HOCHSCHULE HANNOVER
UNIVERSITY OF APPLIED SCIENCES AND ARTS
–
Fakultät IV
Wirtschaft und Informatik

Fahrzeugvernetzung – V2X

Lecture 7: Congestion and Awareness Control

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Lecture 7
Previous Lecture

- Part 1: Security
  - Security Objectives
  - Security Threats
  - Basic Security Algorithms
  - Public Key Infrastructure

- Part 2: Privacy
  - Location Privacy
  - Pseudonymity
  - Pseudonym Switching Strategies

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Outline

- ► Control Theory Approach
- ► Congestion/Awareness Control
- ► Transmission Control Protocol
- ► Channel Load Measures
- ► Decentralized Congestion Control
- ► Transmit Rate Control Mechanism
  - ► LIMERIC
  - ► DynB

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Motivation (1/2)

- Cooperative V2X-system need to be designed **to scale to high densities of radios** without centralized coordination
  - At the same time guaranteeing the requirements of the implemented applications and services, e.g., the stringent needs of active traffic safety applications

- **Rapidly changing topology**, channel characteristics, **distributed medium access**, and challenging active safety application requirements cause many challenges to the **resource management**

- With **increasing vehicle density**, the aggregate of these messages alone can **exceed channel capacity**, unless transmission parameters are adapted

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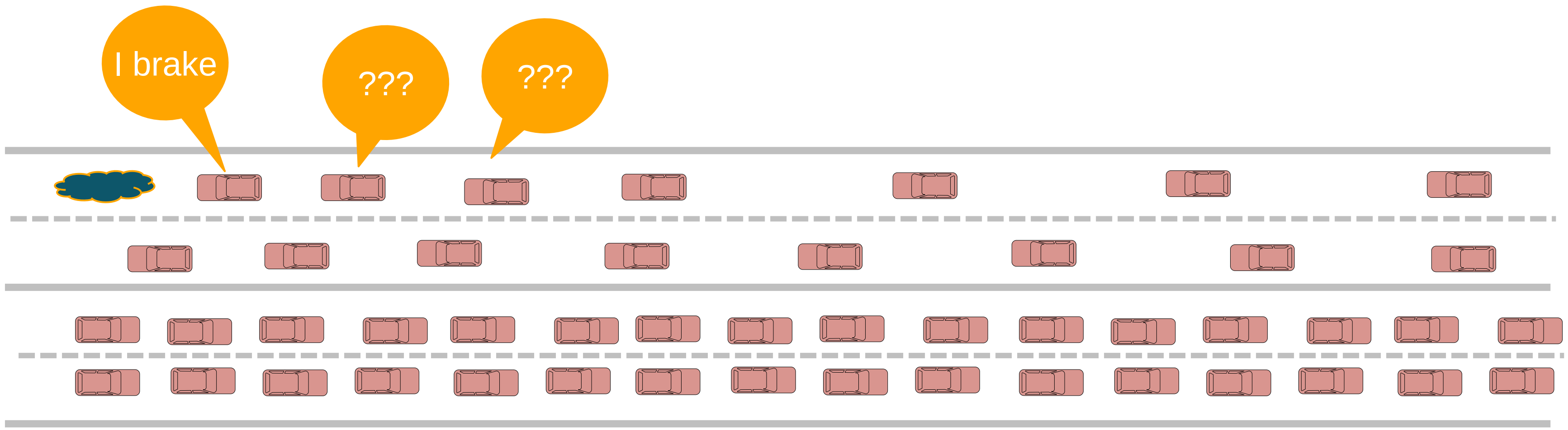
Motivation (2/2)

► **Performance degradations** like packet losses, the reduction of the effective communication range, and packet **transmission delays** are correlated with the **channel load**

► The objective of a **decentralized congestion control**

► To avoid these degradations **by limiting the load** offered by **each vehicle** to the radio channel → A certain **channel load threshold** is not significantly **exceeded**

► CAMs could already **saturate** the channel



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Control Theory Approach (1/3)

- **Analogy to traditional control theory**
  - Process of **restricting the load on the wireless channel**, and thereby the congestion in the wireless network
  - Process of adapting the communications parameters to guarantee a **certain awareness level**
- Lack of a centralized coordination entity in vehicular communication
  - Shared wireless communication channel
- Congestion in the network can not be avoided or reduced
  - if **only one single station** is decreasing its transmission power and/or rate
  - Result of the selected action can not be observed by **the station itself**, but **only by its neighbors**
- For an optimal and reliable control all stations should **act cooperatively** and provide **feedback** about the result of their actions **to each other**

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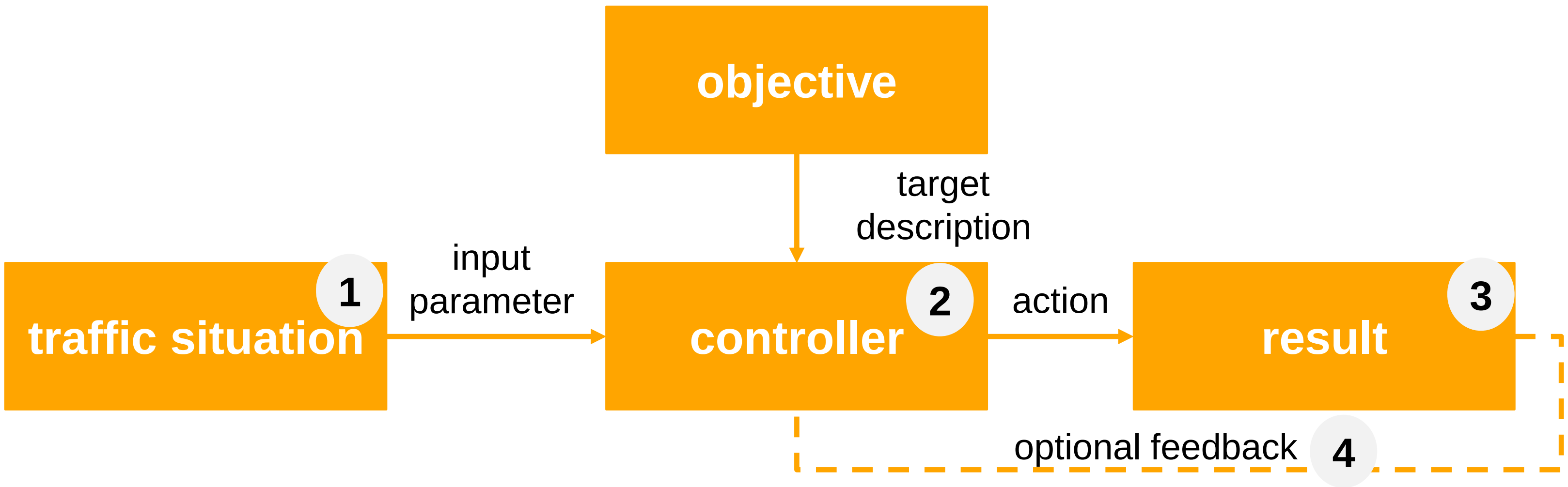
Control Theory Approach (2/3)

1. An algorithm used a sort of detection to **classify the traffic situation** or a scenario which might be used proactively by the controller as **feedforward input**
2. Controller **decides itself how** the transmission will be adjusted depending on the **situation** and the corresponding **target description**, i.e. the current objective
3. Selected action then leads to an **observable result**,
4. which can be **fed back** to the controller in order to **improve its accuracy**



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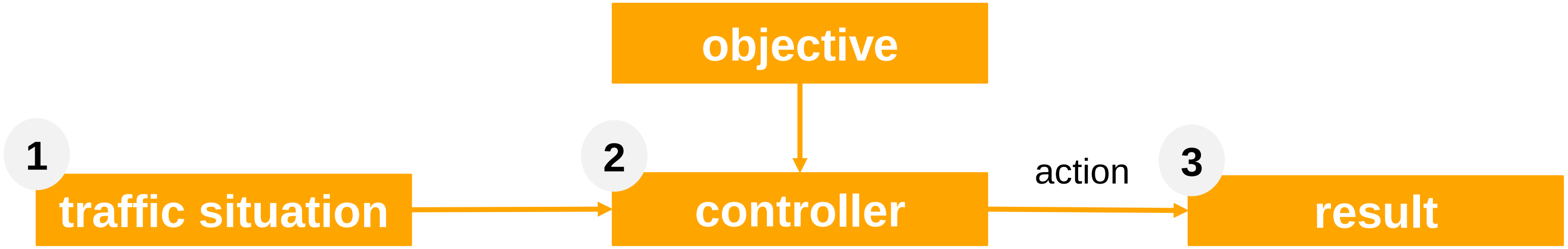
Control Theory Approach (3/3)

- **Closed loop controller**
  - employs **feedback** to determine how well the **objective** has been achieved
  - improves the control due to the **use of feedback data**, at the cost of **communications overhead**
- **Open loop controller**
  - do **not make use of feedback** to correct and **optimize the decisions made** in the **past**, and typically incorporate **a system model** to derive the actions to be taken
    - \+ No additional overhead
    - \- Performance and robustness depend on the **accuracy** of the **system model** used



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Congestion Control

- **Reactive congestion control**
  - uses information about the **channel congestion status** to decide whether and how an action should be undertaken
  - Actions to reduce/limit channel load are undertaken **only after** a congested situation has been detected

- **Proactive congestion control**
  - uses **models** that, based on information such as **number of nodes** in the vicinity and **data generation patterns**, try to estimate **transmission parameters** which will not lead to **congested** channel conditions
  - while at the same time providing the **desired application-level performance**
  - Highly depends on the accuracy of the used models

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Awareness Control

► **Awareness control**

  ► Capability to **control the load** on the radio channels and to ensure each vehicle's capacity to detect and communicate with the **relevant neighboring vehicles**

► **Awareness control protocols**

  ► Techniques aimed at ensuring **each vehicle's capacity** to detect, and possibly communicate with the relevant vehicles and infrastructure nodes present in their local neighborhood, through the dynamic adaptation of their transmission parameters

Potential scenarios:

► Adapt **each vehicle's transmission power** to successfully transmit a message at a given distance

► Or dynamically modify **each vehicle's packet generation rate** to increase the probability of receiving at **least one packet** at a certain distance during a given time window

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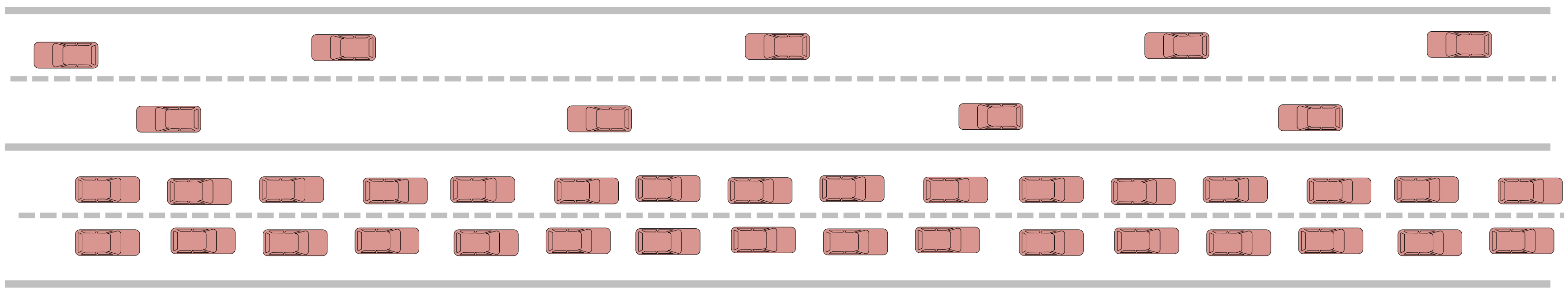
Awareness vs. Congestion Control

- **Awareness control algorithms**
  - Adjust for example the power or rate of **only a selected subset of nodes**, with the objective of fulfilling the requirements of a particular application
- **Congestion control algorithms**
  - Limit the observed load on the wireless channel for **all nodes** in order to provide fair and harmonized access to the wireless medium
- **Possible scenario:** Vehicles under free-flow conditions would require their communication settings to allow for a safe lane change maneuver



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Basic Concepts of Congestion Control

- **Flow control**
  - Scheme which **protects the receiver** of a flow of packets from **being overwhelmed** by too many packets sent from the source
  - Concern **only one source-receiver pair** and has the objective to prevent **the buffer at the receiver** from overflowing

- **Congestion control**
  - Scheme which **protects the network** from being flooded by its users (source and/or destination)

- **Congestion avoidance**
  - Scheme which tries to **keep the network** at its optimal operation point
  - Congestion control and congestion avoidance address the input of any node into the network

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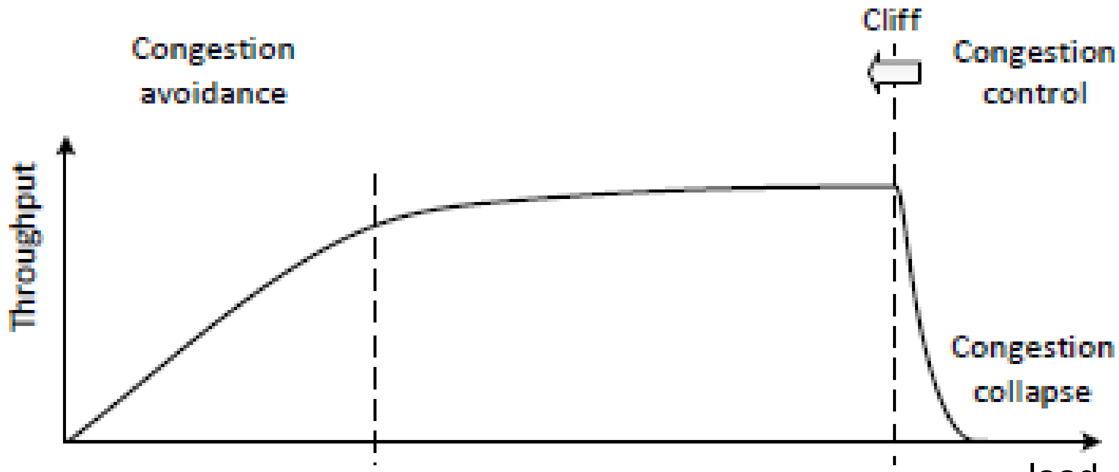
Congestion Avoidance/Control

- **Transition from congestion avoidance to congestion control**
  - Throughput increases with increasing load
  - Saturation point is reached when the load approaches network capacity
  - Throughput **sharply drops to zero** if load is further increased → **Congestion collapse**
    - Buffer overflow throughout the network preventing any packets from coming through
- **Goal of congestion control is to prevent the network from passing the cliff and help the network get back into operational mode if a congestion collapse occurs**



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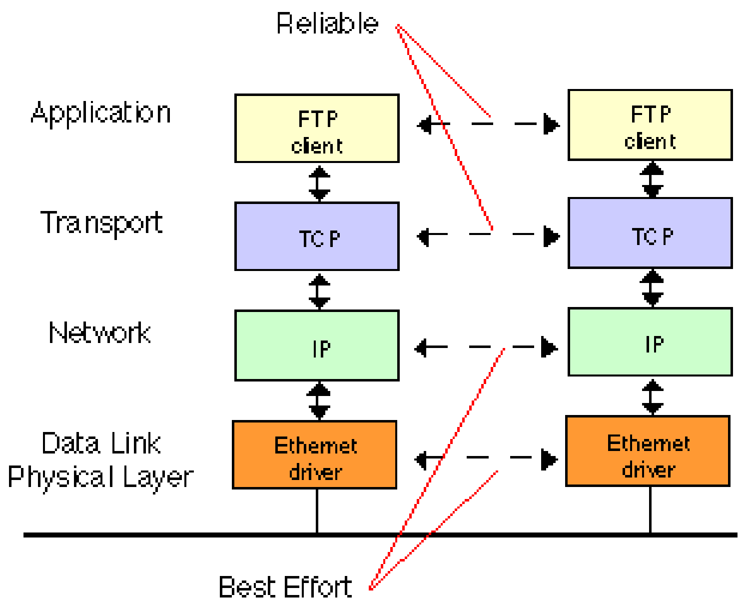
Transmission Control Protocol (TCP)

- Most **prominent protocol** employing **congestion avoidance** and **control mechanisms**
- End-to-end **transport protocol** which establishes a **reliable connection-based**
- Employs a host-centric, feedback-based and window-based congestion control scheme whose core is the **adaptation of a variable called congestion window (CW)**
  - CW indicates how **many bytes the node** may transmit before an **Acknowledgment (ACK)** has been received



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TCP Congestion Detection

- ► Implicit feedback from the network is used to determine **if congestion occurs**
- ► TCP used **packet losses** detected based on **missing acknowledgment**
  - ► It uses a Retransmission Timeout (**RTO**) to decide **if a packet has been lost** and need to be retransmitted

- ► **Fast retransmit:** Second mechanism used by TCP to detect packet losses
  - ► When more than **three duplicate ACKs**
    - ► Acknowledgments for data which has already been acknowledged before, have been received
  - ► TCP suspects that a packet has been lost and does not wait for the RTO to expire before retransmitting.

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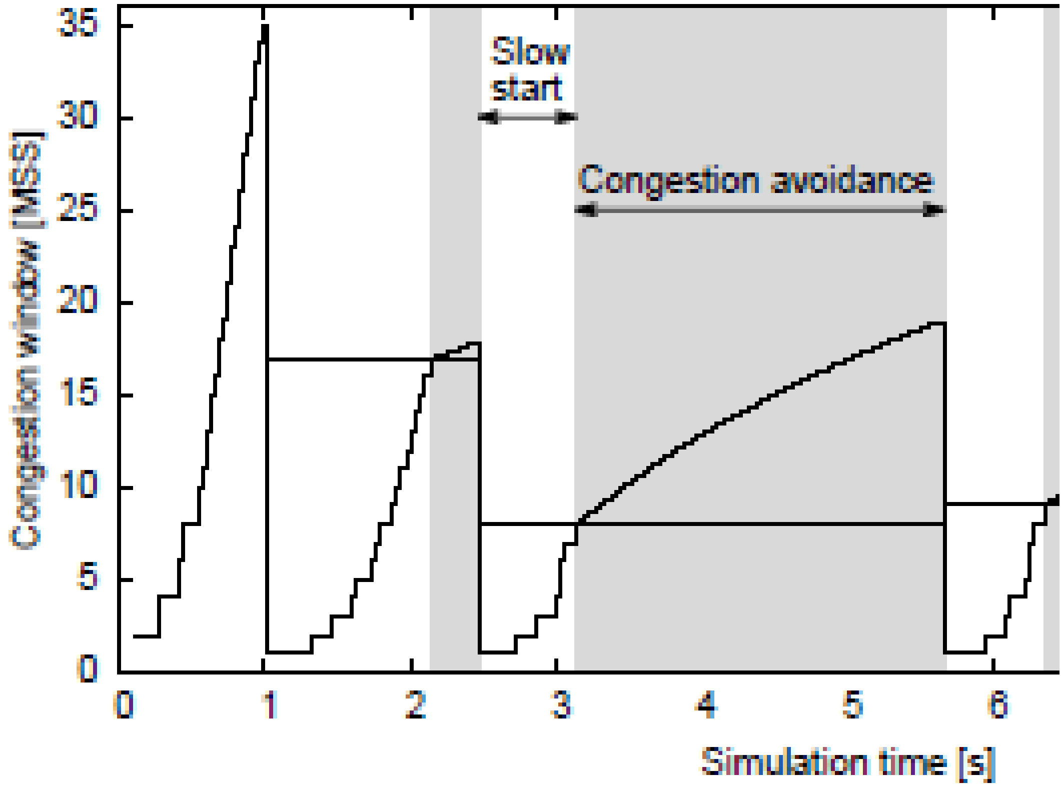
TCP Rate Adaptation

- ► **Slow start:**
  - ► TCP starts with **a low congestion window**, typically one maximum segment size (MSS)
  - ► Congestion window (CW) is increased **exponentially**
    - ► CW is increased by one MSS for each received ACK, until the slow start threshold is reached



- ► **Congestion avoidance**
  - ► After the **slow start threshold** has been reached, CW is increased linearly for each received ACK

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Channel Load Measures - Communication Density (CD)

- CD is the unit of transmissions per unit of time and road length

$$\boldsymbol{CD = \rho \cdot r. d_{TX}}$$

  - ρ is the vehicle density in vehicles/km, r is the transmission rate in Hz and d_{TX} is the communication range in km
- Comparable broadcast transmissions (i.e. the ones with the **same transmission power**) have the same communication performances in very different scenarios as long as the **communication densities** are the **same**
- Scenarios with the same CD, e.g., a scenario with vehicle density ρ and transmission rate r and a second scenario with vehicle density $1/2 \cdot \rho$ and transmission rate $2r$, experience nearly the same packet delivery ratio over distance

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Channel Load Measures - Beaconing Load (BL)

- ► BL is the **average amount of load** offered to the channel within a node's carrier sense range
- ► BL quantifies the offered load within a certain time in bit/second

$$\boldsymbol{BL = \rho \cdot r \cdot 2d_{CS} \cdot M}$$

  - ► ρ is the vehicle density in vehicles/km, r is the transmission rate in Hz and d_{CS} is the carrier sense range in km and M the message size in bytes

- ► Scenario: packet size $M = 400\ \text{Bytes}$, $r = 10\ \text{Hz}$, $\rho = 50\ \text{veh/km/lane}$ and $d_{CS} = 1200\ \text{meter}$, lane=4
  - ► $BL = 7.68\ \text{Mbit}/s$ exceeds a data rate of 6 Mbit/s → At least one of the parameters has to be adapted in order not to overload the channel

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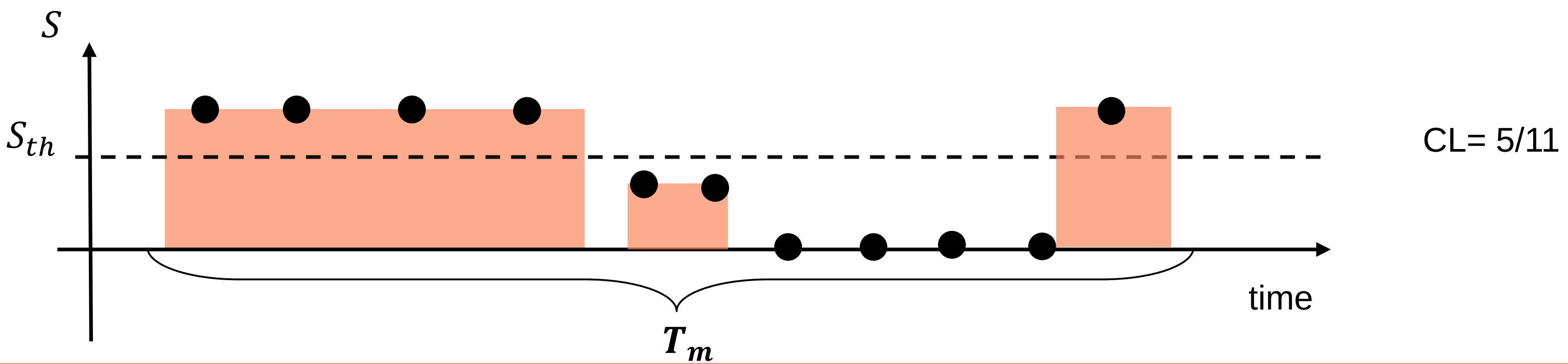
Channel Load Measures – Channel Load (CL)

- Fraction of time that the **received signal level S** is above $\boldsymbol{S_{th}}$
  - CL depends on the selected threshold S_{th}
- **Estimation 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}:
    - $\boldsymbol{CL = \sum(1 \;\forall\; \text{probes with } S \geq S_{th})/N_p}$



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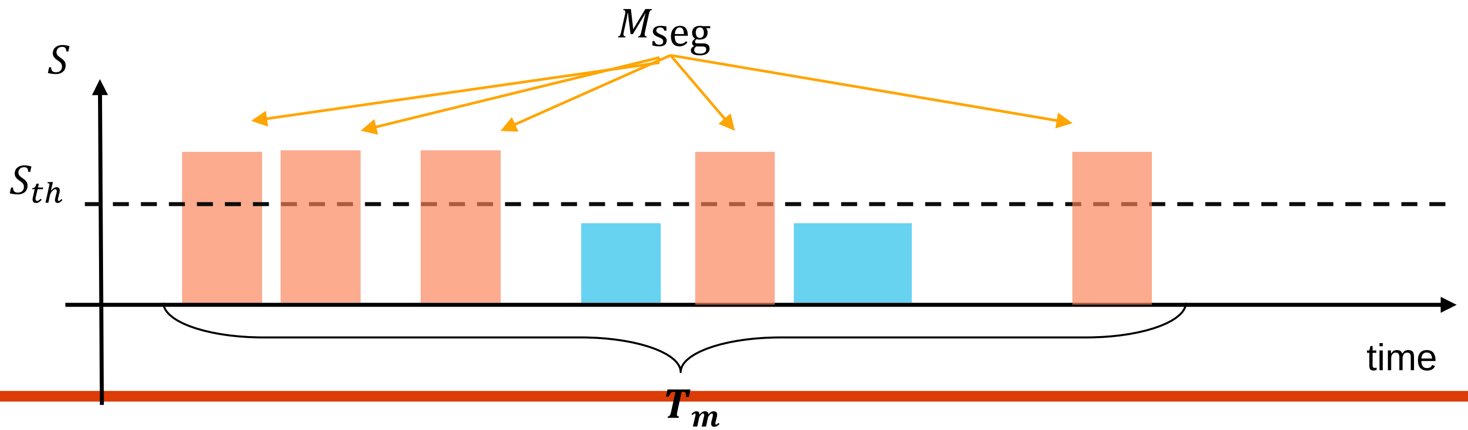
Channel Load Measures – Load Arrival Rate (LA)

- Number of segments with $\boldsymbol{S} \geq \boldsymbol{S_{th}}$ that are arriving per time interval
  - Assuming a segmentation of the received signals in segments with signal level above or below S_{th}
- Received signal is segmented with signal level $\boldsymbol{S} \geq \boldsymbol{S_{th}}$ (load segments) and $S < S_{th}$ (idle segments)
  - Number M_{seg} of load segments within T_m is determined
  - Short segments shorter than the preamble duration T_{pr} are neglected

- $\boldsymbol{LA = \frac{M_{seg}}{T_m}}$



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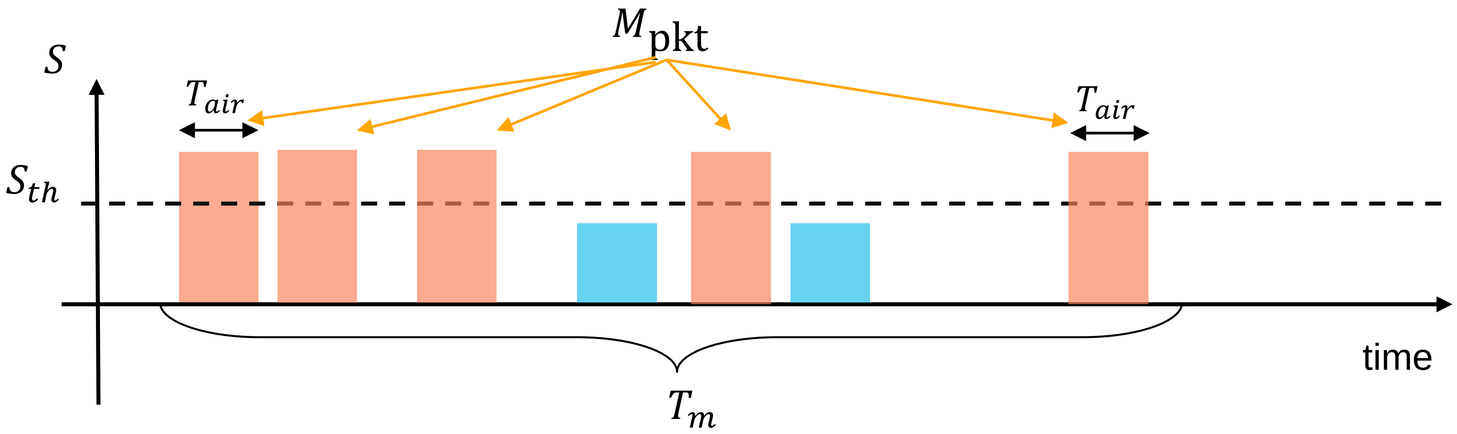
Channel Load Measures – Receive Packet Average Duration (RPD)

- **Average length of all packets** that are detected with signal level $S \geq S_{th}$
  - Average packet duration depends on the preamble detection
- M_{pkt} number of detected packets with $S \geq S_{th}$ within T_m
- T_{air} packet air time is determined using the PLCP header information
  - $\boldsymbol{RPD = \frac{\sum T_{AIR}}{M_{pkt}}}$



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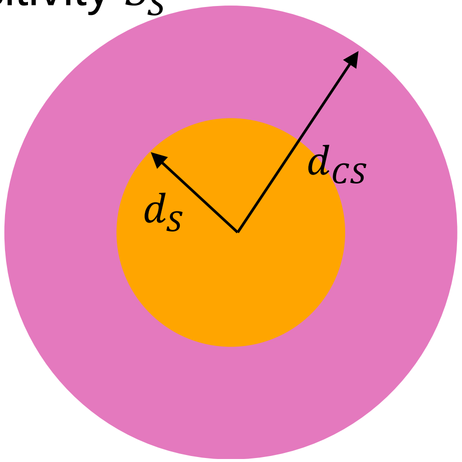
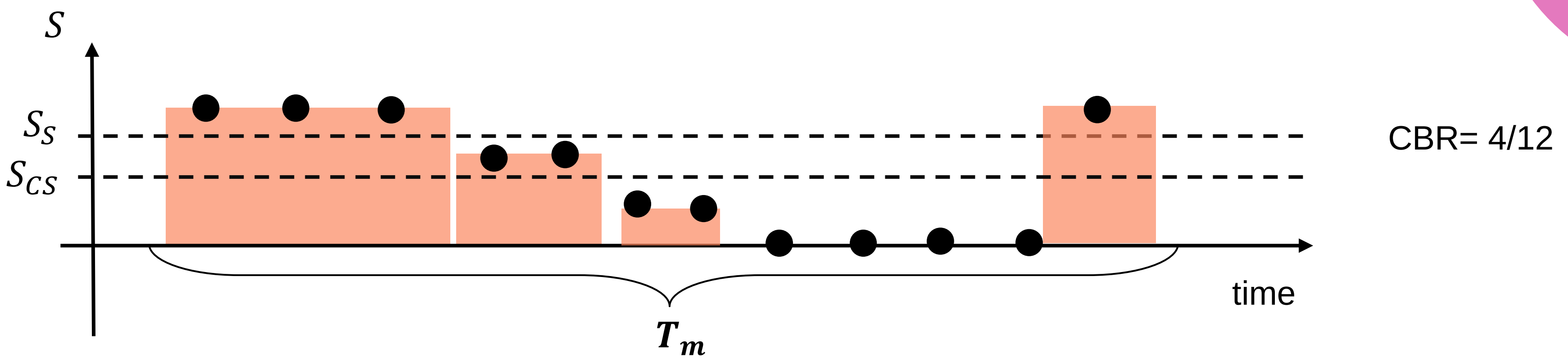
Channel Load Measures – Channel Busy Ratio (CBR)

- **Fraction of time** the channel is regarded as busy also known as channel busy time
  - Channel sensed as busy:
    - A detected packet has a higher signal level than received power sensitivity S_S
    - The received signal level is higher than carrier sense signal S_{CS}
  - N_p probes of the receive signal are taken uniformly distributed within the measuring interval T_m
    - $\boldsymbol{CBR = \sum(1\ \forall\ \text{probes with channel busy})/N_p}$





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Classification of Packet Losses

- Reasons for packet losses and hence degradation of the effective communication range under high load:
  - **Simultaneous Sending**: Collision can occur if at least two stations have the currently lowest backoff slot and thus start the transmission at the same time
  - **Single/Multiple Hidden Station(s):** Collision can occur if the minimum SINR of the receiver is underrun during reception by hidden stations, or the receiver is not even able to sense the packet from the beginning
  - **Exposed Station:** Packet loss implicitly occurs if the medium cannot be accessed in time. Many messages overcrowd the local message queue, so that messages have to be dropped before transmission
  - **Near Adjacent Station:** Interference caused due to adjacent channel interference from near-by transmitting stations can also reduce the SINR below the receiver requirement

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Decentralized Congestion Control (DCC)

- **Scheme** proposed by ETSI utilizing **multiple** transmission parameters **to control congestion**
- DCC is a mandatory component of ITS-G5 stations operating in ITS-G5A and ITS-G5B to maintain network stability, throughput efficiency and **fair resource allocation** to stations
  - Cross-layer protocol influencing several distinct functions of the node’s communication behavior
  - Combines the joint usage of **multiple** transmission parameters
    - Transmission power
    - Data rate
    - Transmit rate

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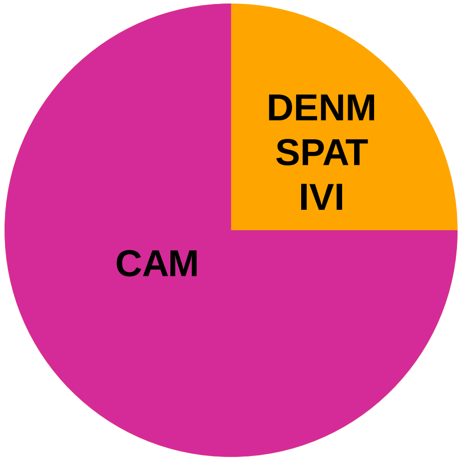
DCC Capabilities

- Provision of **fair allocation of resources** and **fair channel access** among all stations in the same communication area
- **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

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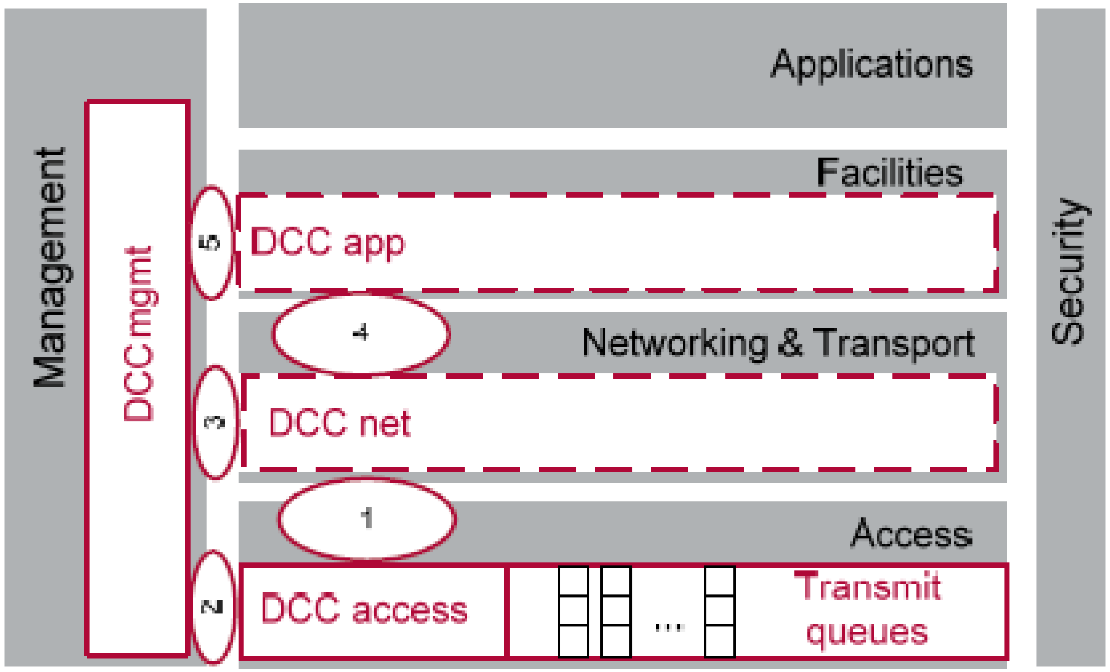
DCC Architecture

- DCC Access comprises following DCC mechanisms:
  - Transmit Power Control (TPC)
  - DCC Sensitivity Control (DSC)
  - Transmit Rate Control (TRC)
  - Transmit Data rate control (TDC)
  - DCC Access Control (TAC)



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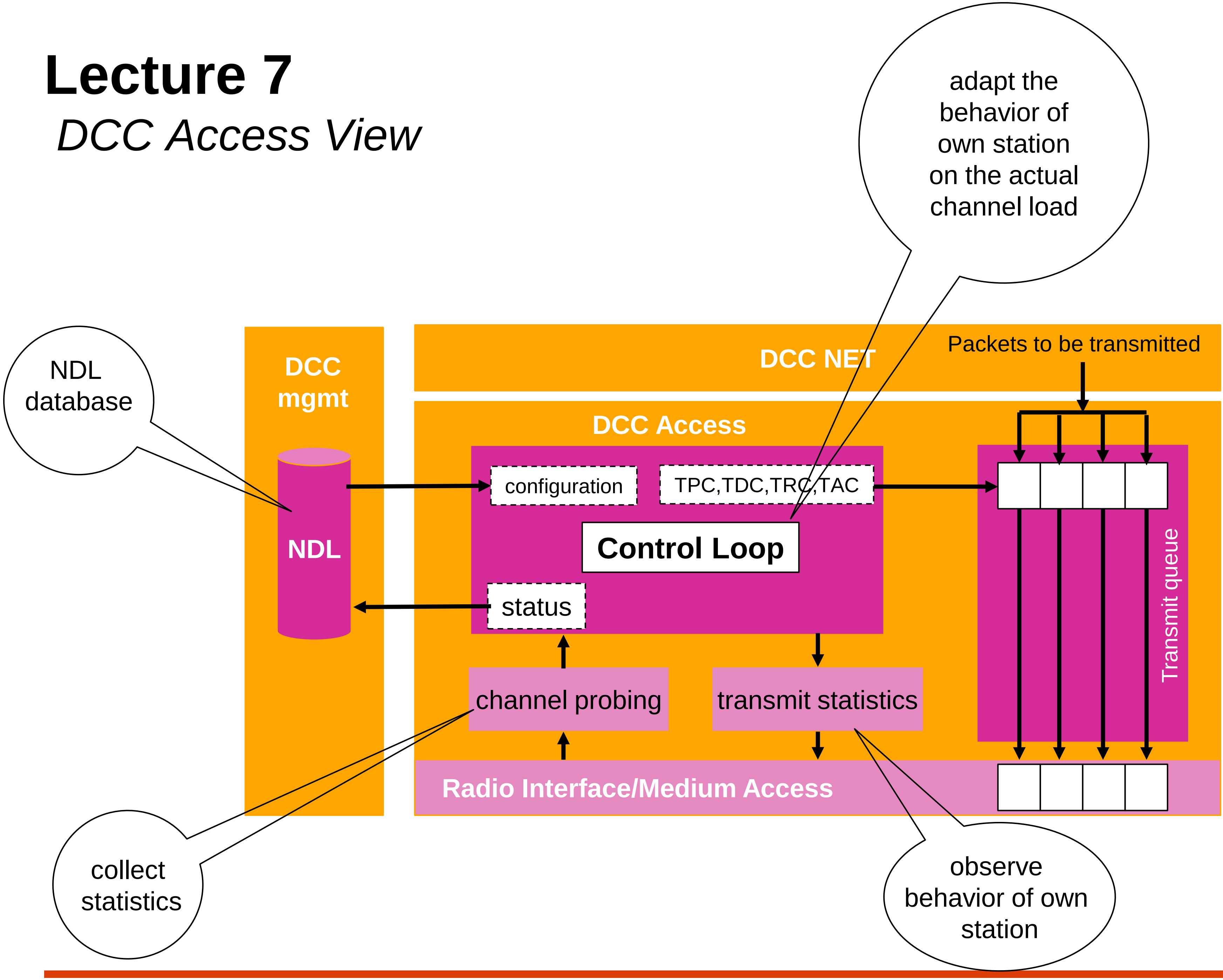
DCC Access View



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Network Design Limits (NDL)

- DCC should keep the actual channel load below predefined limits that are included in NDL database
  - 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**

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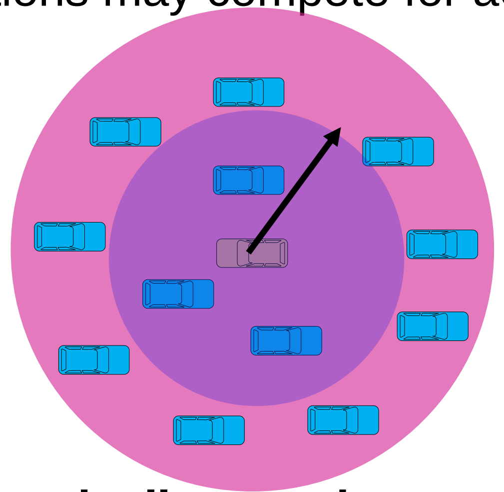
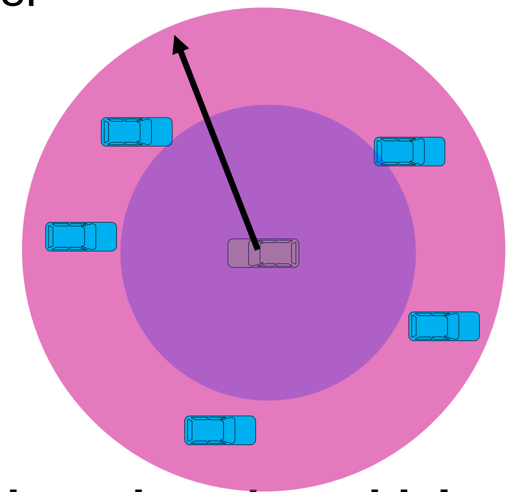
Transmit Power Control (TPC)

- TPC adjusts the **communication range** and thus the **amount of stations** which will be able to receive the transmission
  - Through adjusting the **transmission power** (TP)
- A better awareness can be achieved by **reducing TP** in **dense** scenarios and **increasing** it in **sparse** vehicle density situations
  - **Increasing TP** will increase the **packet collision probability** as a large number of stations may compete for accessing the channel

Decrease TP



Increase TP



- **TPC dynamically sets the communication range based on the vehicle density derived by estimating the number of nodes within the communication range**

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Transmit Rate Control (TRC)

- ► TPC is used to **control the frequency of messages** transferred to the channel
  - ► May reduce the **channel load** for a given number of vehicles
- ► Transmission interval is **adjusted** based on the perceived **channel quality**

- ► Congestion control protocols implementing TRC
  - ► DynB: Dynamic Beaconing
  - ► LIMERIC: LInear MEssage Rate Integrated Control

- ► Awareness control protocol implementing TRC
  - ► ETSI CAM generation rules

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LIMERIC - LInear MEssage Rate Integrated Control

- ► **Congestion control** algorithm adapting the **periodic transmission rate** of CAMs based on **channel conditions**
- ► Linear message rate control algorithm using **channel load (CL)** measurements as a **feedback**
- ► It achieves **local fairness** by adjusting the **message rate** of **each** station
- ► It uses the **difference between the measured CL and the targeted CL_t** to adapt a node's transmission rate r

$$\boldsymbol{r(t) = (1-\alpha)r(t-1) + \beta(CL_t - CL)}$$

  - ► α and β are parameters whose given default values guarantee stability
  - ► Typically $\alpha = 0.1$, $\beta = 0.033$, $0 \leq CL \leq 1, CL_t = 0.7$
- ► β is a linear gain adaptive parameter, which impacts stability and also the convergence speed → Hardly depends on the scenario

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Dynamic Beaconing (DynB)

- DynB dynamically **adapts the message generation interval** based on **channel load**
- It targets maintaining **channel load at a fixed value** to reduce packet collisions
  - Increase the message generation interval whenever the **network becomes denser** (e.g. **there are more neighboring vehicles**)
- Message generation interval is given as

$$\boldsymbol{I = I_{\mathrm{des}}(1 + rN)}$$

- N is the number of one-hop neighbors. r is a measure by which the actual channel load CL_t exceed a desired channel load CL_{des}. $0 \le r \le 1,\ I_{des} = 10\mathrm{ms}$ and $CL_{\mathrm{des}} = 0.25$

$$\boldsymbol{r = \max\left(0, \frac{CL_t}{CL_{\mathrm{des}}} - 1\right)}$$

- When $CL_t < CL_{des}$ → minimum message generation interval I_{des} should be used to send as many packets as possible
- When $CL_t > CL_{des}$ → message generation interval should be increased to send fewer packet

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Other Congestion Control Mechanisms

- ► **Transmit Data rate Control (TDC)** controls the data rate of the wireless link. Lower rates support higher reliability at the cost of reduced capacity

- ► **DCC Sensitivity Control (DSC)** adapts the received power sensitivity to resolve local channel congestion → Similar to TPC

- ► **Transmit Access Control (TAC)** introduced a scheme for transmit queue management to support different message priorities

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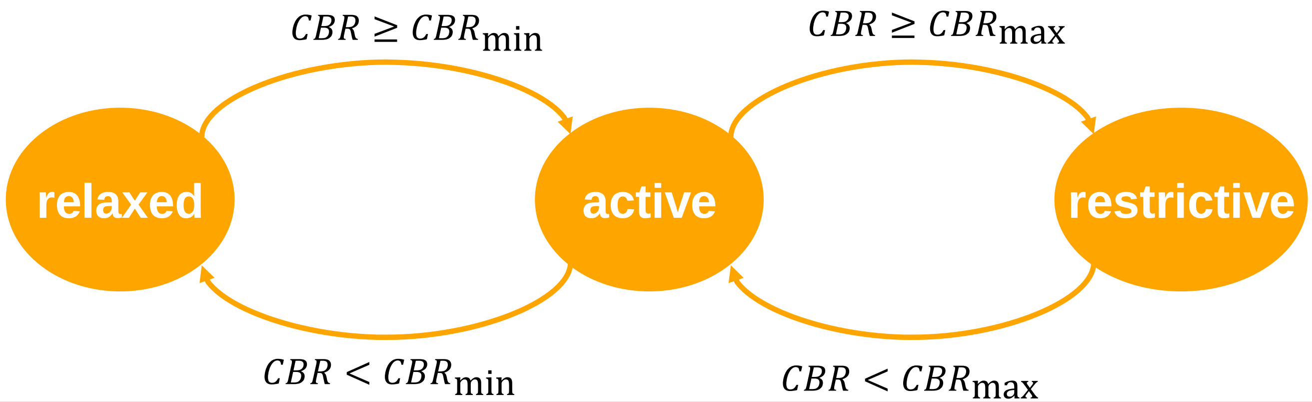
DCC Access Control Loop (1/2)

- DCC maintains **channel load below a threshold** to guarantee the throughput of successfully delivering packets in the network
- It performs as a three-state machine with transitions among RELAXED, ACTIVE, and RESTRICTIVE states based on the measured channel busy ratio (CBR)
  - **RELAXED**: Channel is assumed to be mainly free
  - **RESTRICTIVE**: Channel is assumed to be overloaded

- It can utilized different congestion mechanisms: TPC, DSC, TRC, TDC, TAC



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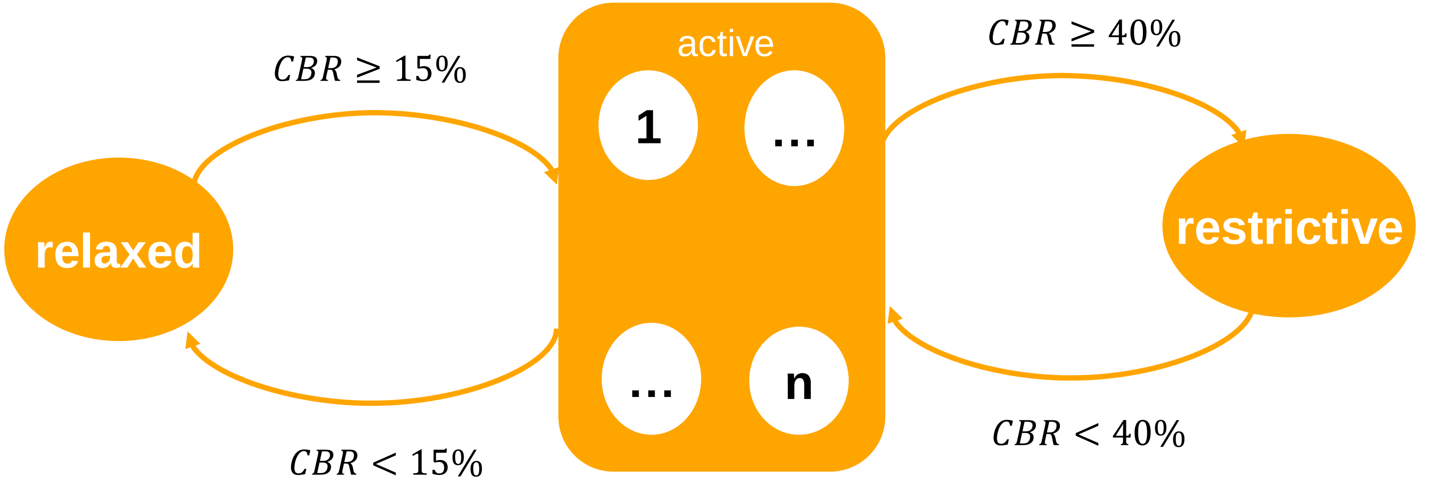
DCC Access Control Loop (1/2)

- Each state is attributed with **a set of parameters both** for the MAC and PHY layer controlling the power, modulation, carrier sense threshold and periodicity of CAMs
- Any number of **different active sub-states** could be selected if channel condition changes
- Relation between perceived channel load and a transmit limitation can be modeled in a **more fine-grained way**
  - Several active sub-states can be used to define a **step-wise function** that sets the transmit interval proportional to the CBR



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DCC Access Control Loop – Reference Parameters

- ► Each state is attributed with a set of parameters both for the MAC and PHY layer controlling
  - ► Power, modulation, carrier sense threshold and periodicity of CAMs

CBR Threshold	Relaxed 15%	Active	Restrictive 40%
TPC: Maximum power	33 dBm	20 dBm	-10 dBm
TRC: Minimum interval	0.04s	0.04s	1s
TDC: Maximum rate	3 Mbit/s	3 Mbit/s	12 Mbit/s
DSC: Carrier sense threshold	-95 dBm	-95 dBm	-65 dBm

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Literature

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- ETSI TR 101 613 V1.1.1: ”Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium; Validation set-up and results”, 2015
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