel use *NDL_tmChannelUse*(*acPrio*) is specified as the fraction of time that the ITS station is expected to use the channel by transmitting packets with priority less or equal *acPrio*. It is derived from the expected transmit packet arrival rate and the expected average duration.

EQ 14 $$NDL\_tmChannelUse(acPrio) = \sum_{n=0\ldots acPrio} NDL\_tmPacketAvgDuration(n) * NDL\_tmPacketArrivalRate(n)$$

The channel use parameters shall be of type *ndlType_channelUse* as specified in Table A.1.

NOTE: *NDL_tmChannelUse*(*acPrio*) could be used as reference parameter by other DCC components, e.g. DCC_net.

NDL_maxChannelUse is the overall channel use with

EQ 15 $$NDL\_maxChannelUse = NDL\_tmChannelUse(NDL\_numQueue-1)$$

5.7 DCC receive model

The mechanisms of DCC_access rely on a receive model that is used to estimate the communication range. This receive model is based on a demodulation model and a channel model.

5.7.1 Receive model parameters

The DCC_mgmt shall maintain the receive model parameters as shown in Table 7.

Table 7: Receive model parameters

Receive model parameter	Definition
NDL_defDccSensitivity	Default DCC receiver sensitivity
NDL_maxCsRange	Maximum carrier sensing range
NDL_refPathloss	Reference pathloss parameter
NDL_minSNR	Minimum SNR to decode 3 Mbit/s datarate

These parameters are used in the demodulation model (Clause 5.7.3) and the channel model (Clause 5.7.2).

NDL_defDccSensitivity is the default receiver sensitivity that DCC_access assumes for other ITS stations. It shall be of type *ndlType_rxPower* as specified in Table A.1.

NDL_maxCsRange is the maximum carrier sensing range that results for the 3 Mbit/s datarate assuming that a packet can be decoded at a signal to noise ratio *NDL_minSNR* whereas the receive signal strength equals *NDL_defDccSensitivity* and the transmit signal power equals *NDL_maxTxPower.*

NDL_refPathloss is the pathloss parameter of the pathloss channel model (Clause 5.7.2) for which the following relation shall hold:

EQ 16: $$1{,}8 \le NDL\_refPathloss \le 4{,}0$$

NDL_refPathloss shall be of type *ndlType_pathloss* as specified in Table A.1.

NDL_minSNR is the expected SNR at which other ITS stations can successfully decode the 3 Mbit/s datarate.

NDL_minSNR shall be of type *ndlType_snr* as specified in Table A.1.

5.7.2 Channel model

DCC_access shall estimate the communication range for line-of-sight communication. The estimates shall be made available to the management entity (Clause 5.7.4).

This estimation relies on the log-distance path loss model given in EQ 17 and EQ 18. The channel model links the *distance* between transmitter and receiver to a receive signal power *rxPower* given a transmit power *txPower* with the following properties:

EQ 17: $$\text{rxPower(distance/2)} = \text{rxPower(distance)} + 3\text{ dB} * \text{NDL\_refPathloss}$$

EQ 18: $$\text{rxPower(NDL\_maxCsRange)} = \text{NDL\_defDccSensitivity} + (\text{txPower} - \text{NDL\_maxTxPower})$$

EQ 17 establishes a linear behavior of the receive signal power (in decibel) when displayed on an logarithmic distance axis (Figure 3). EQ 18 gives a fixed-point as a result of the specification of *NDL_maxCsRange* in Clause 5.7.1.

NOTE: *NDL_refPathloss*=2 gives the free space channel model.

5.7.3 Demodulation model

DCC_access relies on a demodulation model. The SNR demodulation model is based on the assumption that the demodulation and decoding process is successful if the actual SNR is above a given threshold *requiredSnr(datarate).* The detection process is assumed to be successful if the actual SNR is at least *NDL_minSNR.*

On request DCC_access shall provide the required SNR *requiredSnr(datarate)* dependent on the datarate:

EQ 19: $$requiredSnr(datarate) = NDL\_minSNR + NDL\_snrBackoff(datarate)$$

with *NDL_snrBackoff*(*datarate*) as given in Table 8.

All SNR values shall be encoded with type *ndlType_snr* as specified in Table A.1.

Table 8: SNR backoff

MCS	Datarate (Mbit/s)	ΔSNR (dB)
0	3	0
1	4,5	1
2	6	3
3	9	5
4	12	8
5	18	12
6	24	16
7	27	17

NOTE 1: Table 8 is derived from the minimum receiver sensitivity as specified in [1].

NOTE 2: MCS according Table 3 of [2].

5.7.4 Communication ranges

On request DCC_access shall provide the communication ranges as summarized in Table 9 to the management entity.

Table 9: Communication ranges

Communication ranges
carrierSenseRange (*txPower*)
estCommRange(*txPower*, *datarate*)
estCommRangeIntf(*txPower*, *datarate*)

The communication ranges depend on the input parameters *txPower* and the *datarate*.

The specification of the communication ranges is given in Clause A.3.

All communication ranges shall be of type *ndlType_distance* as specified in Table A.1.

5.7.5 Example receive model

Figure 3 shows an example of the receive model. In this example it is assumed that the noise level (-95 dBm) is by *NDL_minSNR* = 10 dB smaller than the *NDL_defDccSensitivity* level (-85 dBm). In case the packet is transmitted at 3 Mbit/s with the maximum transmit power *NDL_maxTxPower*, it can be successfully decoded at a distance of *NDL_maxCsRange* = 1 000 m.

In the same scenario, the successful decoding of a packet transmitted at a datarate of 12 Mbit/s requires a SNR that is by ΔSNR(12 Mbit/s) = 8 dB higher than the one for the packet transmitted at 3 Mbit/s. The corresponding distance reduces to less than 500 m.

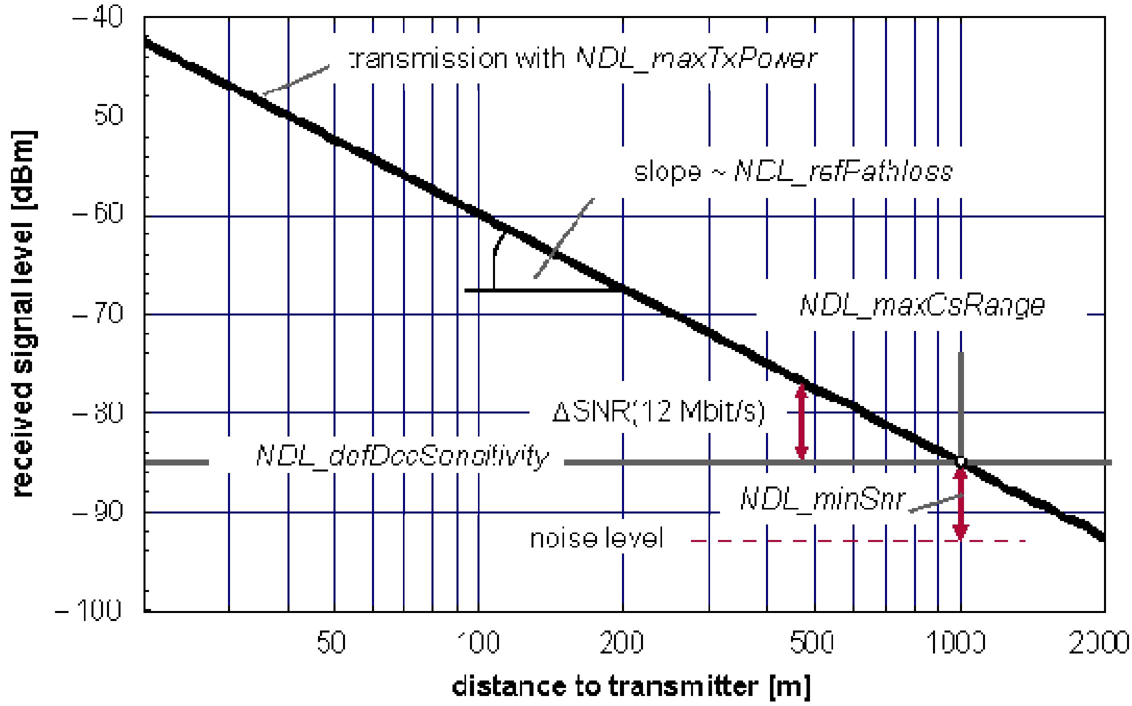

Figure 3: Example receive model

6 DCC_access components

6.1 DCC transmit queueing

ITS-G5 shall use the EDCA mechanism per channel defined in [1]. DCC transmit queuing shall support one transmit queue per EDCA queue. The EDCA parameters (AIFS, CWmin, CWmax and TXOP) shall be set as specified in [1] on a per-queue basis.

Additionally to the standard EDCA mechanisms in [1] the DCC_access transmit queuing shall meet the DCC_access transceiver requirements for TPC, TRC and TDC (Clause 5). The following additional parameters are used to define the characteristic of each queue.

Table 10: DCC transmit queuing parameter

Channel load thresholds	Definition
NDL_refTxPower(acPrio)	Reference transmit power per queue (implements TPC)
NDL_refPacketInterval(acPrio)	Reference frame rate per queue (implements TRC)
NDL_refDatarate(acPrio)	Reference frame datarate per queue (implements TDC)
NDL_refCarrierSense(acPrio)	Reference threshold for D-CCA (implements DSC)
NDL_queueLen(acPrio)	Maximum count of pending frames

NOTE: According to [1] at least 4 transmit queues are available (AC_VI, AC_VO, AC_BE and AC_BK), but typical WLAN controllers implement up to 10 transmit queues.

6.2 Channel probing

DCC relies on channel probing, i.e. the extraction of channel load measures from the received signal and detected packets (PLCP header).

DCC_access shall provide the channel load measures as listed in Table 10 as a service (Clause 4.2). The channel load measures are specified in Clause A.1.

Table 11: Channel load measures

Channel load measure
channelLoad(ds)
loadArrivalRate(ds)
loadAvgDuration(ds)
packetArrivalRate(ds)
packetAvgDuration(ds)
channelBusyTime(ds, cs)

The channel load measures depend on the DCC sensitivity *ds* and the carrier sense threshold *cs.* Although the channel load measures are defined for all values of *ds* and *cs*, only the following settings are mandatory:

ds = cs = NDL_defCarrierSense

NOTE: The default value *NDL_defCarrierSense* is not changed. Therefore the channel load measurements are independent of the adaptation by the DCC control loop.

Channel probing shall use the threshold *NDL_defCarrierSense (Clause A.1.2).*

D-CCA (Clause 5.4.2) shall use *NDL_refCarrierSense*

The DCC_access methods TPC, TRC and TDC rely on the channel load measures *channelLoad(ds)* or *channelBusyTime(ds, cs)*. The other measures are provided to other DCC components as a service (Clause 4.2).

6.3 Transmit packet statistics

DCC relies on packet statistics, i.e. how often packets are transmitted by the ITS station of a given priority. All transmitted packets are taken into account including system generated packets like RTS, CTS, ACK and packet repetitions.

DCC_access shall provide the transmit packet statistics as a service (Clause 4.2). The transmit packet statistics are summarized in Table 12 and specified in Clause A.2.

Table 12: Transmit packet statistics

Transmit packet statistics	Definition
txPacketArrivalRate(*acPrio*)	transmit packet arrival rate
txPacketAvgDuration(*acPrio*)	transmit packet average duration
txSignalAvgPower(*acPrio*)	transmit signal average power
txChannelUse(*acPrio*)	cumulative transmit channel use

The transmit model parameter *tmChannelUse*(*acPrio*) as specified in Table 6 serve as thresholds for the actual channel use *txChannelUse*(*acPrio*).

RTS, CTS and ACK shall be accounted with the highest priority (AC_VI) and packet repetitions shall be accounted with the same priority as the original packet.

6.4 DCC access control loop

6.4.1 State machine

The DCC_access control loop is the central element of DCC_access. It distinguishes three states RELAXED, RESTRICTIVE and ACTIVE building a "state-machine" (SM) as displayed in, Figure 4.

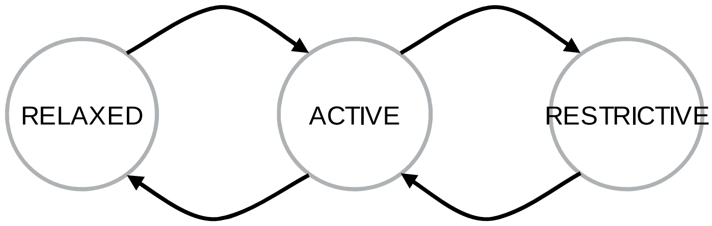

Figure 4: DCC_access state machine

The SM relies on channel load threshods as listed Table 13. The DCC_mgmt shall maintain the channel load thresholds for the selected channel from ITS-G5A or ITS-G5B.

Table 13: State machine parameters

Channel load thresholds	Definition
NDL_minChannelLoad	relaxed channel load
NDL_maxChannelLoad	restrictive channel load

The channel load *channelLoad*(*ds*) is specified as the fraction of time that the received signal level is above *ds* (Clause A.1). The objective of DCC_access is to keep the channel load below *NDL_maxChannelLoad*, i.e.

EQ 20: $$channelLoad(NDL\_defDccSensitivity) \leq NDL\_maxChannelLoad$$

The NDL channel load thresholds shall fulfil the following relation:

EQ 21: $$NDL\_minChannelLoad \leq NDL\_maxChannelLoad$$

NDL_minChannelLoad is the minimum channel load below which the channel is assumed to be mainly free and DCC_access will be in state RELAXED.

NDL_maxChannelLoad is the maximum channel load above which the channel is assumed to be overloaded and DCC_access will be in state RESTRICTIVE.

The state changes are triggered if the measured channel load exceeds given thresholds for a period of time. The DCC_mgmt shall maintain the state machine time constants (Table 14) for the selected channel from ITS-G5A or ITS-G5B.

Table 14: State machine time constants

State machine time constants	
NDL_TimeUp	Time constant ramping up (more restrictive)
NDL_TimeDown	Time constant ramping down (less restrictive)
NDL_minDccSampling	sampling time of the DCC_access SM

Two time constants *NDL_TimeUp* and *NDL_TimeDown* control how fast the SM react on changes of the channel load.

NDL_TimeUp controls how fast the control loop reacts if the channel load is increased.

NDL_TimeDown controls how fast the control loop reacts if the channel load is decreased.

NDL_minDccSampling is the minimum time interval between subsequent checks for SM transitions (Clause 6.4.2)

The state machine time constants shall fulfil the following relation:

EQ 22: $$NDL\_minDccSampling \leq NDL\_timeUp \leq NDL\_timeDown$$

6.4.2 State transitions

The state transitions of the SM shall be based on two input signals:

- *minCL*(*NDL_timeUp*)
  Minimum channel load for the past time period of length *NDL_timeUp*

- *maxCL minCL*(*NDL_timeDown*).
  Maximum channel load for the past time period of length *NDL_timeDown*

The channel load measure *channelLoad*(*NDL_defCarrierSense*) shall be used to determine *minCL*(*NDL_timeUp*) and *maxCL* (*NDL_timeDown*).

The initial state shall be the state RELAXED.

The state transitions of the SM shall be event driven according the following rules:

In state RELAXED:

- the state shall be switched to ACTIVE if *clMin*(*NDL_timeUp) ≥ NDL_minChannelLoad*.

In state RESTRICTIVE:

- the state shall be switched to ACTIVE if *clMax*(*NDL_timeDown) < NDL_maxChannelLoad.*

In state ACTIVE:

- the state shall be switched to RELAXED if *clMax*(*NDL_timeDowm) < NDL_minChannelLoad*.
- the state shall be switched to RESTRICTIVE if *clMin*(*NDL_timeUp) ≥ NDL_maxChannelLoad*.

The time interval between subsequent checks of the rules above shall be not greater than *NDL_minDccSampling.*

6.4.3 State configuration

The DCC_access states are configured using state parameter sets (Table 15). The DCC_mgmt shall maintain the state parameter sets dependent on the selected channel from ITS-G5A or ITS-G5B.

Table 15: State parameter set

State parameter	Mechanism	RELAXED	RESTRICTIVE
asStateId		0	*NDL_numActiveState*+1
asChanLoad		*NDL_minChannelLoad*	*NDL_maxChannelLoad*
asDcc(acPrio)		ALL	ALL
asTxPower(acPrio)	TPC	*NDL_maxTxPower*	*NDL_minTxPower*
asPacketInterval(acPrio)	TRC	*NDL_minPacketInterval*	*NDL_maxPacketInterval*
asDatarate(acPrio)	TDC	*NDL_minDatarate*	*NDL_maxDatarate*
asCarrierSense(acPrio)	DSC	*NDL_minCarrierSense*	*NDL_maxCarrierSense*

NOTE 1: The state parameters *asDcc*(acPrio), *asTxPower*(acPrio), *asPacketInterval*(acPrio) and *asDatarate*(acPrio) and *asCarrierSense*(acPrio) are arrays of length *NDL_numTxQueue*.

There is a fixed state parameter set for the states RELAXED and RESTRICTIVE (Table 17). The parameters are applied to all transmit queues if the corresponding conditions are fulfilled (Clause 6.4.4).

The number of parameters sets in the ACTIVE state is *NDL_numActiveState*, corresponding to ACTIVE sub-states Active(1) … Active(*NDL_numActiveState*) as shown in Figure 5 for *NDL_numActiveState*=2.

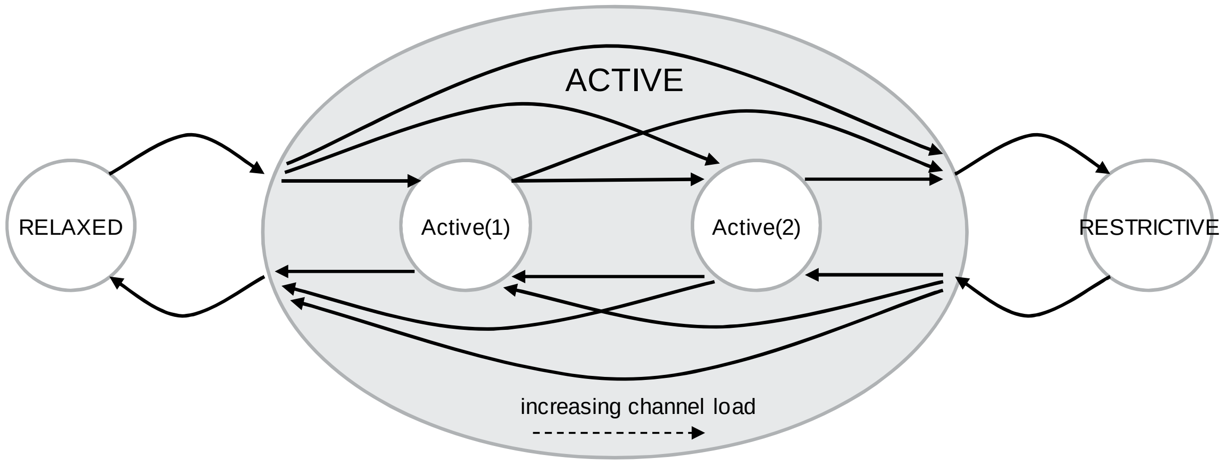

Figure 5: ACTIVE sub-states (*NDL_numActiveState*=2)

NOTE 2: The ACTIVE sub-states are fully meshed. The current sub-state depends on the channel load history. Nevertheless if the channel load changes slowly the list index *n* increases and decreases accordingly.

The DCC_mgmt shall maintain the number of ACTIVE sub-states and the current state of the SM as listed in Table 16.

Table 16: SM status parameter

DCC parameters	Definition
NDL_numActiveState	number of ACTIVE sub-states
NDL_curActiveState	current state

The configuration of the ACTIVE sub-states describes the DCC_access mechanisms TPC, TRC, TDC and DSC.

All parameter sets are collected in a state list *stateList* with list index *asStateId*. The parameter set of the state RELAXED is *stateList*(0). The parameter set the of state RESTRICTIVE is *stateList*(*NDL_numActiveState*+1). The parameter sets of the ACTIVE sub-states have list indices *NDL_asStateId* ∈ {1… *NDL_numActiveState*}.

The state list *stateList* shall form an ordered list with respect to the channel load parameter *NDL_asChanLoad*, i.e.:

EQ 23
$$NDL\_asChanLoad(n-1) < NDL\_asChanLoad(n) \quad \text{for } n \in \{1; 2; \ldots ; NDL\_numActiveState+1\}$$

Hereby *NDL_asChanLoad*(*n*) is the parameter *NDL_asChanLoad* of the parameter set *stateList*(*n*), i.e. the argument *n* is the sub-state selector.

The state parameters *asDcc*(*acPrio*), *asTxPower*(*acPrio*), *asPacketInterval(acPrio*), *asDatarate*(*acPrio*) and *asCarrierSense*(acPrio) are arrays of length *NDL_numTxQueue.*

The parameter *asDcc* of *type ndlType_dccMechanism* (Table A.2) is used to select which DCC_access mechanisms are selected (Table A.2).

6.4.4 State processing

When a state is entered the state output parameters are set as listed in Table 17. The state output parameters are in a set of the same type as the configured state parameter sets of Table 15. This enables the assignment of a state parameter set to the state output parameters.

Table 17: State output parameters

State output parameter	Definition
NDL_refStateId	State identifier
NDL_refChannelLoad	applied channel load threshold
NDL_refDcc	applied DCC_access mechanism
NDL_refTxPower	applied TPC parameter
NDL_refPacketInterval	applied TRC parameter
NDL_refDatarate	applied TDC parameter
NDL_refCarrierSense	applied DSC parameter

When a state change occur the following state output parameters shall be set:

In state RELAXED:

- Set the state output parameters to the RELAXED parameter set of Table 15.

In state RESTRICTIVE:

- Set the state output parameters to the RESTRICTIVE parameter set of Table 15.

In state ACTIVE:

- Find *asStateId* = MAX(*stateUp*, *stateDown*) with:

EQ 24
$$minCL(NDL\_timeUp) \geq NDL\_asChanLoad(stateUp - 1)$$
$$minCL(NDL\_timeUp) < NDL\_asChanLoad(stateUp)$$

EQ 25
$$maxCL\ (NDL\_timeDown) < NDL\_asChanLoad(stateDown + 1)$$
$$maxCL\ (NDL\_timeDown) \geq NDL\_asChanLoad(stateDown)$$

- Set the state output parameters to the ACTIVE sub-state parameter set *stateList*(*asStateId*). If a DCC_access mechanism is not selected in *stateList*(*asStateId*), the corresponding reference parameters shall not be changed, i.e. the value shall be taken from the previous state output parameter set.

When leaving a state the SM status shall be updated, i.e. *NDL_curActiveState* shall be set to *asStateId*.

In Figure 6 an example for the timing of state transitions is shown with two ACTIVE sub-states Active(1) and Active(2). The measured channel load is used to calculate the input signals *minCL*(*NDL_timeUp*) and *maxCL* (*NDL_timeDown*). State transitions to state *stateId* are triggered if these signals cross the channel load thresholds *NDL_asChanLoad*(*stateId*). In Figure 6 the measured channel load is first increasing linearly then decreasing. When increasing the triggering times are based on *minCL*(*NDL_timeUp*). When decreasing the triggering times are based on *maxCL*(*NDL_timeDown*).

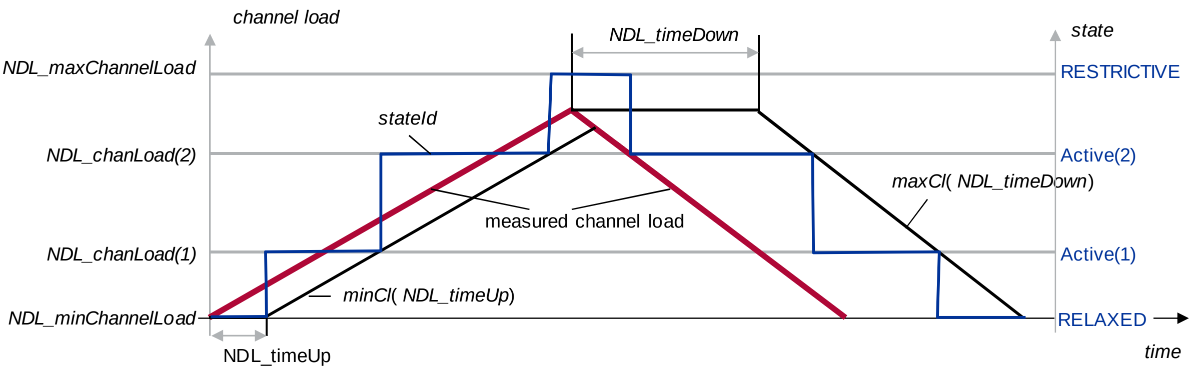

Figure 6: Example: Timing of state transitions

The state transitions of the SM (Clause 6.4.2) and the sub-state transitions in state ACTIVE (EQ 24, EQ 25) depend on conditions for the channel load. The time interval between subsequent checks of the rules above shall be not greater than *NDL_minDccSampling*.

7 DCC access interfaces

In this clause the interfaces are specified to an extent, which is required for a proper interaction of DCC_access with DCC_net and DCC_mgmt. This means that the present document does not claim to specify a complete set of services, related primitives and parameters lists, which may be required for access layer functionalities that are beyond the scope of DCC_access.

In the context of the present document the following interfaces are relevant :

- IN-SAP: Access ↔ Network & Transport (Clause 7.1)
- MI-SAP: Access ↔ Management (Clause 7.2)

The interfaces shall be as defined in [i.4].

7.1 Interface 1: IN-UNITDATA service

This clause specifies the IN-SAP based on IEEE 802.2 [6] and defines the IN-DATA service that enables an unacknowledged, connectionless mode data transfer. The following service primitives apply:

- IN-UNITDATA.request
- IN-UNITDATA-STATUS.indication

The primitive **IN-UNITDATA-STATUS.indication** is used by DCC_access as a local acknowledge following a previously received **IN-UNITDATA.request.**

The interface shall be as defined in [i.3].

7.2 Interface 2: MI-SET and MI-GET services

The MI-SET and MI-GET services gives full access to the network design limits database, which shall be located in the management entity (Clause A.4). The NDL database stores configuration parameters for DCC_access, which can partly be set by higher communication layer mechanisms (e.g. DCC_net). In turn DCC_access can store information (e.g. ***NDL_channelLoad (ds)***), which may be relevant for other DCC components, e.g. DCC_net. In order to set and retrieve parameters to and from the NDL database the following services of the MI-SAP are relevant for DCC_access:

- MI-SET
- MI-GET

The MI-SET service is used by DCC_access in order to set a configuration parameter in the NDL database. For this it uses the MI-SET.request primitive, which contains a key-value pair of parameters to be configured in the database. The request is confirmed by the management entity with the aid of the MI-SET.confirm primitive.

In order to retrieve configuration data from the NDL database DCC_access uses the MI-GET service. For this it uses the MI-GET.request primitive, which contains a complete list of desired parameters. On this request the management entity responds using the MI-GET.confirm primitive. It contains a list of key-value pairs according to the previous MI-GET.request.

The services, related service primitives and their parameter lists shall be in accordance with [i.2].

Annex A (normative): DCC parameter

A.1 Channel load measures

A.1.1 Parameters

The methods for channel measurements are implementation dependent. Therefore in the following clauses *reference* measuring methods are defined. Other methods could be used but they should not yield lower values of the channel load.

The *reference* measuring methods use different time scales:

- Probing interval T_p.
  T_p should be small compared to the minimum packet length. Typically it is in the order of ~10 µs.
- Measuring interval T_m.
  T_m shall be long compared to the maximum packet length. Typically it is in the order of ~1 s

In addition some IEEE 802.11 [1] based parameters are used, e.g.:

- Preamble duration T_{pr},
  duration of PLCP preamble; and
- Average time for channel access T_{ca},
  considering interframe space and length of contention window.

The channel measuring methods shall either select a given number N_p of probes during the measuring interval T_m or count the number of segments M_{seg} or packets M_{pkt}. Obviously these numbers should be high enough to give stochastical evidence.

The number of probes N_p shall be determined by the lowest assumed transmission duration given by packet size and the datarate.

A.1.2 Channel load

The channel load *channelLoad*(S_{th}) is specified as the fraction of time that the received signal level is above S_{th} . The estimated channel load depends on the selected threshold S_{th}.

The estimation could be done using the following reference method:

- N_p probes of the receive signal are taken uniformly distributed within the measuring interval T_m. For all channel probes (of length T_p) the average signal level S is determined. Then the channel load measured for the receive signal level threshold S_{th} is given as:

$$channelLoad(S_{th}) = \sum (1\ \forall \text{ probes with } S > S_{th}) / N_p$$

If other methods are used, these methods shall not yield lower values.

A.1.3 Load arrival rate

The load arrival rate *loadArrivalRate*(S_{th}) is specified as the number of segments with $S \geq S_{th}$ (load state) that are arriving per time interval, assuming a segmentation of the received signals in segments with signal level above or below S_{th}.

The estimation could be done using the following reference method:

- The received signal is segmented with signal level $S \geq S_{th}$ (load segments) and $S < S_{th}$ (idle segments) . The number M_{seg} of load segments within T_m is determined. Hereby short load segment are neglected, e.g. load segments shorter than the preamble duration T_{pr}.

- The load arrival rate is estimated as:

$$loadArrivalRate(S_{th}) = M_{seg} / T_m$$

If other methods are used, these methods shall not yield lower values.

A.1.4 Load average duration

The load average duration $loadAvgDuration(S_{th})$ is specified as the average length of the load segments derived from a segmentation of the received signal in segments with signal level $S \geq S_{th}$ (load segments) and $S < S_{th}$ (idle segments).

The estimation could be done using the following reference method:

- The load average duration is determined as:

$$loadAvgDuration(S_{th}) = channelLoad(S_{th}) / loadArrivalRate(S_{th})$$

If other methods are used, these methods shall not yield higher values.

A.1.5 Receive packet arrival rate

The receive packet arrival rate $rxPacketArrivalRate(S_{th})$ is specified as the number of detected packets per time interval. Hereby only those packets are counted that arrive with signal level higher than S_{th}.

The receive packet arrival rate depends on the preamble detection, i.e. the evaluation of the PLCP header.

The estimation could be done using the following reference method:

- The number M_{pkt} of detected packets with $S \geq S_{th}$ within T_m is determined.

- The packet arrival rate is estimated as:

$$rxPacketArrivalRate(S_{th}) = M_{pkt} / T_m$$

If other methods are used, these methods shall not yield lower values.

A.1.6 Receive packet average duration

The receive packet average duration rx*PacketAvgDuration* (S_{th}) is specified as the average length of all packets that are detected with signal level $S \geq S_{th}$. The average packet duration depends on the preamble detection.

The estimation could be done using the following reference method:

- The number M_{pkt} of detected packets with $S \geq S_{th}$ within T_m is determined.

For those packets the packet air time T_{AIR} is determined according

- EQ 5 using the PLCP header information.

- The receive packet average duration is determined as:

$$rxPacketAvgDuration(S_{th}) = \sum T_{AIR} / M_{pkt}$$

If other methods are used, these methods shall not yield higher values.

A.1.7 Packet Occupancy

The packet occupancy *packetOccupancy*(S_{th}) is specified as the fraction of time that the channel is occupied by packets detected with receive signal level above S_{th} including the waiting times between subsequent packets due to channel access.

Therefore a *packetOccupancy*(S_{th}) = 100 % occurs if the detected packets with $S \geq S_{th}$ are ideally lined up.

The *packetOccupancy* can be estimated by the following reference method:

- The packet occupancy is determined as:

$$packetOccupancy(S_{th}) = rxPacketArrivalRate(S_{th}) * (rxPacketAvgDuration(S_{th}) + T_{CA})$$

If other methods are used, these methods shall not yield lower values.

A.1.8 Channel busy time

The channel busy time *channelBusyTime* is specified as the fraction of time the channel is regarded as busy, i.e. when one of the following conditions are met:

- A detected packet has a higher signal level than *NDL_defDccSensitivity*.
- The received signal level is higher than *NDL_defCarrierSense*.

The estimation could be done using the following reference method:

- The received signal is segmented in *busy* and *idle* channel states: The channel is sensed busy for the duration of detected packets with S ≥ *NDL_defDccSensitivity*. Furthermore the channel is sensed busy if the received signal level is higher than *NDL_defCarrierSense*. This defines the channel busy signal.
- *Np* probes of the channel busy signal are taken uniformly distributed within the measuring interval T_m. An estimation of the channel busy time is given by:

$$channelBusyTime = \sum (1 \ \forall \text{ probes with channel } busy) / Np$$

If other methods are used, these methods shall not yield lower values.

NOTE: The reference method uses an ensemble average that is equivalent to time averaging (OFDM regarded as ergodic process).

A.2 Transmit packet statistics

A.2.1 Transmit packet rate

The transmit packet rate *txPacketRate*(*acPrio*) is specified as the number of packets with priority equal to *acPrio* that are locally transmitted per unit of time.

The estimation could be done using the following reference method:

- Count M_{pkt} (*acPrio*), i.e. the number of transmitted packets with priority equal to *acPrio* during a measuring period of T_m.
- The transmit packet rate is determined as:

$$txPacketRate(acPrio) = M_{pkt}(acPrio) / T_m$$

NOTE 1: The measuring period T_m should be high enough to give stochastical evidence. Typically T_m is in the order of ~10 s.

NOTE 2: The measuring parameters M_{pkt} and T_m are defined in Clause A.1.1.

If other methods are used, these methods shall not yield lower values.

A.2.2 Transmit packet average duration

The transmit packet average duration *txPacketAvgDuration*(*acPrio*) is specified as the average duration of packets with priority equal to *acPrio* that are transmitted per time unit.

The estimation could be done using the following reference method:

- Count M_{pkt} (*acPrio*), i.e. the number of transmitted packets with priority equal to *acPrio* during a measuring period of T_m.

For those packets the packet air time T_{AIR} is determined according

- EQ 5 using the PLCP header information.
- The transmit packet average duration is determined as:

$$txPacketAvgDuration(acPrio) = \sum T_{AIR} (\forall \text{ packets with priority} = acPrio) \;/\; T_m$$

If other methods are used, these methods shall not yield lower values.

A.2.3 Average transmit signal power

The transmit signal average power *txSignalAvgPower*(*acPrio*) is specified as the average signal power of packets with priority equal to *acPrio*.

The estimation could be done using the following reference method:

- Count M_{pkt} (*acPrio*), i.e. the number of transmitted packets with priority equal to *acPrio* during a measuring period of T_m.

For those packets the air time T_{AIR} is determined according

- EQ 5 using the PLCP header information.
- For those packets the signal power SP is determined (in decibel).
- The average transmit signal power is determined as:

$$txSignalAvgPower(acPrio) = \mathrm{dB}((\sum (\mathrm{T_{AIR}} * \mathrm{dBinv(SP)}))/ \sum \mathrm{T_{AIR})}$$

If other methods are used, these methods shall not yield lower values.

A.2.4 Transmit channel use

The cumulative transmit channel use *txChannelUse*(*acPrio*) is specified as the fraction of time that the ITS station transmit packets with an priority less or equal to *acPrio*.

The estimation could be done using the following reference method:

$$txChannelUse(acPrio) = \sum_{\mathrm{n=0\ldots acPrio}} txArrivalRate(n) * txPacketAvgDuration(n).$$

A.3 Communication Ranges

A.3.1 Carrier Sense Range

DCC_access shall provide the estimated detection range *carrierSenseRange*(*txPower)*. The detection range is specified as a *distance* between transmitter and receiver within which the detection of that packet is very likely assuming a free channel and the pathloss channel model.

The definition of the pathloss channel model is based on *NDL_maxCsRange* with:

$$carrierSenseRange(NDL\_maxTxPower) = NDL\_maxCsRange$$

Using less transmit power *txPower* the detection range shrinks according to the signal power backoff:

$$txPowerBackoff = NDL\_maxTxPower - txPower$$

Using the pathloss channel model the receive signal power is calculated:

$$rxPower(txPower, distance) = NDL\_defDccSensitivity - txPowerBackoff - NDL\_refPathLoss * \mathrm{dB}(distance / NDL\_maxCsRange)$$

with the decibel function $y=\mathrm{dB}(x)=10*\log_{10}(x)$ and the inverse decibel function $x=\mathrm{dBinv}(y)=10^{y/10}$.

Solving *rxPower*(*txPower, carrierSenseRange*(*txPower*)) = *NDL_defDccSensitivity* yields

EQ 26: $$carrierSenseRange(txPower) = maxCarrierSenseRange * \mathrm{dBinv}(-txPowerBackoff / NDL\_refPathloss)$$

EXAMPLE: *NDL_maxTxPower*=33 dBm, *NDL_refPathloss*=2,5 and *NDL_maxCsRange*=1 000 m,
⇒ *carrierSenseRange*(23 dBm) = 398 m
⇒ *carrierSenseRange*(13 dBm) = 158 m

A.3.2 Estimated communication range

DCC_access shall provide the estimated communication range *estCommRange*(*txPower, datarate*) dependent on the transmit signal power *txPower* and the datarate assuming the SNR demodulation model.

EQ 27: $$estCommRange(txPower, datarate) = carrierSenseRange(txPower) * \mathrm{dBinv}(-\Delta\mathrm{SNR}(datarate) / NDL\_refPathloss)$$

The SNR backoff ΔSNR(datarate) is taken from Table 8.

EXAMPLE *NDL_maxTxPower*=33 dBm, *NDL_refPathloss*=2,5 and *NDL_maxCsRange*=1 000 m,
⇒ *estCommRange*(13 dBm, 12 Mbit/s) = 76 m

A.3.3 Estimated communication range under interference

DCC_access shall provide the estimated reliable communication range under interference that is specified as that range where hidden stations do not have a significant impact, according to the receive model.

EQ 28: $$estCommRangeIntf(txPower, datarate) = refCarrierSenseRange / (1+\mathrm{dBinv}(gamma(txPower, datarate) / NDL\_refPathloss))$$

Hereby all stations are assumed to transmit with *refTxPower*. This leads to the reference detection range:

EQ 29: $$refCarrierSenseRange = carrierSenseRange(NDL\_refTxPower)$$

with

EQ 30: $$gamma(txPower, datarate) = requiredSnr(\mathrm{datarate}) + (NDL\_refTxPower - txPower)$$

A.4 Network Design Limits

A.4.1 NDL types and formats

In table A.1 the NDL types and formats are given. All parameters are encoded as INTEGER *number* with a given range. A reference value and a step size are given, such that the corresponding physical value is given by:

$$\text{physicalValue} = referenceValue + number * stepSize$$

The NDL types and formats can be accessed directly or via the table index.

Table A.1: NDL types and formats

Type	Format	stepSize	referenceValue
ndlType_acPrio	INTEGER (0...7)	1	*number*
ndlType_controlLoop	INTEGER (0...7)	1	0
ndlType_arrivalRate	INTEGER (0..8191)	0,01 /s	0
ndlType_channelLoad	INTEGER (0..1000)	0,1 %	0 %
ndlType_channelUse	INTEGER (0..8000)	0,0125 %	0 %
ndlType_datarate	INTEGER (0..7)		Table 8
ndlType_distance	INTEGER (0..4095)	1 m	0
ndlType_numberElements	INTEGER (0..63)		*number*
ndlType_packetDuration	INTEGER (0..2047)	T_{SYM}	0
ndlType_packetInterval	INTEGER (0..1023)	10 ms	0
ndlType_pathloss	INTEGER (0..31)	0,1	1,0
ndlType_rxPower	INTEGER (0..127)	-0,5 dB	-40 dBm
ndlType_snr	INTEGER (0..127)	0,5 dB	-10 dB
ndlType_timing	INTEGER (0..4095)	10 ms	0
ndlType_txPower	INTEGER (0..127)	0,5 dB	-20 dBm
ndlType_ratio	INTEGER (0..100)	1 %	0 %
ndlType_exponent	INTEGER (0..100)	0,1	0
ndlType_queueStatus	Enumeration		Table A.2
ndlType_dccMechanism	Bitset		Table A.2

A.4.2 NDL Input parameter and constants

Table A.2: Enumeration, Bitset, Indices and Constants

Bitset and Enumeration	Variable	Type	Reference
ndlType_dccMechanism	asDcc	1= TPC; 2= TRC; 4=TDC; 8= DSC; 16=TAC;32=reserved; remark: 0=NONE; 63= ALL	Clause 6.4.2
ndlType_queueStatus		0=CLOSED, 1=OPEN	
Indices		**Type**	**Reference**
ndlType_acPrio	*acPrio*	ndlType_acPrio	Clause 6.1
ndlType_datarate	*datarate*	ndlType_datarate	Table 8

A.4.3 NDL database

Table A.3: NDL database

Transmit power threshold	**ACR**	**Type**	**Default**	**Ref.**
NDL_minTxPower	RR	ndlType_txPower	Table A.5	Table 1
NDL_maxTxPower	RR			
NDL_defTxPower(*acPrio*)	RR			
NDL_refTxPower(*acPrio*)	WW			
Packet timing thresholds				
NDL_maxPacketDuration(*acPrio*)	RW	ndlType_packetDuration	Table A.6	Table 2
NDL_minPacketInterval	RW	ndlType_packetInterval		
NDL_maxPacketInterval	RW			
NDL_defPacketInterval(*acPrio*)	RW			
NDL_refPacketInterval(*acPrio*)	WW			
Packet datarate thresholds				
NDL_minDatarate	RR	ndlType_datarate	Table A.7	Table 3
NDL_maxDatarate	RR			
NDL_defDatarate(*acPrio*)	RW			
NDL_refDatarate(*acPrio*)	WW			
Receive signal thresholds				
NDL_minCarrierSense	RR	ndlType_rxPower	-95 dBm	Table 4
NDL_maxCarrierSense	RR		-65 dBm	
NDL_defCarrierSense	RR		-85 dBm	
NDL_refCarrierSense	WW		-85 dBm	
Receive model parameter				
NDL_defDccSensitivity	RC	ndlType_rxPower	-85 dBm	Table 7
NDL_maxCsRange	RC	ndlType_distance	1 000 m	
NDL_refPathloss	RC	ndlType_pathloss	2,0	
NDL_minSNR	RC	ndlType_snr	10 dB	
Demodulation model parameter				
NDL_snrBackoff(*datarate*)	RC	ndlType_snr		Table 8
Transmit model parameter				
NDL_tmPacketArrivalRate(*acPrio*)	WR	ndlType_arrivalRate	n.a.	
NDL_tmPacketAvgDuration(*acPrio*)	WR	ndlType_packetDuration		
NDL_tmSignalAvgPower(*acPrio*)	WR	ndlType_txPower		
NDL_maxChannelUse	WR	ndlType_channelUse	See note 2	Table 6
NDL_tmChannelUse(*acPrio*)	WR			
Channel load thresholds				
NDL_minChannelLoad	RC	ndlType_channelLoad	Table A.8	Table 11
NDL_maxChannelLoad	RC			
Transmit queue parameter				
NDL_numQueue	RR	ndlType_acPrio	4	Table 5
NDL_refQueueStatus(acPrio)	WW	ndlType_queueStatus	OPEN	
NDL_queueLen(*acPrio*)	RC	ndlType_numberElements	Table A.9	Table 10

NOTE 1: The ACR column indicates the access rights for DCC_access (1st letter) and other DCC components (2nd letter): X: no access, R: read-only access, W: read-write access everytime, C: read-write once access (before startup).

NOTE 2: NDL_maxChannelUse and NDL_tmChannelUse(*acPrio*) could be used by other DCC components, e.g. DCC_mgmt or DCC_net, to support various channel usage schemes.

A.4.4 NDL output parameters

Table A.4: Output parameter

Demodulation model	ACR		
NDL_requiredSnr(*datarate*)	WR	ndlType_snr	Clause 5.7.3
Communication ranges			
NDL_carrierSenseRange (*txPower*)	WR	ndlType_distance	Table 9
NDL_estCommRange(*txPower*, *datarate*)	WR	ndlType_distance	
NDL_estCommRangeIntf(*txPower*, *datarate*)	WR	ndlType_distance	
Channel load measures			
NDL_channelLoad (*ds*)	WR	ndlType_channelLoad	Table 11
NDL_loadArrivalRate(*ds*)	WR	ndlType_arrivalRate	
NDL_loadAvgDuration(*ds*)	WR	ndlType_packetDuration	
NDL_packetArrivalRate(*ds*)	WR	ndlType_arrivalRate	
NDL_packetAvgDuration(*ds*)	WR	ndlType_packetDuration	
NDL_channelBusyTime(*ds*, *cs*)	WR	ndlType_channelLoad	
Transmit packet statistics			
NDL_txPacketArrivalRate(*acPrio*)	WR	ndlType_arrivalRate	Table 12
NDL_txPacketAvgDuration(*acPrio*)	WR	ndlType_packetDuration	
NDL_txChannelUse(*acPrio*)	WR	ndlType_channelUse	
NDL_txSignalAvgPower(*acPrio*)	WR	ndlType_txPower	

A.4.5 Channel dependent parameter

Table A.5: Transmit power defaults

Transmit power defaults	ACR	G5CC	G5SC
NDL_maxTxPower	RW	33 dBm	33 dBm
NDL_minTxPower	RW	-10 dBm	-10 dBm
NDL_defTxPower	RW	23 dBm	23 dBm

Table A.6: Packet timing defaults

Transmit power defaults	ACR	G5CC	G5SC
NDL_maxPacketDuration	RC	0,6 ms	1,0 ms
NDL_minPacketInterval	RC	0,04 s	0,04 s
NDL_maxPacketInterval	RC	1 s	2 s
NDL_defPacketInterval	RC	0,5 s	0,5 s

Table A.7: Packet datarate defaults

Transmit power defaults	ACR	G5CC	G5SC
NDL_minDatarate	RR	3 Mbit/s	6 Mbit/s
NDL_maxDatarate	RR	12 Mbit/s	18 Mbit/s
NDL_defDatarate	RR	6 Mbit/s	6 Mbit/s

Table A.8: Channel load defaults

Transmit power defaults	ACR	G5CC	G5SC
NDL_minChannelLoad	RR	15 %	20 %
NDL_maxChannelLoad	RR	40 %	50 %

A.4.6 Priority dependent parameters

Table A.9: DCC transmit queuing defaults

DCC Transmit queuing default	ACR	Type	G5CC	G5SC
NDL_queueLen(AC_VI)	RC	ndlType_numberElements	2	8
NDL_queueLen(AC_VO)	RC	ndlType_numberElements	2	8
NDL_queueLen(AC_BE)	RC	ndlType_numberElements	2	8
NDL_queueLen(AC_BK)	RC	ndlType_numberElements	2	8

A.4.7 Basic control loop NDL database

Table A.10: Basic DCC configuration

Generel configuration	ACR	Type	G5CC	G5SC
NDL_timeUp	RW	ndlType_timing	1 s	1 s
NDL_timeDown	RW	ndlType_timing	5 s	5 s
NDL_numActiveState	RR	ndlType_numberElements	1	4
NDL_curActiveState	WR	ndlType_numberElements	0	0
Active state configuration			**(Clause 6.4.3)**	
NDL_asStateId	RW	ndlType_numberElements	Table A.11	Table A.12
NDL_asTimeDn	RW	ndlType_timing		
NDL_asChanLoad	RW	ndlType_channelLoad		
NDL_asDcc	RW	ndlType_dccMechanism		
NDL_asTxPower(acPrio)	RW	ndlType_txPower		
NDL_asPacketInterval(acPrio)	RW	ndlType_packetInterval		
NDL_asDatarate(acPrio)	RW	ndlType_dataRate		
NDL_asCarrierSense(acPrio)	RW	ndlType_rxPower		

NOTE 1: Active state configuration is an array of *NDL_numActiveState* elements.

Table A.11: Default configuration G5CC

Value	Active 1			
	AC_VI	AC_VO	AC_BE	AC_BK
asStateId	1			
NDL_asChanLoad	20 %			
NDL_asDcc	0	TPC	TPC	TPC
NDL_asTxPower [dBm]	*ref*	25	20	15
NDL_asPacketInterval	*ref*	*ref*	*ref*	*ref*
NDL_asDatarate	*ref*	*ref*	*ref*	*ref*
NDL_asCarrierSense	*ref*	*ref*	*ref*	*ref*

NOTE 2: Value *ref* indicates that the parameter is unchanged and the previous value of the corresponding reference parameter is used, e.g. *NDL_asTxPower = NDL_refTxPower*.

Table A.12: Default configuration G5SC

Value	Active 1			
	AC_VI	AC_VO	AC_BE	AC_BK
NDL_asStateId	1			
NDL_asChanLoadUp	25 %			
NDL_asDcc	0	0	1	1
NDL_asTxPower	*ref*	*ref*	25	20
NDL_asPacketInterval	*ref*	*ref*	*ref*	*ref*
NDL_asDatarate	*ref*	*ref*	*ref*	*ref*
NDL_asCarrierSense	*ref*	*ref*	*ref*	*ref*
Value	**Active 2**			
	AC_VI	AC_VO	AC_BE	AC_BK
NDL_asStateId	2			
NDL_asChanLoad	30 %			
NDL_asDcc	1	1	1	3
NDL_asTxPower [dBm]	25	25	20	10
NDL_asPacketInterval [s]	*ref*	*ref*	*ref*	1
NDL_asDatarate	*ref*	*ref*	*ref*	*ref*
NDL_asasCarrierSense	*ref*	*ref*	*ref*	*ref*
Value	**Active 3**			
	AC_VI	AC_VO	AC_BE	AC_BK
NDL_asStateId	3			
NDL_asChanLoad	35 %			
NDL_asDcc	1	1	7	7
NDL_asTxPower [dBm]	15	15	10	5
NDL_asPacketInterval [s]	*ref*	*ref*	1	1,5
NDL_asDatarate [Mbit/s]	*ref*	*ref*	9	9
NDL_asasCarrierSense	*ref*			
Value	**Active 4**			
	AC_VI	AC_VO	AC_BE	AC_BK
NDL_asStateId	3			
NDL_asChanLoadUp	40 %			
NDL_asDcc	5	7	7	7
NDL_asTxPower [dBm]	5	0	-5	-10
NDL_asPacketInterval [s]	*ref*	1	1,5	2
NDL_asDatarate [Mbit/s]	12	12	18	18
NDL_asasCarrierSense	*ref*	*ref*	*ref*	*ref*

NOTE 3: Value *ref* indicates that the parameter is unchanged and the previous value of the corresponding reference parameter is used, e.g. *NDL_asTxPower = NDL_refTxPower*.

A.4.8 Enhanced DCC algorithm NDL database

Table A.13: Enhanced DCC algorithm configuration

Generel configuration	Type	Default	Ref.
NDL_excessThresholdDown	ndlType_channelLoad	2 %	Table A.13
NDL_excessThresholdUp	ndlType_channelLoad	5 %	
NDL_upperRankThreshold	ndlType_ratio	50 %	
NDL_lowerRankThreshold	ndlType_ratio	50 %	

Annex B (informative): Transmit power calibration

B.1 Common principles of transmit power calibration

To ensure fair use of the radio resources and a proper functioning of the DCC methods, the RF output power level of an ITS station should be calibrated.

Clauses B.2 and B.3 describe two calibration methods. that are sufficient to certify defined transmit power levels and transmit power steps of an ITS station. The calibration itself is out of scope of the present document. If other calibration methods are used the accuracy should not be less that the accuracy of the proposed methods. The appropriate method is chosen by the nature of the ITS station. If it is an inherent unchangeable part of another entity, like a vehicle, the method described in Clause B.2 is suited. If the ITS station consists of discrete parts that can be combined in different ways, like a transmitter, cabling, and antenna, the method described in Clause B.3 applies.

Clause B.4 lists the transmit power levels and their recommended accuracy to be use for the certification process.

B.2 Transmit power certification process for non modular ITS stations

B.2.1 Applicability and overview for non modular ITS stations

The transmit power calibration procedure described in Clause B.2 applies to ITS stations that are an inherent unchangeable part of another entity, or to ITS stations where the RF transmitter and the antenna are connected in a way that prevents them from detachment. In the following this entity will be called DUT.

EXAMPLE: The ITS station is part of a vehicle.
The RF transmitter and the antenna are in the same housing.

The calibration is performed in two steps. First the antenna pattern of the UUT is determined according to Clause B.2.2, than the maximum e.i.r.p. is measured according to Clause B.2.3.

B.2.2 Determination of antenna pattern for non modular ITS stations

The determination of the antenna pattern is needed to find the direction of maximum e.i.r.p. (boresight).

If the manufacturer declares borsight for a directional antenna with a gain of more than 6 dBi, no antenna pattern measurement is necessary. Otherwise the antenna pattern should be measured according to following procedure.

For correct placement of the UUT during measurement, the manufacturer should declare how the UUT is placed or mounted during normal operation.

EXAMPLE: A vehicle is placed on a horizontal street.
A fixed ITS station uses an antenna with defined mounting requirements.

The antenna pattern of the UUT should be measured in free space. The antenna patter of the UUT should be measured with 5° steps in azimuth and elevation angle.

The direction of the e.i.r.p. measurement is given by the direction of the maximum measured antenna gain. To determine this maximum, the absolute antenna gain is irrelevant, only the relative accuracy should be below ±1 dB.

The detailed description of the test procedure and setup is, though necessary, out of scope of the present document.

B.2.3 Measurement of e.i.r.p. for non modular ITS stations

If the antenna of the UUT is intended to be directional with a gain of more than 6 dBi than the e.i.r.p. should be measured in boresight as declared by the manufacturer.

If the antenna gain does not exceed 6 dBi in any direction, the e.i.r.p. is measured in the direction that was determined in the measurement as described in Clause B.2.2.

The measurement uncertainty of the e.i.r.p. test equipment should be less than ±1 dB. With this test equipment the measured e.i.r.p. should be the nominal value from Clause B.4 ±3 dB.

B.3 Transmit power certification process for modular ITS stations

B.3.1 Applicability and overview for modular ITS stations

This transmit power calibration procedure applies to ITS stations that consist of discrete parts that can be combined in different ways.

EXAMPLE: The ITS transmitter and the antenna are connected by an interchangeable cable.
An ITS transmitter can be equipped with different antennas.

The calibration is done in three steps:

- The maximum antenna gain of all antennas to be certified is measured (see Clause B.3.2).
- The cable loss of all cables to be certified is measured (see Clause B.3.3).
- The transmit output power level is measured for all configurations to be certified (see Clause B.3.4).

B.3.2 Determination of antenna pattern for modular ITS stations

The same procedure that was described for the whole UUT in Clause B.2.2 applies to the determination of the antenna pattern for a modular ITS station. But in case of a modular ITS station the antenna gain should be measured with an **absolute** accuracy of ±1 dB.

B.3.3 Determination of cable loss for modular ITS stations

If the antenna is connected by a cable to the transmitter, the loss of this cable should be measured with an accuracy of ±1 dB.

B.3.4 Determination of output power level for modular ITS stations

If more than one combination of transmitter, cable, and antenna are certified, than a tool should exist that allows configuring of the transmitter to compensate for the appropriate cable loss and antenna gain.

The nominal compensated output power level P_{TX} of the transmitter can be calculated from the in Clause B.4 specified e.i.r.p. level, the maximum measured antenna gain g_A, and the cable loss a_c:

$$P_{TXnom} = \text{e.i.r.p.} - g_A + a_c$$

NOTE: If the antenna is directly plugged to the transmitter connector a_c is zero.

The output power level of the transmitter should be measured with an accuracy of ±1 dB. With this test equipment the measured output power level of the transmitter should be in the range of P_{TXnom} ±2 dB.

B.4 Specified e.i.r.p. levels and step requirements to be calibrated

Each of following e.i.r.p. levels at which an ITS station is capable to transmit, should be calibrated according to the procedure described in Clauses B.2 or B.3.

Table B.1: Calibration levels

e.i.r.p.
-10 dBm
0 dBm
10 dBm
20 dBm
26 dBm
33 dBm

In between the calibrated values, the output power level should be adjustable in steps with a maximum step size of 3 dB. The step size must not be calibrated, but the steps should be monotonic.

NOTE: It is recommended to use a small but monotonic step size of approximately 1 dB or even less.

Annex C (informative): Example of a DCC_Net algorithm

C.1 Enhanced DCC algorithm

The enhanced DCC algorithm is an alternative to the ACTIVE state control loop described in Clause 6.4 in order to improve the performance and the stability of the overall basic DCC algorithm. As such, the enhanced DCC algorithm is only applied during the ACTIVE state of the basic DCC algorithm. The enhanced DCC algorithm is a DCC_Net algorithm because it is based on remote information (Clause C.2) transmitted in the LLC header.

The enhanced DCC control loop implementation uses additional DCC information from neighboring stations, e.g. the measured channel load, the currently used transmit power value and packet generation rates as provided by the DCC header defined in Clause C.2, to decide whether to increase or decrease the own transmission parameters.

The used transmission parameter values and channel load observations sent by neighbors should be collected by the DCC_access layer upon reception of a packet and should be stored in separate data structures to maintain the currently used transmit power, the currently used transmit packet rate and the observed channel load of the neighbors. In particular, the DCC_access should maintain the following data structures:

1) Data structure N as the set of all neighbors from which a DCC header has been received during the past second.

2) Data structure $T := \{t_n : n \in N\}$ as the set of transmit powers currently used by the neighbors listed in N including the own power value stored in NDL_refTxPower.

3) Data structure $R := \{r_n : n \in N\}$ as the set of transmit packet rates currently used by the neighbors listed in N including the own rate value indicated by NDL_refPacketInterval.

4) Data structure $CL := \{c_n : n \in N\}$ as the set of channel load values currently observed by the neighbors listed in N, excluding the own observation.

Based on the information received by neighbors, the enhanced DCC algorithm should work as follows:

1) Compute the average amount of channel load excess E_{above} and lower deviation E_{below} over all neighbors in N:

   $E_{above} := (1 / |N|) \sum \max (0, c_n - \mathit{NDL\_maxChannelUse})$

   $E_{below} := (1 / |N|) \sum \max (0, \mathit{NDL\_maxChannelUse} - c_n)$

2) Compute the values p_T and p_R, such that they reflect the own position inside the (ranked) lists T and R (at increasing order).

3) Compare E_{above} and E_{below} with maximum excess threshold *NDL_excessThresholdUp* and lower deviation threshold *NDL_excessThresholdDown:*

   a) If (E_{above} > *NDL_excessThresholdUp*) check the following conditions:

      i) If ((p_T / |N|) > NDL_upperRankThreshold) → decrease NDL_refTxPower

      ii) If ((p_R / |N|) > NDL_upperRankThreshold) → increase NDL_refPacketInterval

   b) If (E_{below} > *NDL_excessThresholdDown*) check the following conditions:

      i) If ((p_T / |N|) < NDL_lowerRankThreshold) → increase NDL_refTxPower

      ii) If ((p_R / |N|) < NDL_lowerRankThreshold) → decrease NDL_refPacketInterval

The above algorithm is illustrated in Figure C.1 and ensures that every node obtains a network view on the currently observed channel load and the currently used transmit parameters. Based on this view, it is determined whether any action has to be taken by the network as a whole in order to reduce the channel load (step 1) and finally whether the node itself participates in the distributed action. The latter decision is based on a comparison of the own transmit power/packet rate and the settings currently used by the neighbors, i.e. it is checked whether the node belongs to the relative subset of nodes that is using the highest/lowest transmission parameter configuration. Table 17 lists the default values for the thresholds *NDL_excessThresholdUp*, *NDL_excessThresholdDown*, *NDL_upperRankThreshold* and *NDL_lowerRankThreshold*.

Table C.1: Enhanced DCC algorithm configuration

DCC parameters	Value	Definition
NDL_excessThresholdUp	2 %	Excess threshold required to reduce TX parameters
NDL_excessThresholdDown	5 %	Lower deviation threshold required to increase TX parameters
NDL_upperRankThreshold	50 %	Threshold for classification of nodes with highest TX parameters
NDL_lowerRankThreshold	50 %	Threshold for classification of nodes with lowest TX parameters

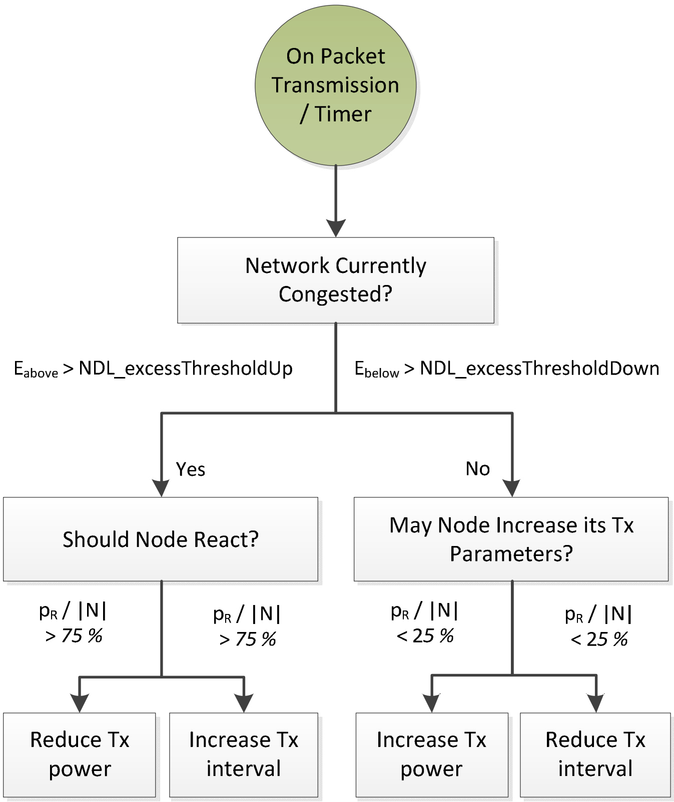

Figure C.1: Enhanced DCC algorithm

NOTE: The thresholds *NDL_excessThresholdDown*, *NDL_excessThresholdUp*, *NDL_upperRankThreshold* and *NDL_lowerRankThreshold* are used to tune the sensitivity of the protocol, and to address the convergence time versus oscillation tradeoff.

C.2 Remote information

For defining an enhanced control algorithm (Clause C.1) the following information of surrounding ITS stations is needed: the average transmit power level currently used, the observed channel load, the average transmit interval timing and the applied CCA sensitivity threshold. For this a DCC header is introduced, immediately follows the SNAP header. Another option would be to exchange this information on DCC network layer.

Currently all 802.11 frames are sent as Type1, UI command frames defined by LLC Control field values 0x03 (see IEEE 802.2 [6], Figure 10). To define the Frames as Type 1, UI command frames + DCC header the value 0x07 is used in the LLC Control field. This value does not conflict with any defined values (see IEEE 802.2 [6], Figures 10 and 16).

DSAP =0xAA	SSAP =0xAA	LLC Control	SNAP OUI	SNAP Pid	Opt. DCC header	NPDU

Figure C.2: DCC LLC structure

The DCC header itself contains the values needed for running the enhanced DCC algorithm.

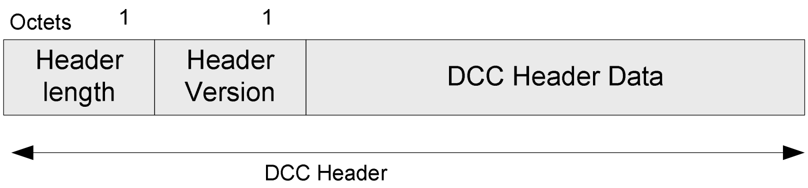

Figure C.3: DCC header structure

Header length

1 octet in length. Length of DCC header including this length field.

Header version

1 octet in length. Version for the DCC header.

DCC Header Data

4 octets in length. Contains:

- the observed channel load value (during the last second) as of type *ndlType_channelLoad*;
- the used transmit power of type *ndlType_txPower;*
- the used transmission interval of type *ndlType_timing;*
- the applied CCA sensitivity value with a step size of 1dB ranging between *NDL_minCarrierSense* and *NDL_maxCarrierSense*.

Annex D (informative): Validation

D.1 Validation scenarios

Systematic validation scenarios are used to verify algorithm behaviour. Since it is possible to overwrite some components of DCC_access by corresponding methods of other DCC components (e.g. DCC_net) these other methods should be verified using the validation scenarios and performance criteria as described in this annex.

Validation scenarios are classified based on two factors:

a) Extent of dynamic environment - Quantified as the number of new observed vehicles and vehicles no longer observed during a time unit. The main tool to emulate changing environment is adding mobility to the validation, manifested by different speed per vehicles and non-uniform space distribution. A dynamic environment challenges the algorithm by having to adapt to a changing situation.

b) Ratio of hidden stations - Quantified as ratio between neighbours within carrier sense range that potentially may receive hidden station transmissions and total number of neighbours within carrier sense range. The simplest increasing hidden station ratio is testing around urban intersections. High ratio of hidden stations will increase the difficulty of an algorithm to predict the current congestion in surrounding area.

These 2 factors are creating 4 scenarios: "Parking lot", "Clogged city", "Highway" and "Urban mobility".

1) "Parking lot" - static environment at low ratio of hidden stations

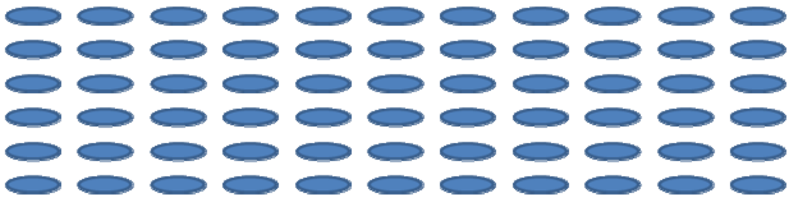

Figure D.1: "Parking lot" test scenario

Goal is basic sanity check.

2) "Clogged city" - static environment at high ratio of hidden stations. Buildings block direct transmission between close vehicles.

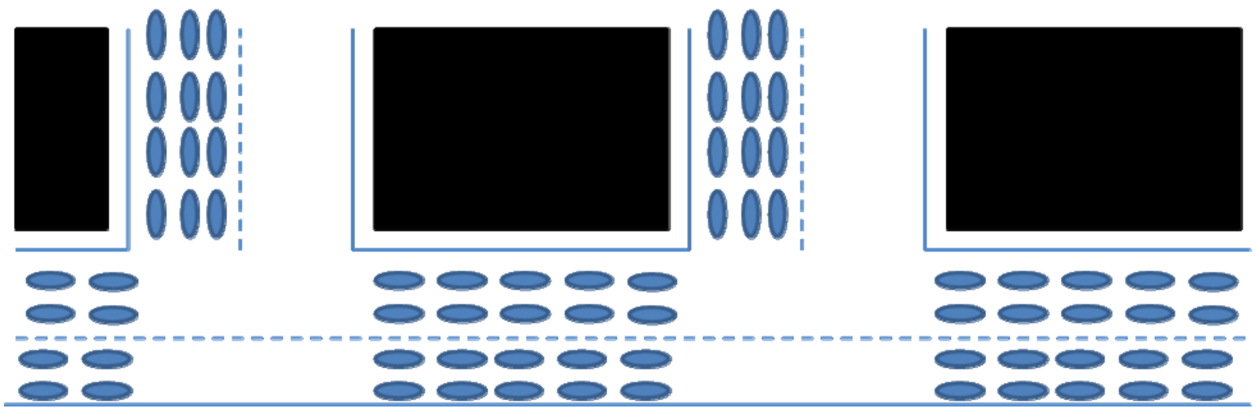

Figure D.2: "Clogged city" test scenario

3) "Highway" - dynamic environment with bidirectional multiple lanes road at low ratio of hidden stations.

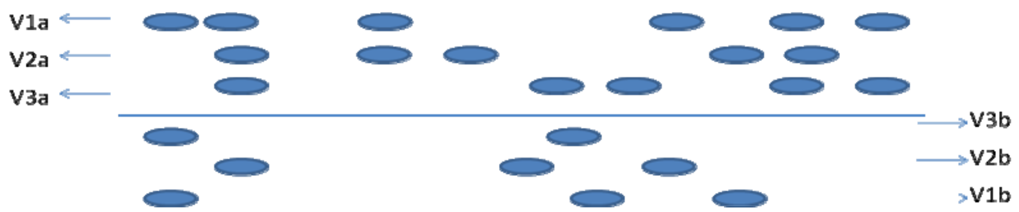

Figure D.3: "Highway" test scenario

Goal is testing ability to adjust to a varying environment

4) "Urban movement" - dynamic environment at high ratio of hidden stations.

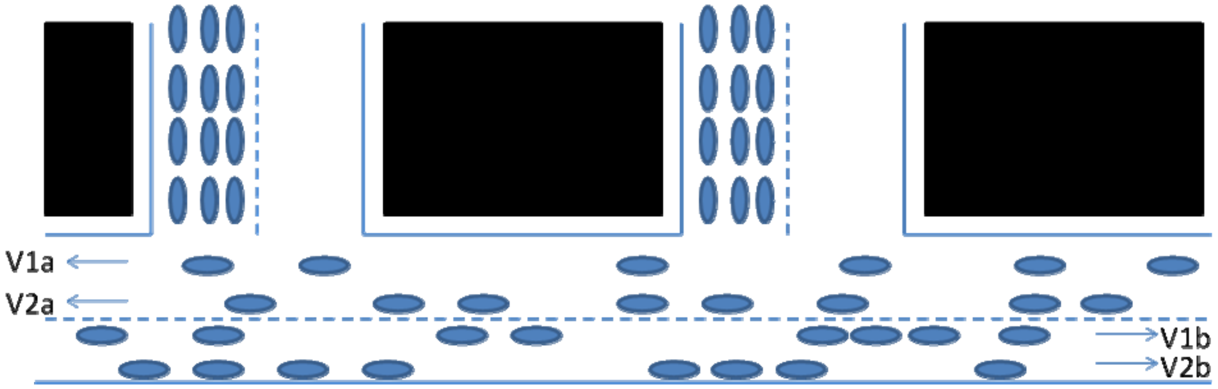

Figure D.4: "Urban movement" test scenario

Goal is testing ability to adjust to a varying environment while maintaining fairness.

Additional parameters are configured for each of the combinations:

1) Vehicles' density - number of vehicles in a certain area.

2) Vehicles' speed.

D.2 Validation performance criteria

The following criteria could be used to validate the algorithms.

Table D.1: Performance criteria

Criterion name	Function	Indication type	Note
Aggregated number of received packets	Incremented by any vehicle after any packet is received successfully	Network capacity	Transmitted packet may be counted multiple times
Aggregated number of packet collisions	Incremented by any vehicle after any packet is badly received due to collision	Responsiveness and reach	Weak indication since two contradicting indications are mixed
Transmit power deviation over area	Standard deviation of transmission power of vehicles inside an area (e.g. 1 000 sqm segment) in a given time unit (e.g. 1 second), averaged over time and over area.	Fairness and convergences	Vehicles in close proximity should use similar transmission power
Transmit power variation	Average over time of vehicles' transmission power variation during a time unit (e.g. 1 second)	Stability	Detecting oscillations
Average distance	Average of distance between source and receiver for all valid packets	Reachability	Most important parameter from safety application perspective

Annex E (informative): Bibliography

- Joining Forces for VANETs: A Combined Transmit Power and Rate Control Algorithm
Roberto Baldessari, Damiano Scanferla, Long Le, Wenhui Zhang, Andreas Festag
NEC Europe Ltd., Network Laboratories, Universit`a degli Studi di Padova
Proceedings of WIT2010, Hamburg, Germany.

- Evaluation of Time-Space Efficiency in CSMA/CA and Slotted Vanets
Riccardo Scopigno, Hector Agustin Cozzetti
Istituto Superiore Mario Boella, Turin, Italia
Proceedings of VTC2010-4, Ottawa, Canada.

- Architecture for Decentralized Mitigation of Local Congestion in VANETs.
Robert K. Schmidt, Tim Leinmüller, Bert Böddeker, DENSO AUTOMOTIVE Deutschland GmbH, Germany;
Achim Brakemeier, Daimler AG, Research and Technology, Ulm Germany;
Günter Schäfer: Telematics/Computer Networks Research Group, Technische Universität Ilmenau, Germany.
2010 International Conference on ITS Telecommunications (ITST 2010, Nov 9-11, 2010), Kyoto, Japan.

- C2C-CC White Paper on Network Design Limits and VANET performance *Achim Brakemeier*, Daimler AG, v0.6(2009-01).

NOTE: Available at www.car-2-car.org.

- Path Loss Modeling for Vehicle-to-Vehicle Communications
Karedal, J.; Czink, N.; Paier, A.; Tufvesson, F.; Molisch, A.F.;
Vehicular Technology, IEEE Transactions on, Volume: 60,
Issue: 1 Publication Year: 2011 , Page(s): 323 - 328

NOTE: Available at: Path Loss Modeling for Vehicle-to-Vehicle Communications, Vehicular Technology, IEEE Transactions

- ECC/DEC/(08)01: "ECC Decision of 14 March 2008 on the harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS)".

- ECC/REC/(08)01: "ECC Recommendation (08)01 on the use of band 5855-5875 MHz for intelligent transport systems (ITS)".

- ECC Report 101: "Compatibility Studies in the Band 5855- 5925 MHz between Intelligent Transport Systems (ITS) and other Systems, Bern, February 2007".

- ETSI TS 102 636-3: "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 3: Network architecture".

History

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