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# The Smart Highway to Babel: the Coexistence of Different Generations of Intelligent Transport Systems

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[*]Halmstad University (Sweden)
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# Today's presenter

- Oscar Amador Molina
- M.Sc. and Ph.D. in Telematics Engineering by Universidad Carlos III de Madrid (Spain) – 2015-2020
- Postdoc in Vehicular Communications at Halmstad University – 2021—2023
- Associate Senior Lecturer in Vehicular Communications in Halmstad University – 2023—present
- Special focus in Vulnerable Road User protection


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# Road Fatalities

- Traffic Accidents killed 19 897 people in the EU in 2021
  - 17.8% of all people killed on the road are pedestrians
  - 9.2% are cyclists
- Worldwide, 270 000 pedestrians die every year
- 1.8 road fatalities per 100K inhabitants in Sweden (2021):
  - 12.2% pedestrians
  - 7.6% cyclists


Photos: 20minutos.es

Photo: Dan Zelazo

Photo: Dan Zelazo


Photo: Charles Nadeau

Photo: Dan Zelazo


Photo: Pixabay

# EC Vision Zero: Day 1

| | Day 1 Awareness Starts | Day 2 Automation Starts | Day 3 Cooperation Starts | Day 4 Future Mobility | |
|---|---|---|---|---|---|
| Cooperative | "I share what I am and what I hear" | "I share what I see" | "We share our intentions" | "We coordinate all maneuvers" | Cooperative, Connected and Automated |
| Connected | Hybrid connectivity: 4G + ITS-G5 | Hybrid + 5G | Hybrid + New technologies | Hybrid + New technologies | |
| Automated | Advanced Driver Assistance Systems | Automation in some roads. Human backup. | Automation in most roads. No human backup. | Fully automated. | |

Source: G.V. der Linen, "Preparation for C-ITS in Europe". 9th ETSI ITS Workshop. March 2018

# EC Vision Zero: Day 1 Services

*Hazardous location notification*

- Slow or stationary vehicle(s) & traffic ahead warning
- Road works warning
- Weather conditions
- Emergency brake light
- Emergency vehicle approaching
- Other hazards

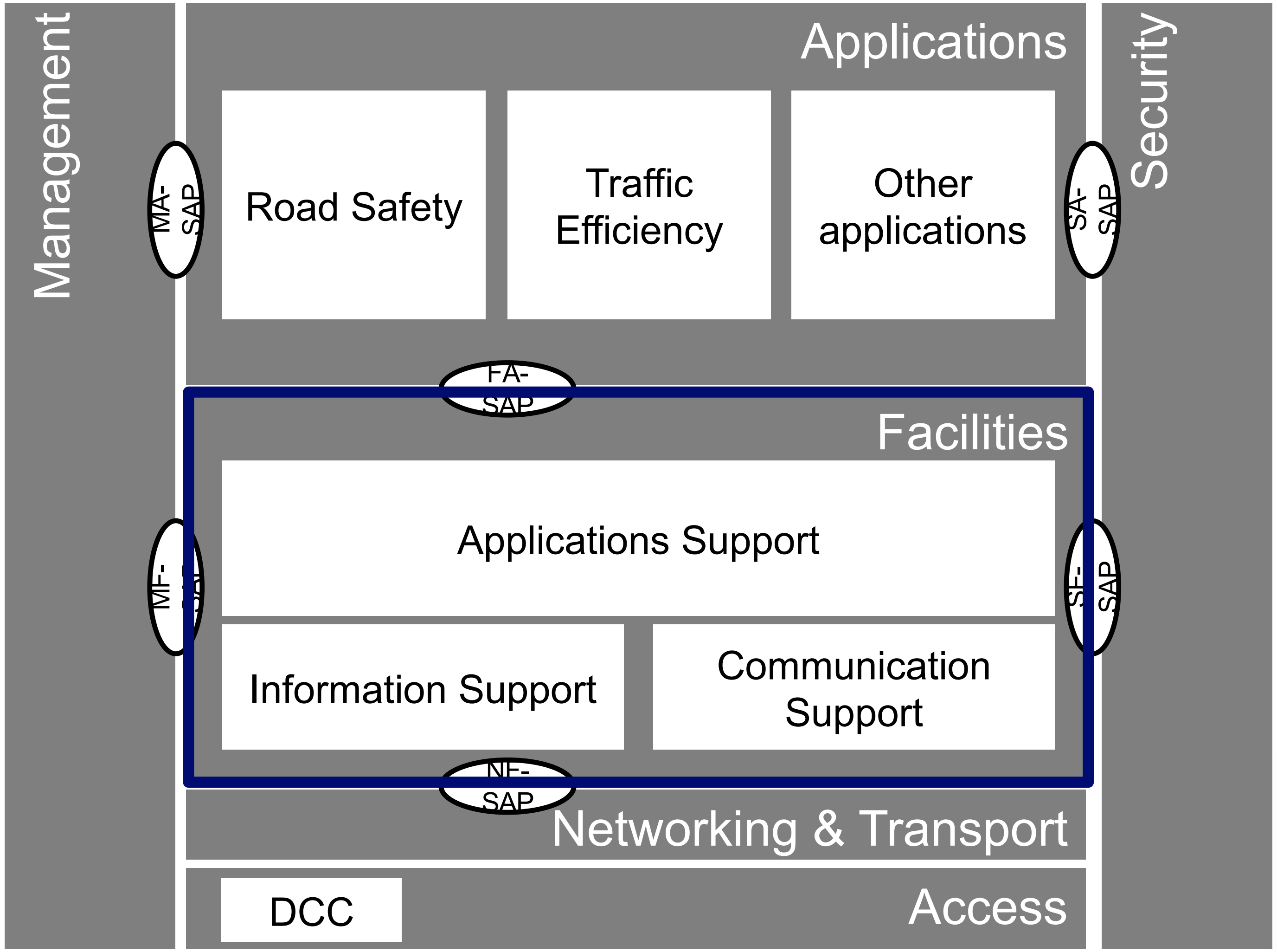
*Signage applications*

- In-vehicle signage
- In-vehicle speed limits
- Signal violation / intersection safety
- Traffic signal priority request by designated vehicles
- Green light optimal speed advisory
- Probe vehicle data
- Shockwave damping

# Future Mobility Services

- Road Safety and Traffic Efficiency
  - Collective Perception
    - Vehicles perform object detection and share it through broadcasted messages
  - Intention Sharing
    - Road users calculate their future position and share it with neighbors
  - Maneuver Coordination
    - Road users negotiate maneuvers such as:
      - Overtaking
      - Platoon formation
      - “Unsignaled” intersection crossing
  - These services shall be present in all roads and at all times

# Day 1 services and ETSI ITS architecture




- Cooperative Awareness basic service
- Decentralized Environmental Notification basic service
- Traffic Light Maneuver service entity
- Road and Lane Topology service entity
- Infrastructure to Vehicle Information service entity

# Why standards matter

- Ensure that components will communicate with each other, and that different products from different manufacturers work together harmonically
- If we develop compliant solutions, implementation times in different scenarios decrease
- Something that takes a shorter time to get up and running can start saving lives earlier

# Challenges

1. New services requiring more technological capabilities are being developed, specified, and standardized.
2. There is an offset between the speed at which standards are defined and adopted and the speed at which adoption and deployment occurs.
3. The behavior of the vehicular market causes a phenomena where vehicles of different *generations* share the road.

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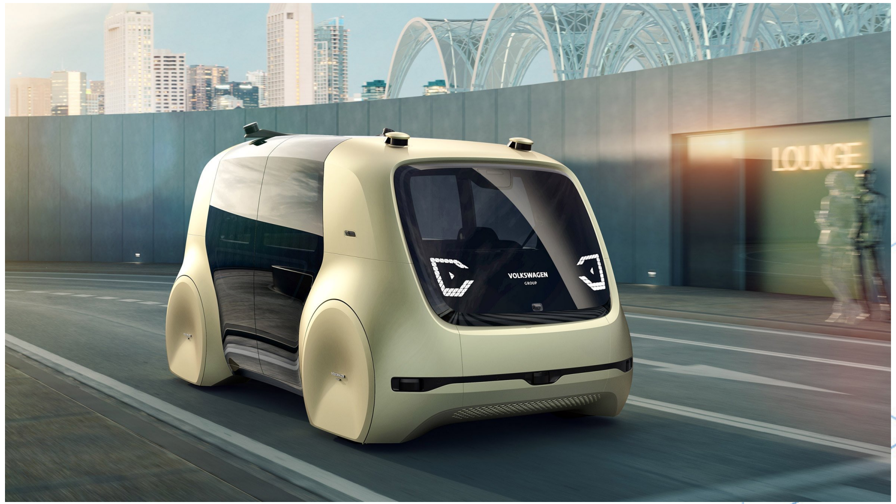
# Standard-compliant, connected cars are on the road now

# And the same car might be on the road in 20 years

Sharing the road with its grandson…


… who might not *understand* what grandpa says

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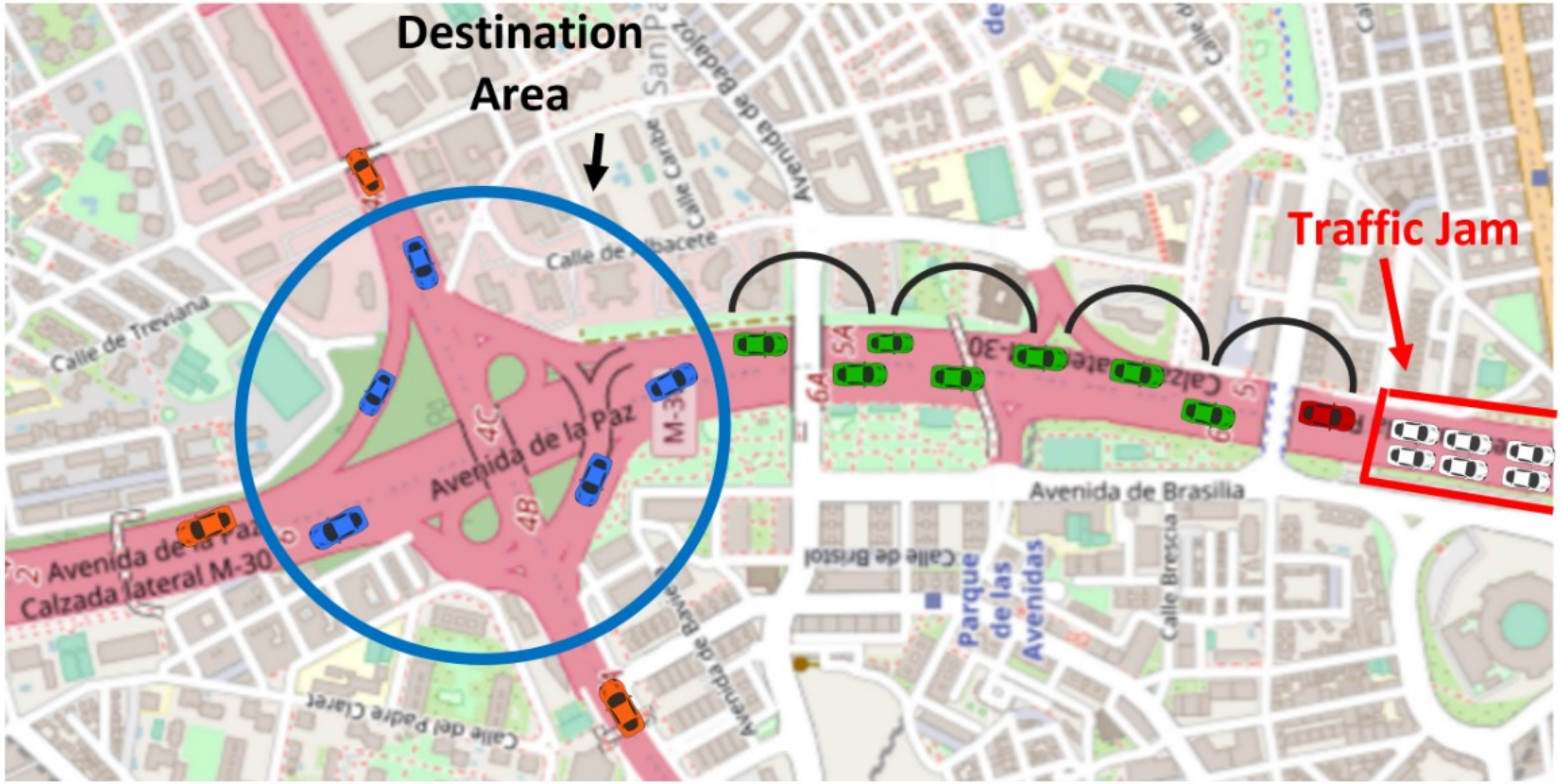
# ETSI GeoNetworking

Two Releases of a Standardized Protocol

# GeoNetworking: Non-Area Forwarding

- Objective:
  - **Delivering information to a specific geographical area**



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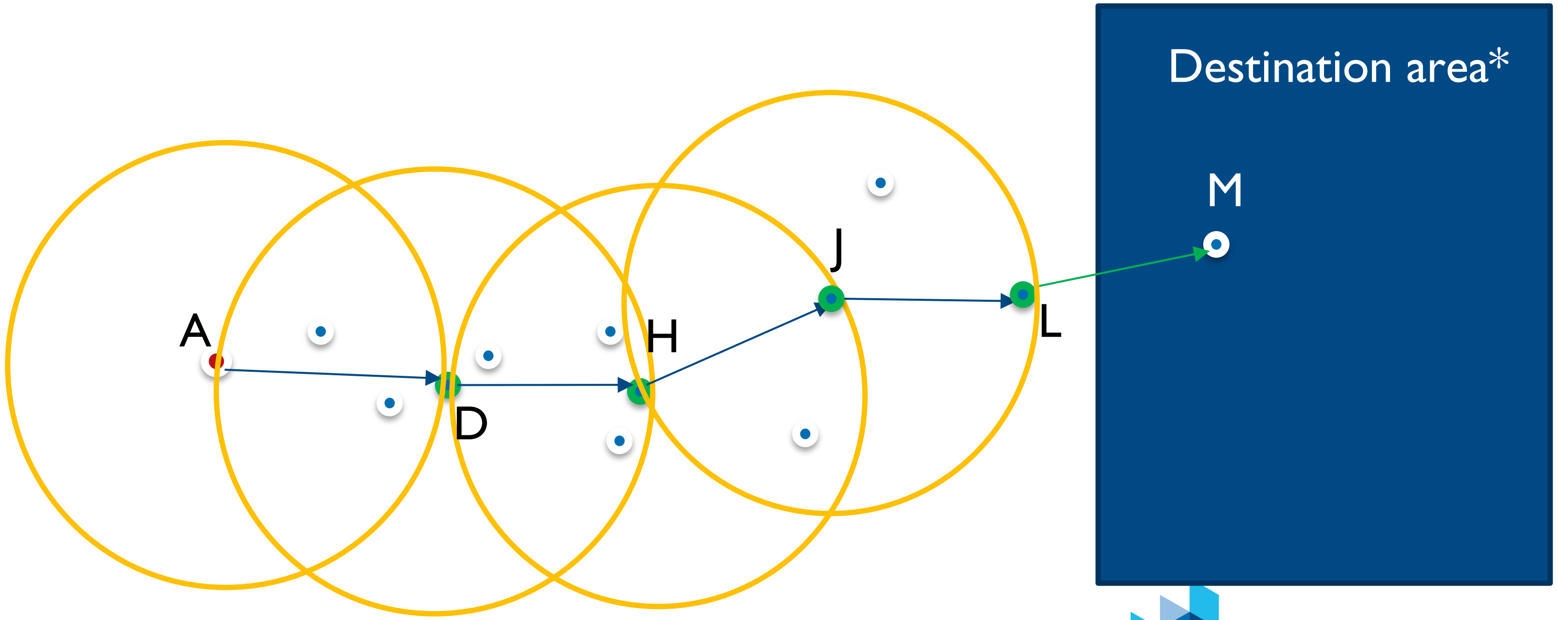
# GeoNetworking: Non-Area Forwarding

- Objective:
  - **Delivering information to a specific geographical area**
- Challenges:
  - Operating in an Ad-hoc environment (highly dynamic)
  - Possibility of asymmetrical links
  - Varying network reliability

- Approaches:
  - Sender-based: Greedy forwarding
  - Receiver-based: Contention-based Forwarding (CBF)

# Greedy Forwarding

- A message has to get from the red node to the destination area.
- "Red" (A) determines the next hop (D) by selecting its most advanced "neighbor" towards the area.
- Each next hop (green nodes) repeats the process.
- Messages are **unicast**



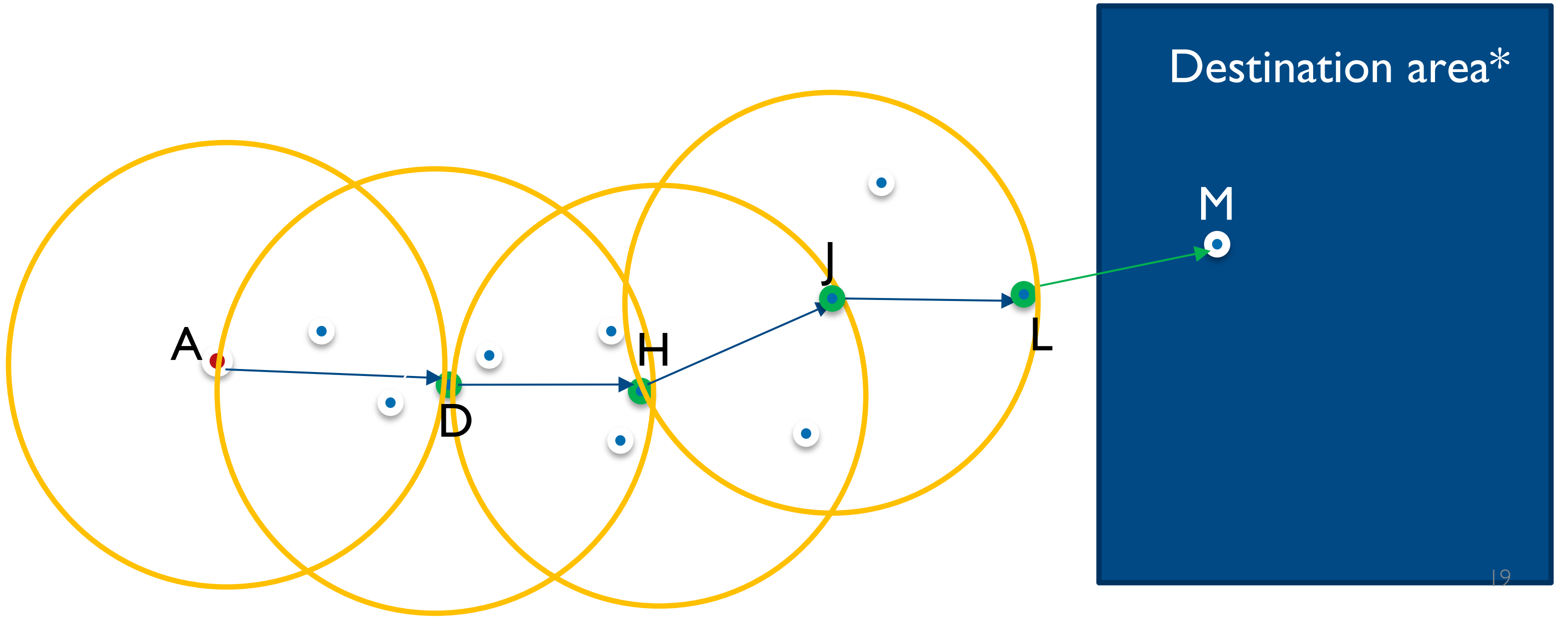
# Greedy Forwarding: probability of success

$\Pr\{success\ in\ n\ attempts\} = (1 - p_{att-1}) \vee (p_{att-1})(1 - p_{att-2}) \vee \cdots \vee (p\ of\ failing\ n-1\ atts)(1 - p_{att-n})$ ,
for 8 attempts with failure p=0.8

$$\Pr\{successful\ hop\} = 1 - p^n = 1 - 0.8^8 = 0.8322$$

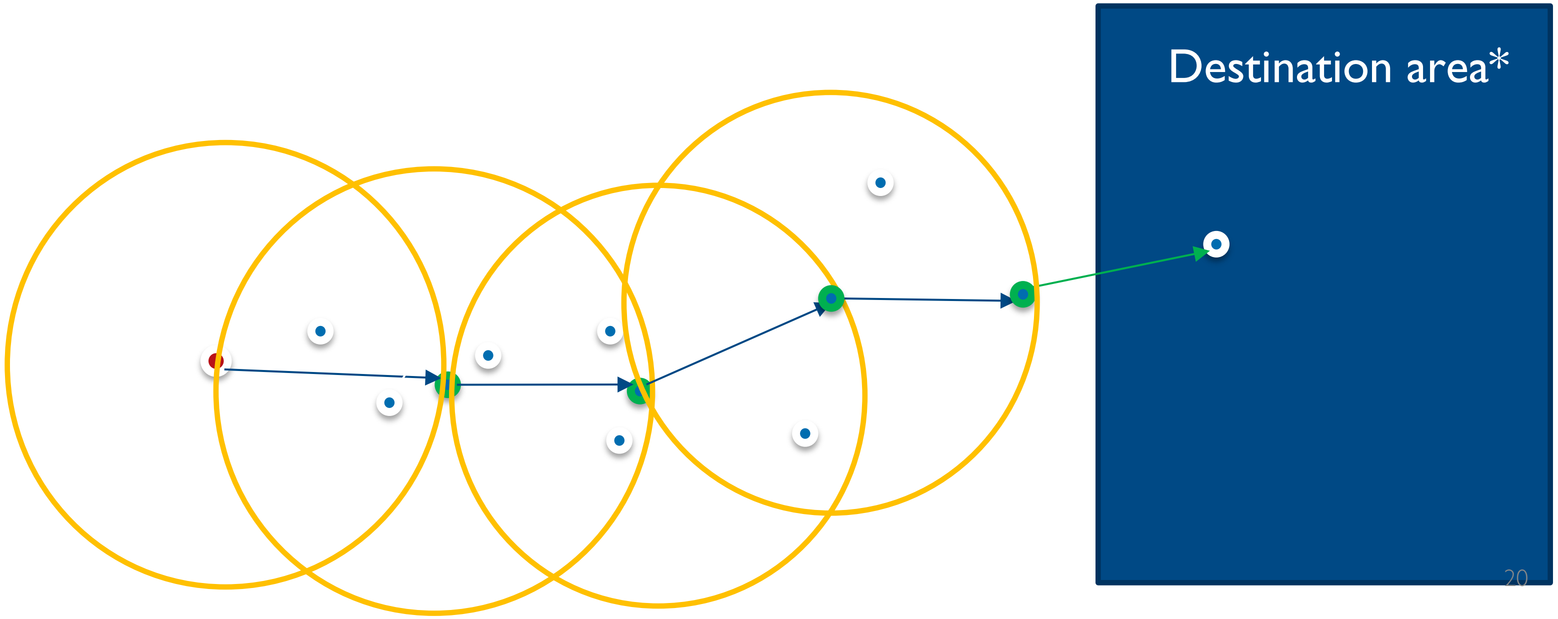
$$\Pr\{A\ to\ M\} = (1 - p_{AD}) \wedge (1 - p_{DH}) \wedge (1 - \mathrm{p_{HJ}}) \wedge (1 - p_{JL}) \wedge (1 - p_{LM})$$

$$\Pr\{A\ to\ M\} = (0.8322)(0.8322)(0.8322)(0.8322)(0.8322) = 0.3991$$



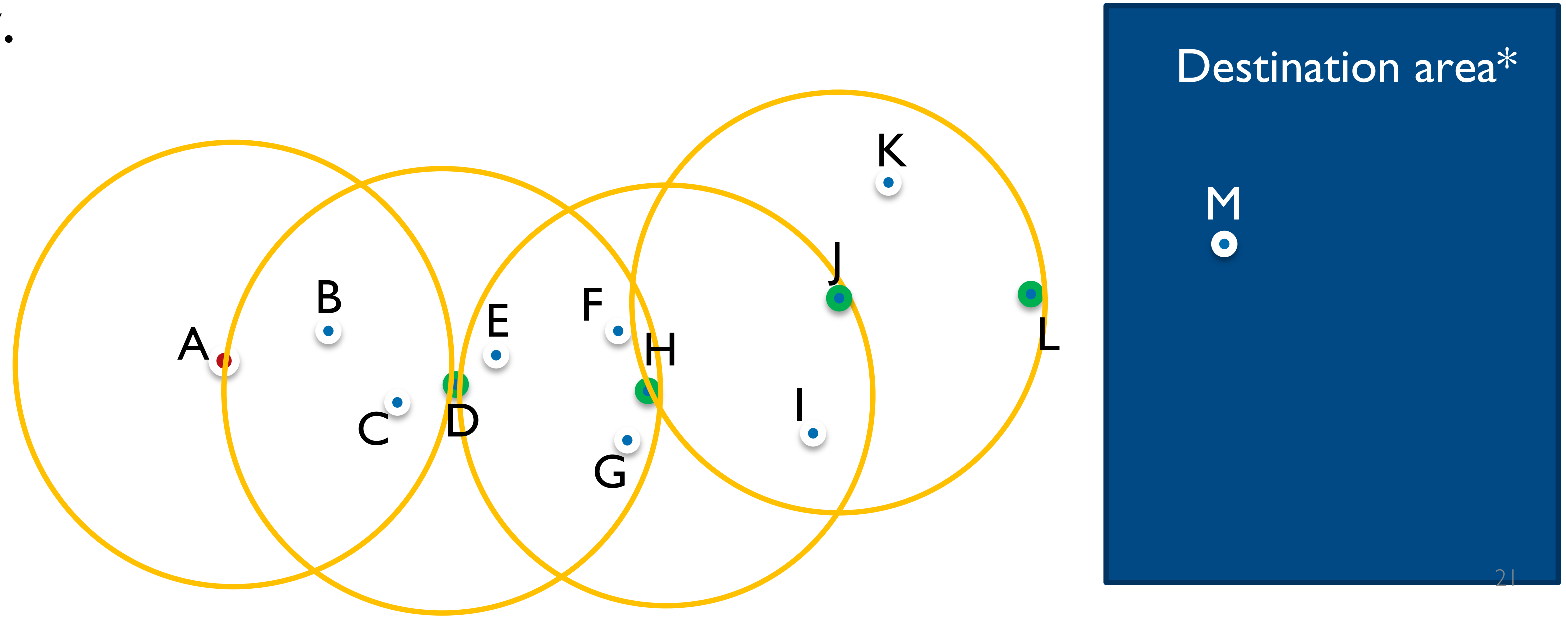
# Greedy Forwarding: way too greedy

- The literature identifies Greedy forwarding as an unreliable mechanism for GeoBroadcasting in vehicular networking
- The ETSI specification recommends it (acknowledging reliability issues), but real-world implementations (e.g., C-Roads, Car-to-Car) use other mechanisms.



# Contention-based Forwarding (CBF)

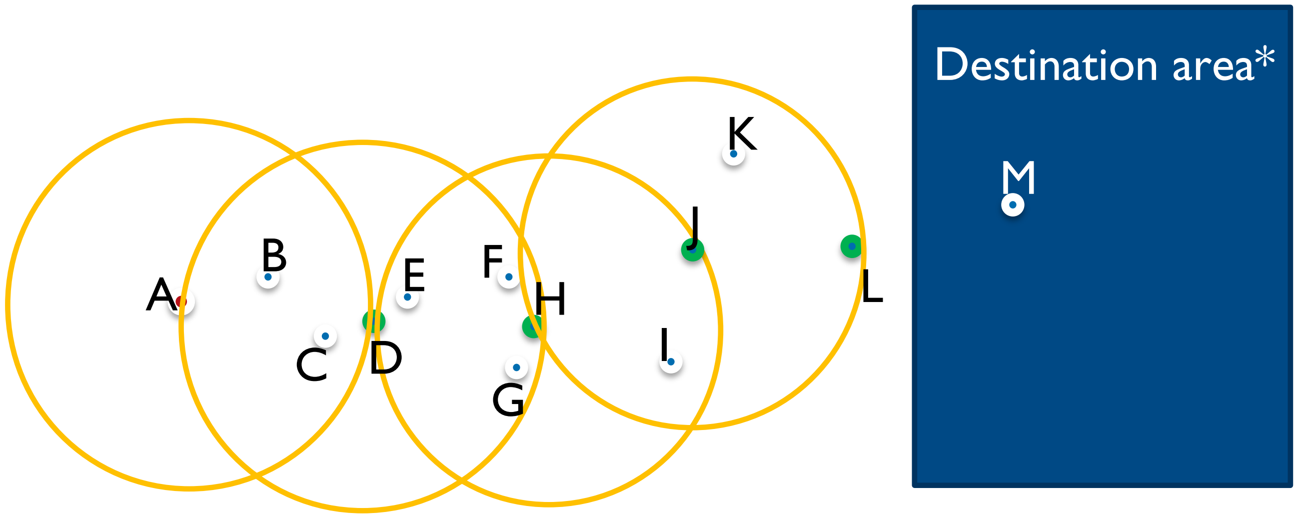
- Messages are sent as **broadcast**, and any node that hears it can become a forwarder.
- After receiving a message, a forwarder determines if it offers a progress towards the destination area.
- Using the "progress" since the last forwarder, it calculates a "contention" timer.
- If it "hears" a forwarded message, it cancels its timer. Otherwise, it transmits upon timer expiry.



# Contention-based Forwarding (CBF) – Release 1

$$T_{CBF} \begin{cases} \boldsymbol{T_{CBF-MAX} - \frac{T_{CBF-MAX} - T_{CBF-MIN}}{DIST_{MAX}} \times PROG} \\ \quad if\ PROG \le DIST_{MAX}, \\ \\ \boldsymbol{T_{CBF-MIN}}\ otherwise \end{cases}$$

$$T_{CBF-MAX} = 100\text{ms}$$
$$T_{CBF-MIN} = 1\text{ms}$$
$$DIST_{MAX} = 1000\text{m}$$



“No plan survives first contact with the enemy”

Helmuth von Moltke

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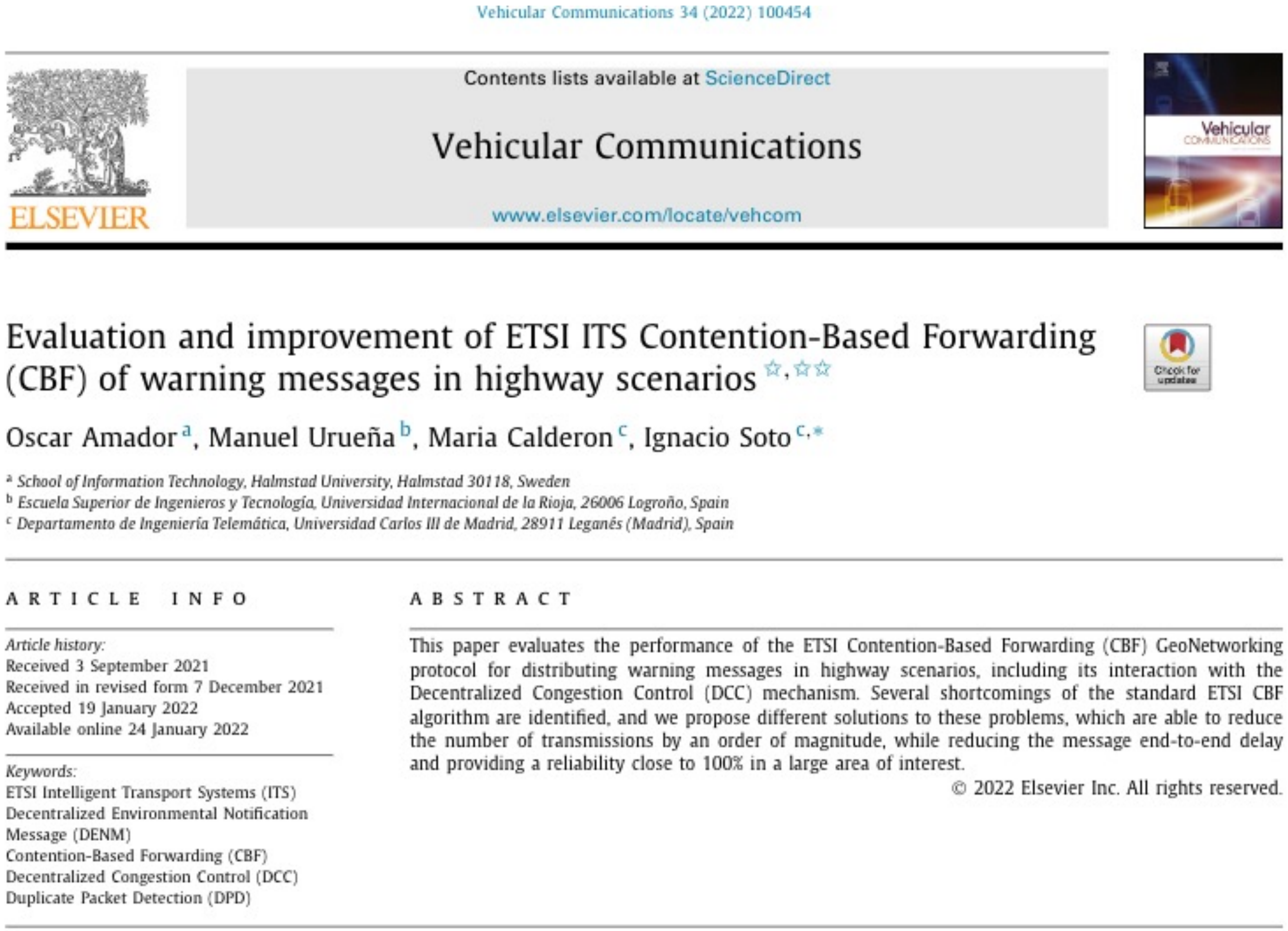
"Everyone has a plan until they get punched in the mouth."

Michael Gerard Tyson

# ETSI Contention-based forwarding (highways)

- Evaluation and improvement of ETSI CBF (in highways)
  - Disseminate DENMs using the ETSI ITS-G5 architecture
  - The standard is **effective,** but it can be more **efficient**.
  - Decreased transmissions an order of magnitude and kept PDR at 100%



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Duplicate Packet Detection (DPD)

ABSTRACT

This paper evaluates the performance of the ETSI Contention-Based Forwarding (CBF) GeoNetworking protocol for distributing warning messages in highway scenarios, including its interaction with the Decentralized Congestion Control (DCC) mechanism. Several shortcomings of the standard ETSI CBF algorithm are identified, and we propose different solutions to these problems, which are able to reduce the number of transmissions by an order of magnitude, while reducing the message end-to-end delay and providing a reliability close to 100% in a large area of interest.

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- Evaluation and improvement of ETSI CBF (in highways)
  - Disseminate DENMs using the ETSI ITS-G5 architecture
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| Density (veh/km lane) | ETSI | DPD | GPC | FoT |
|---|---|---|---|---|
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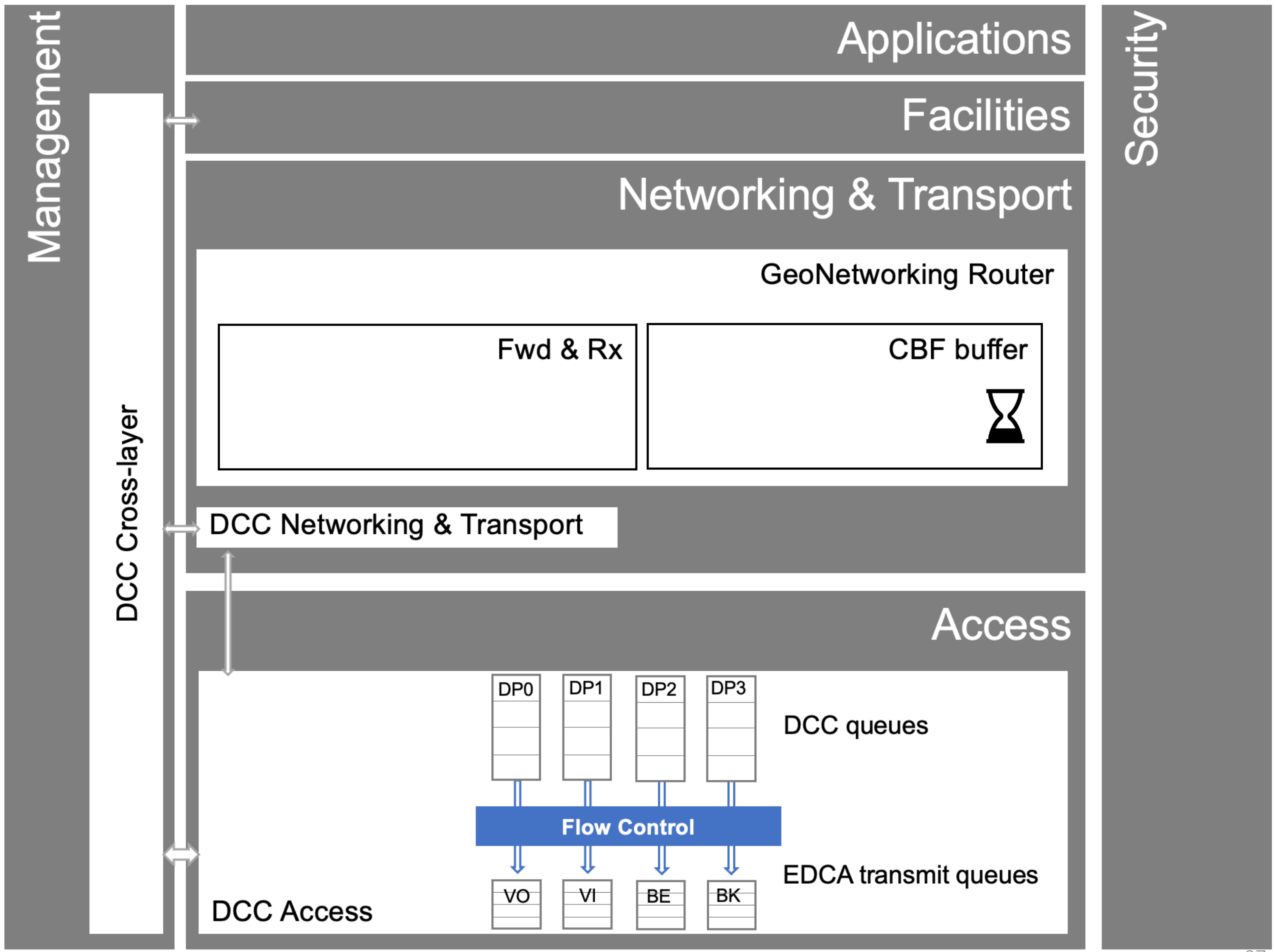
| 20 | 26,515.0 | 1,095.6 | 1,480.8 | 1,030.0 |
| 30 | 19,878.4 | 1,229.8 | 1,900.6 | 1,459.6 |
| 40 | 19,063.6 | 1,029.2 | 2,167.6 | 1,075.2 |
| 50 | 16,542.2 | 1,720.6 | 2,483.6 | 1,859.6 |

# ETSI Area Contention-based Forwarding



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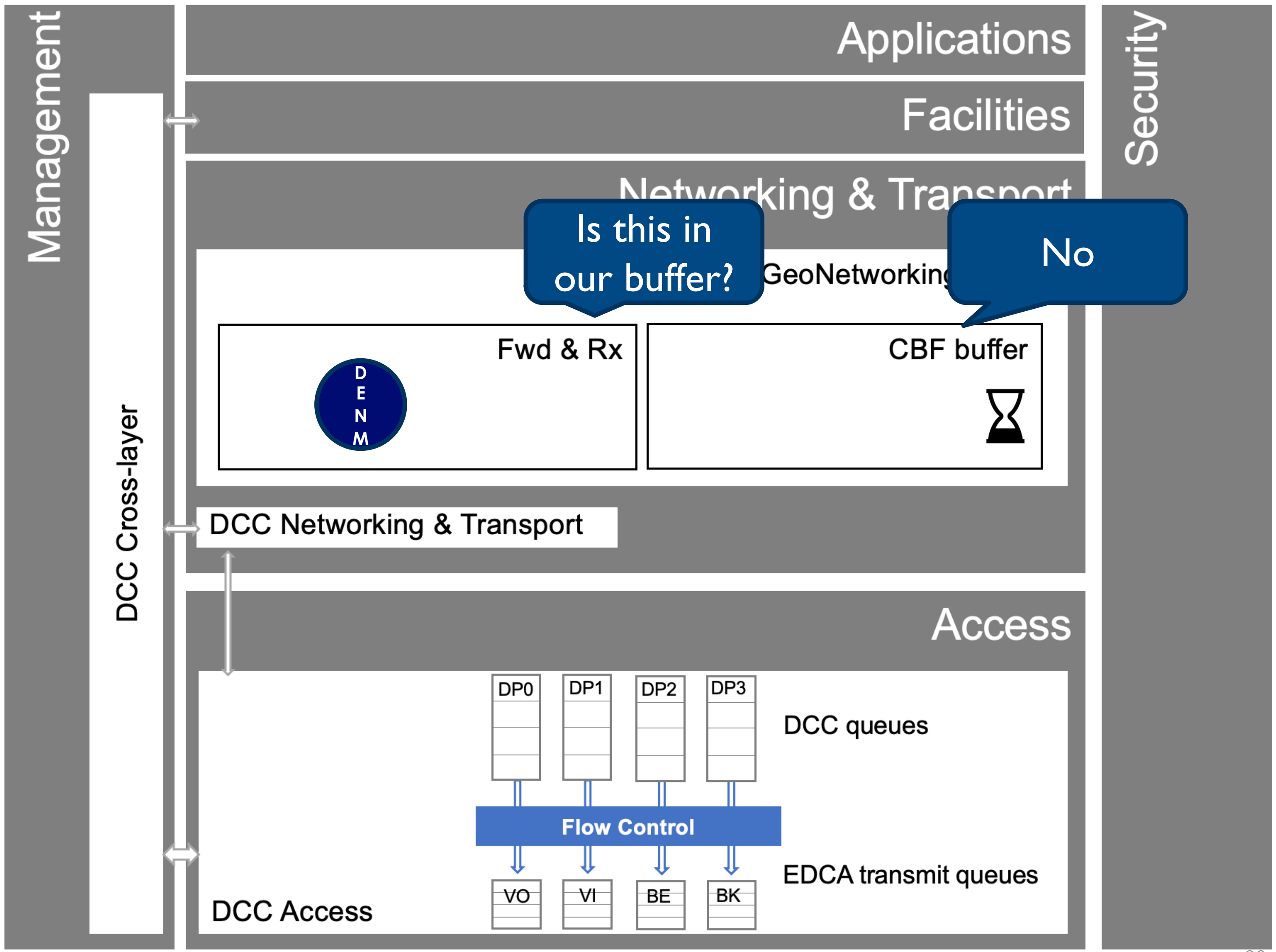

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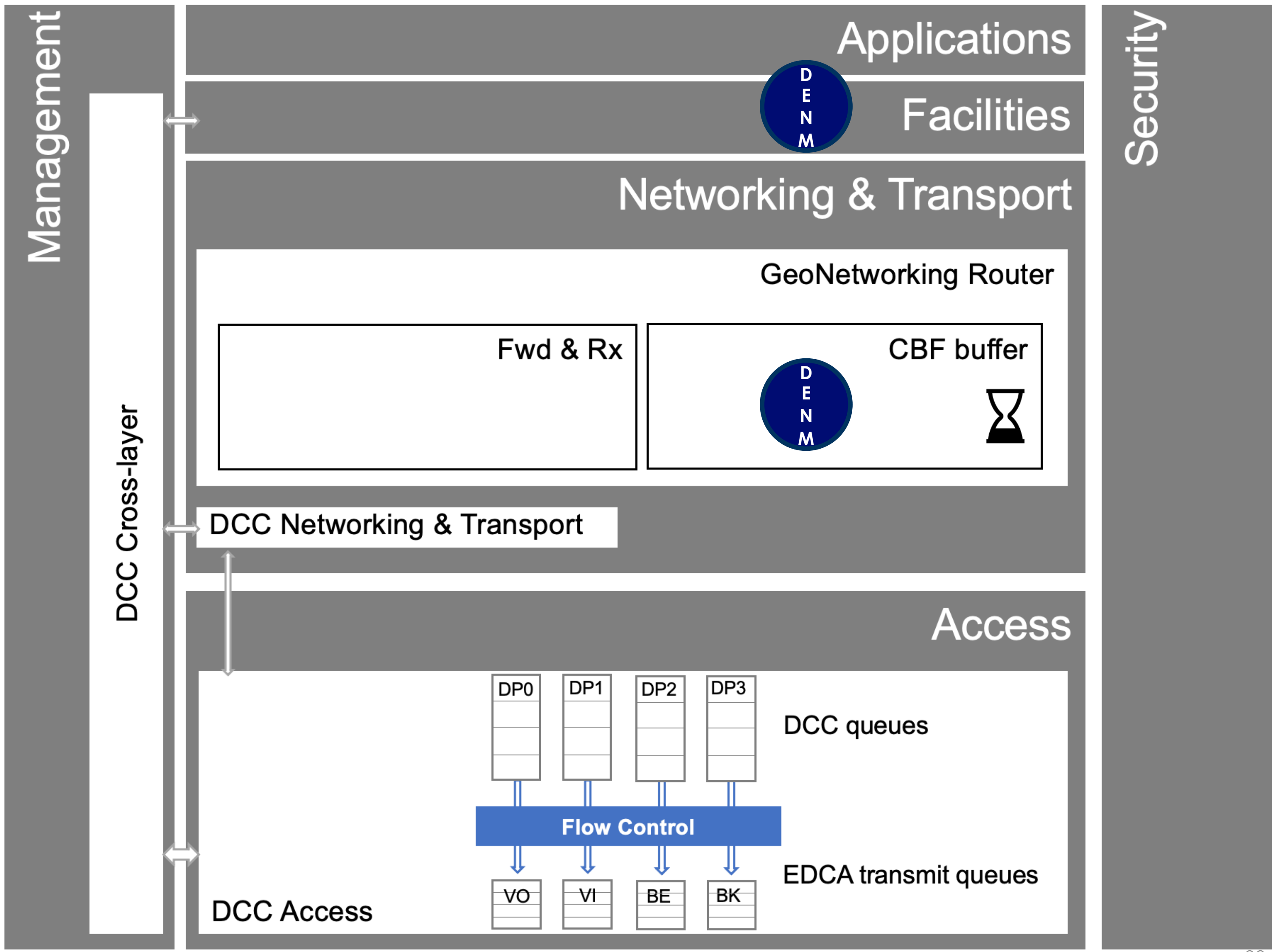
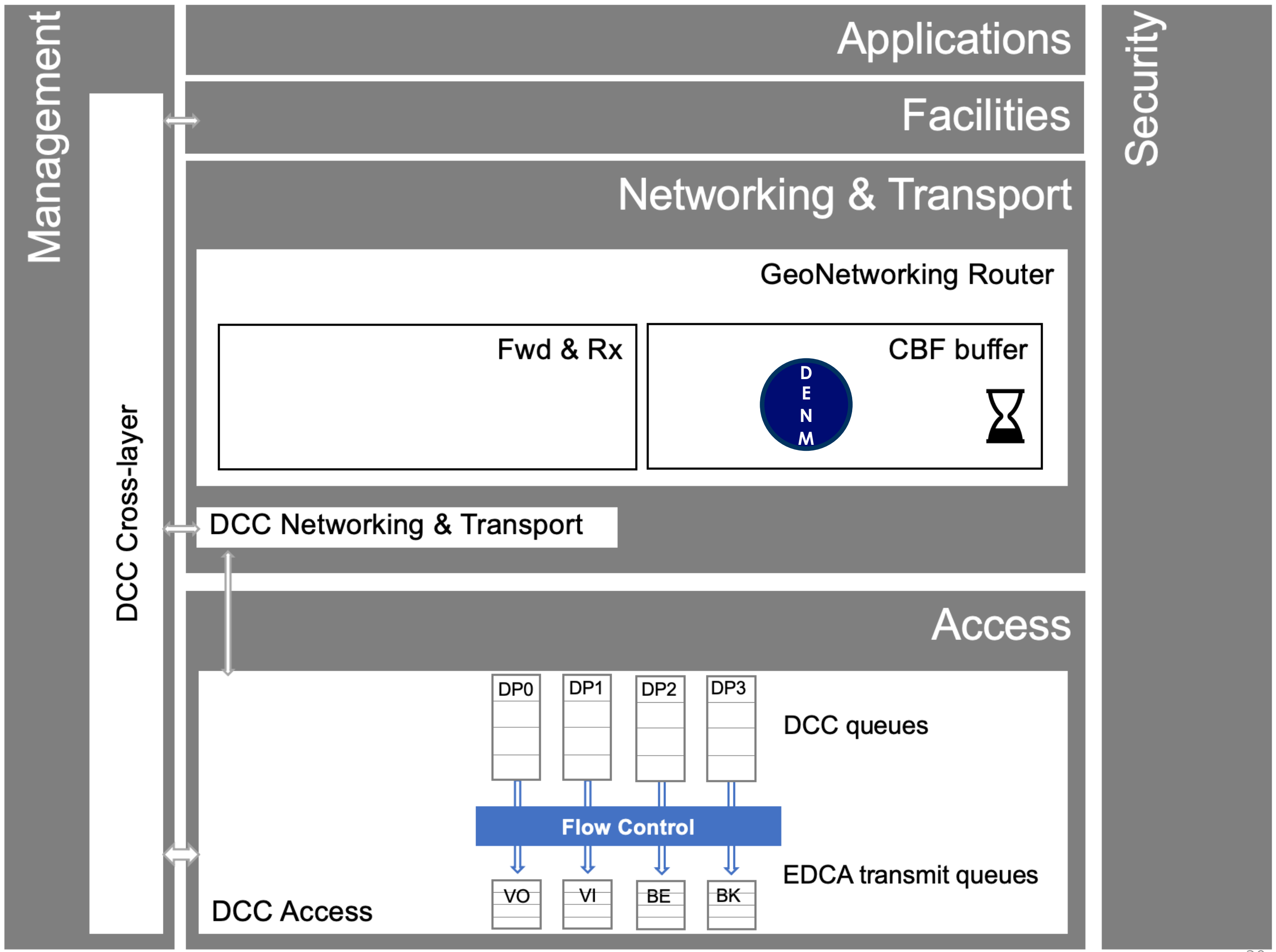


# ETSI CBF – packet cancellation

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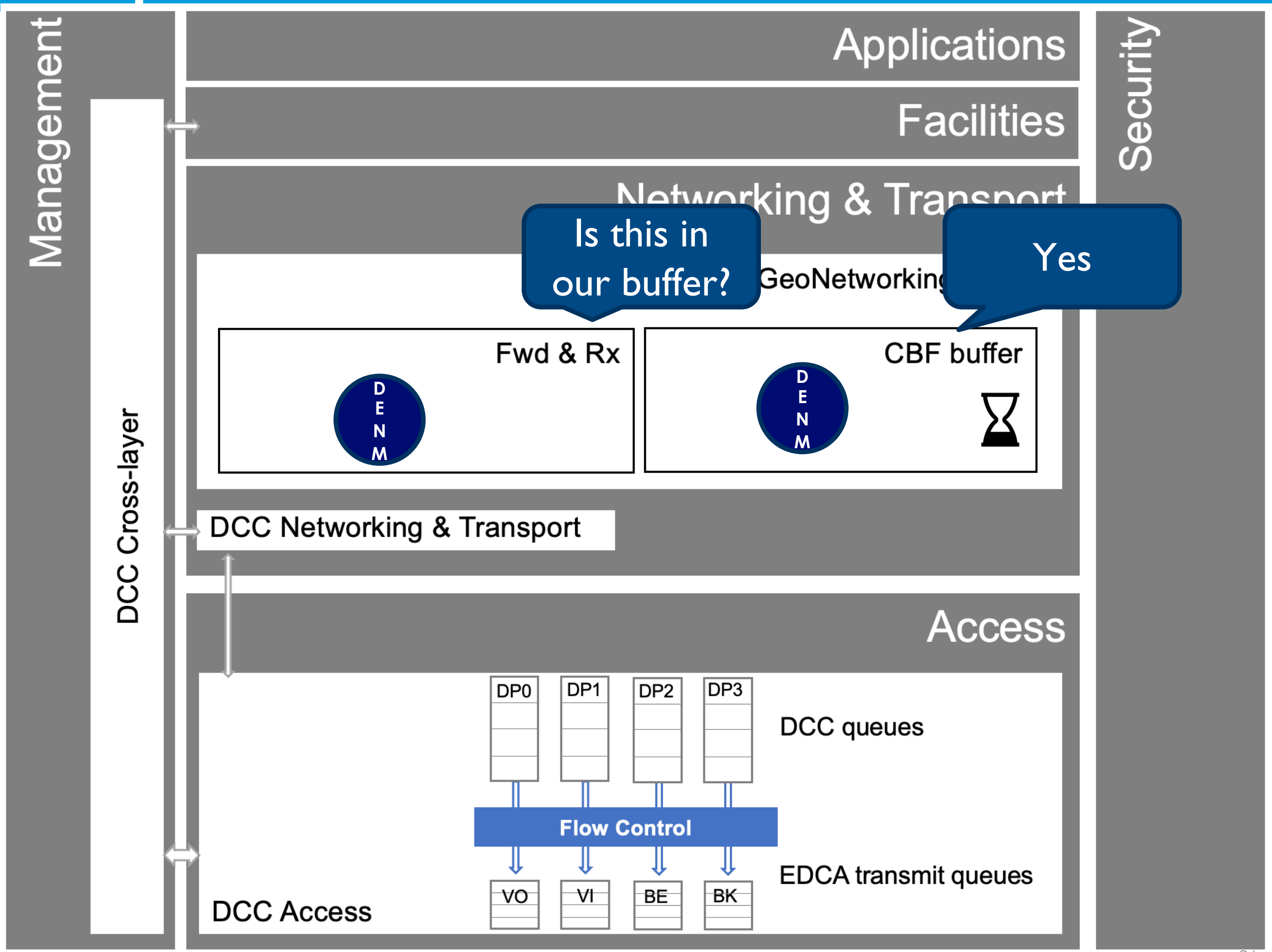

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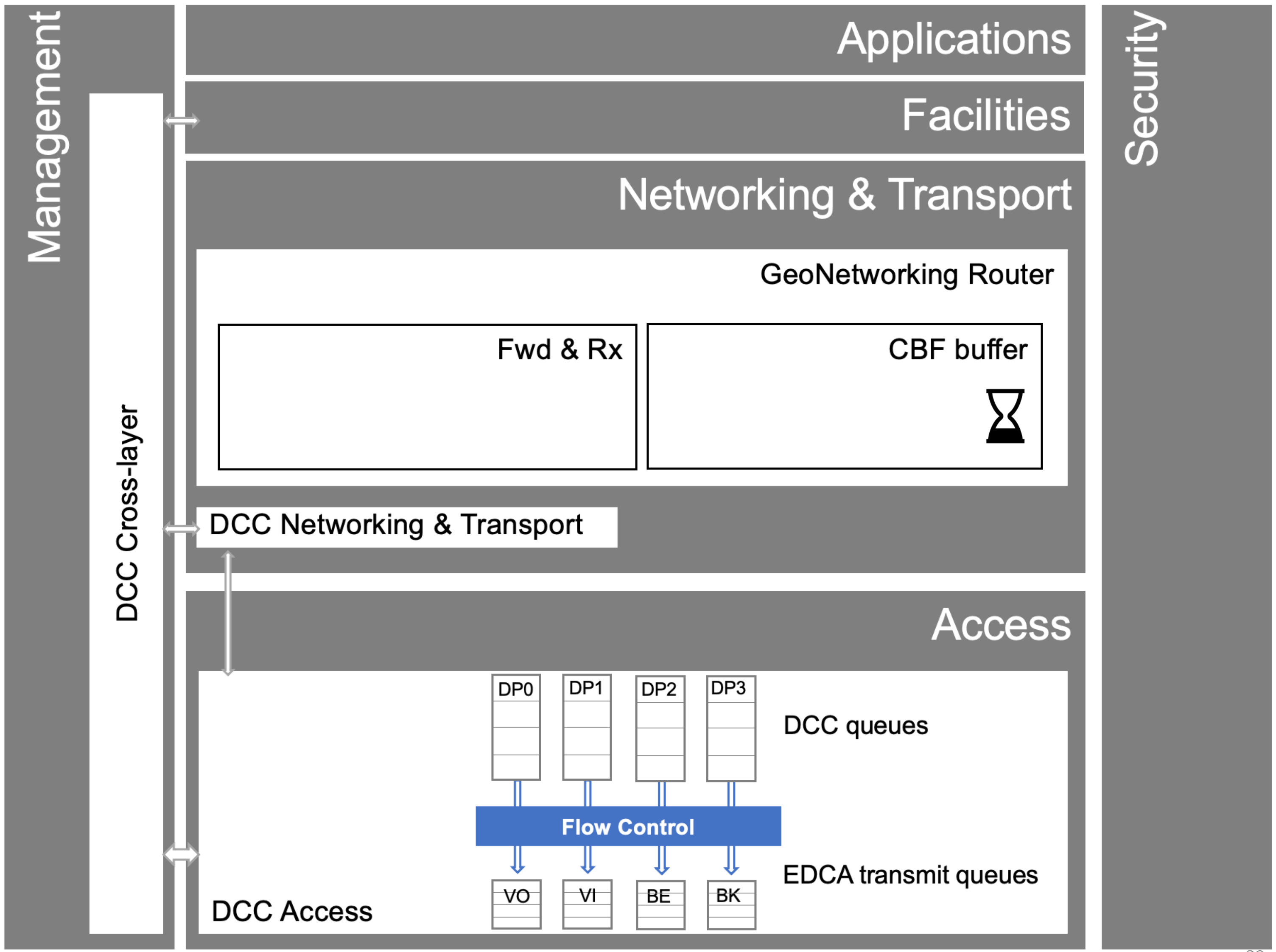
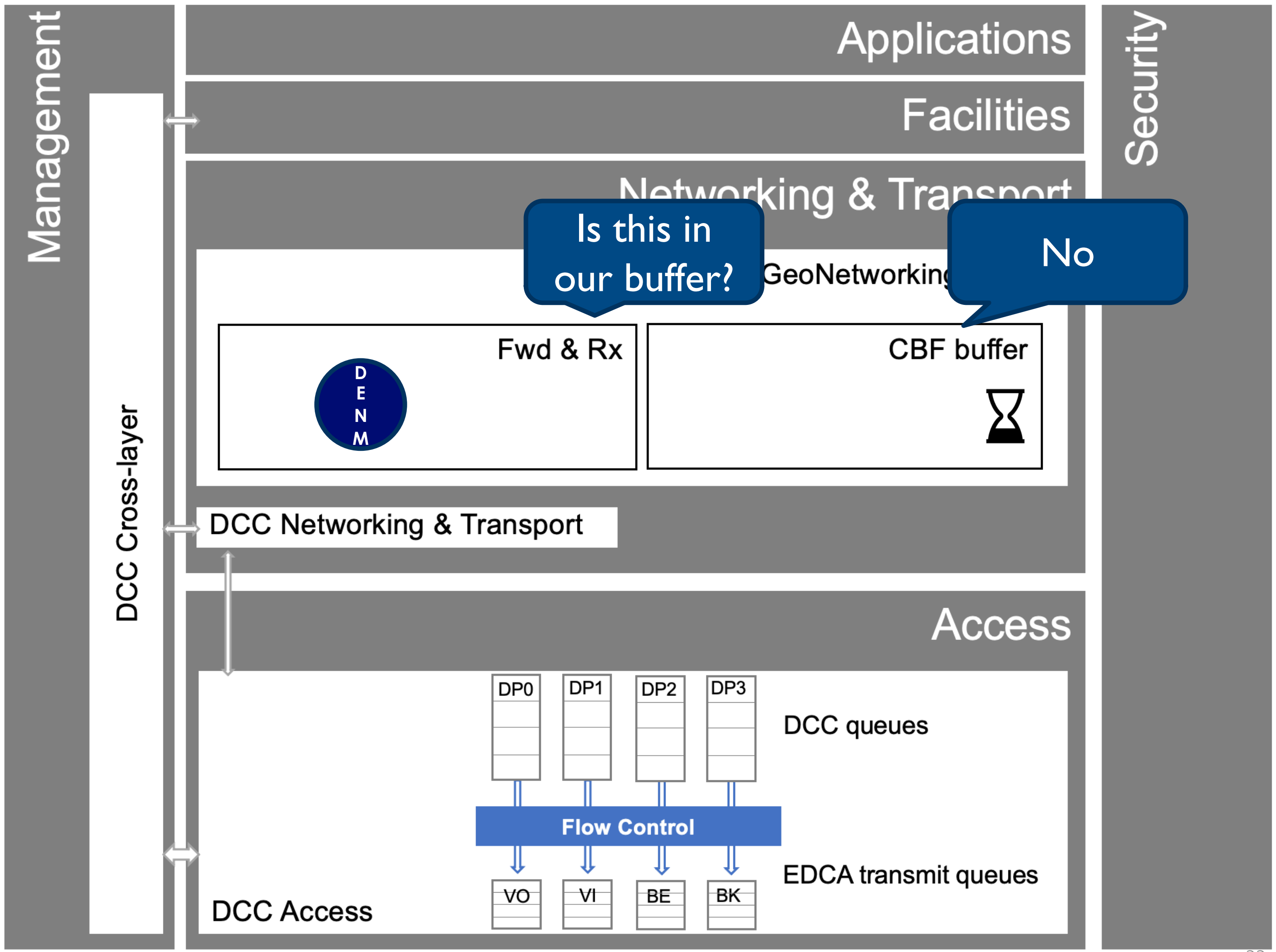


# ETSI CBF and DCC interaction



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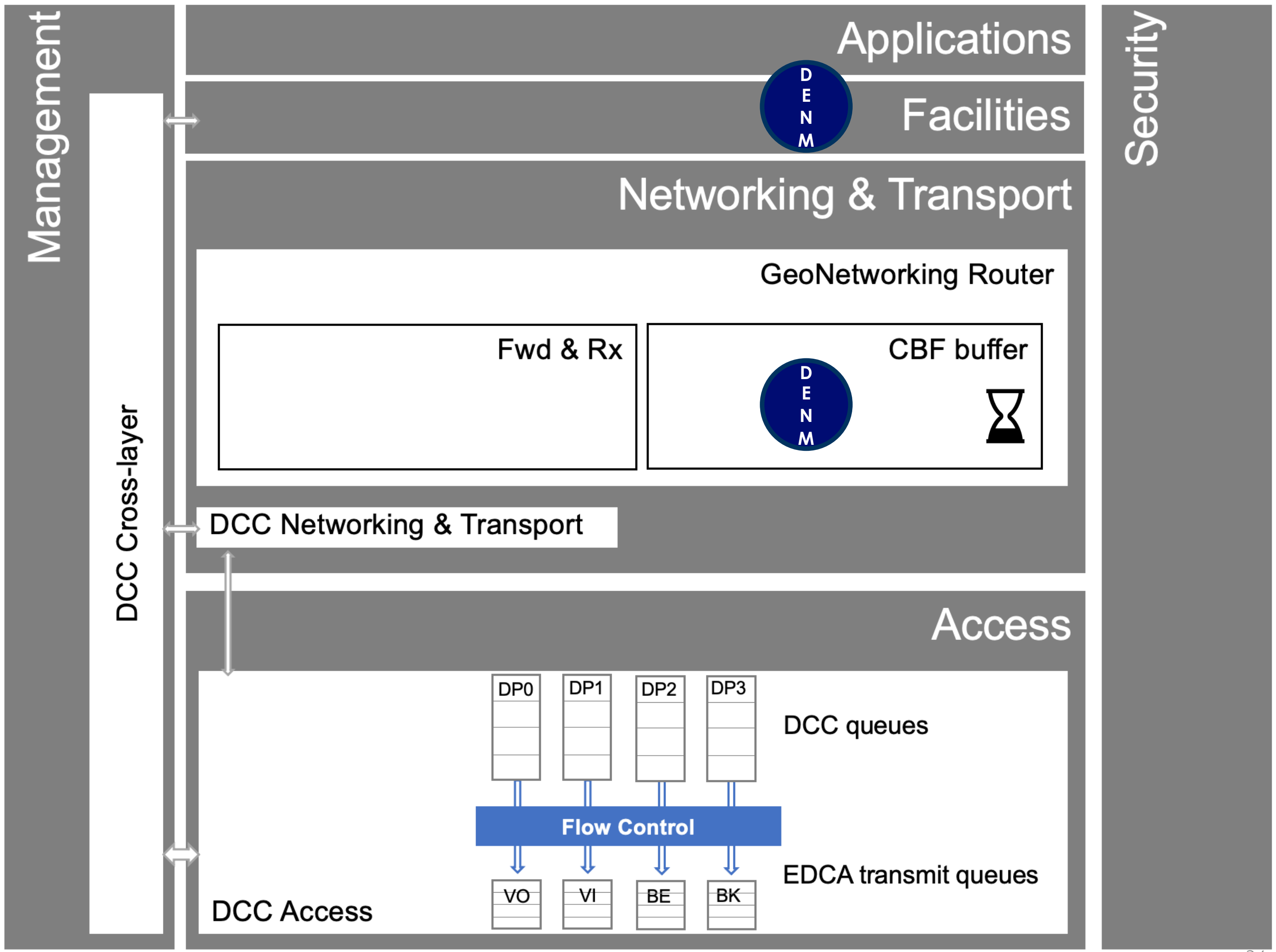

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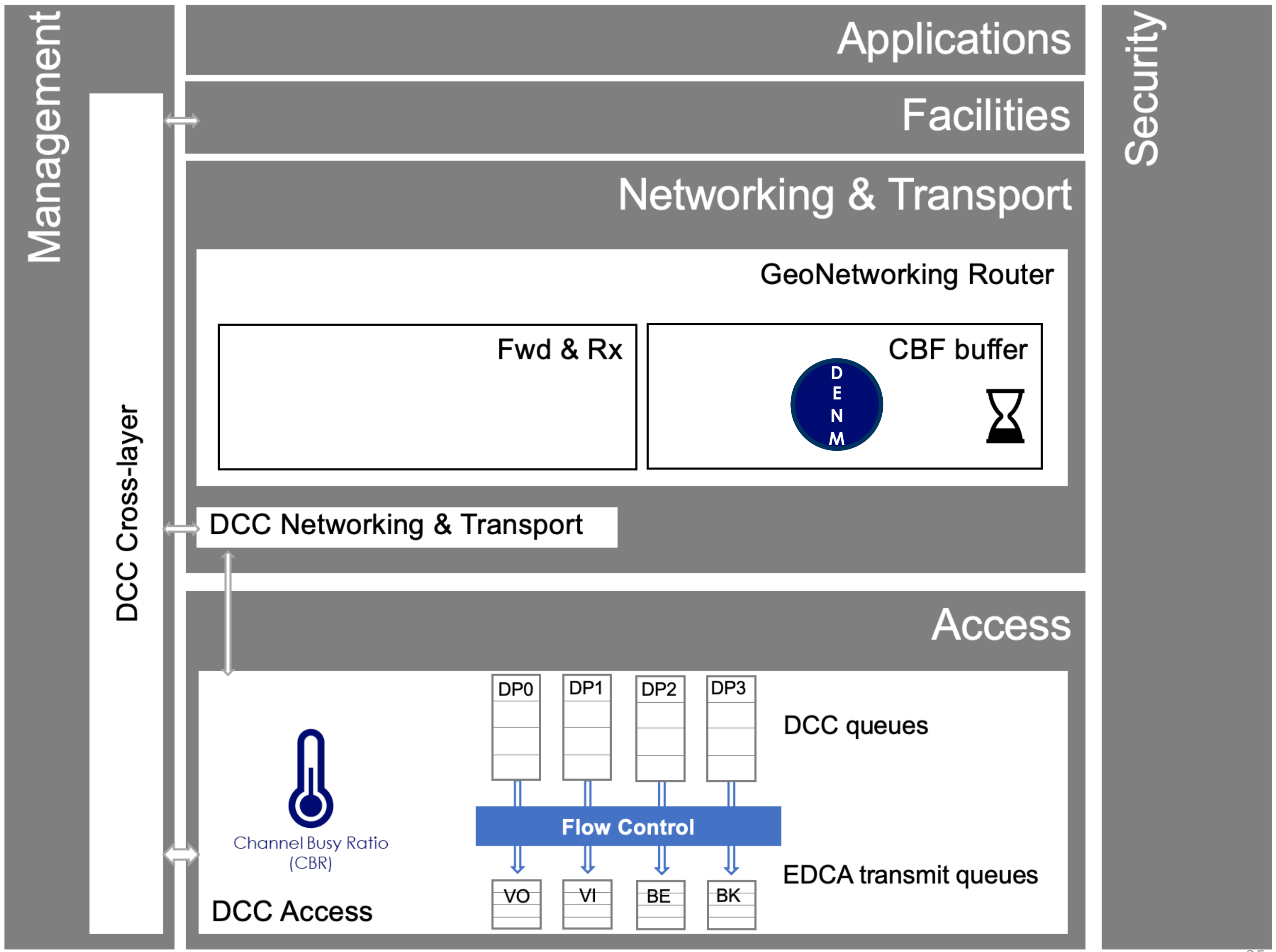
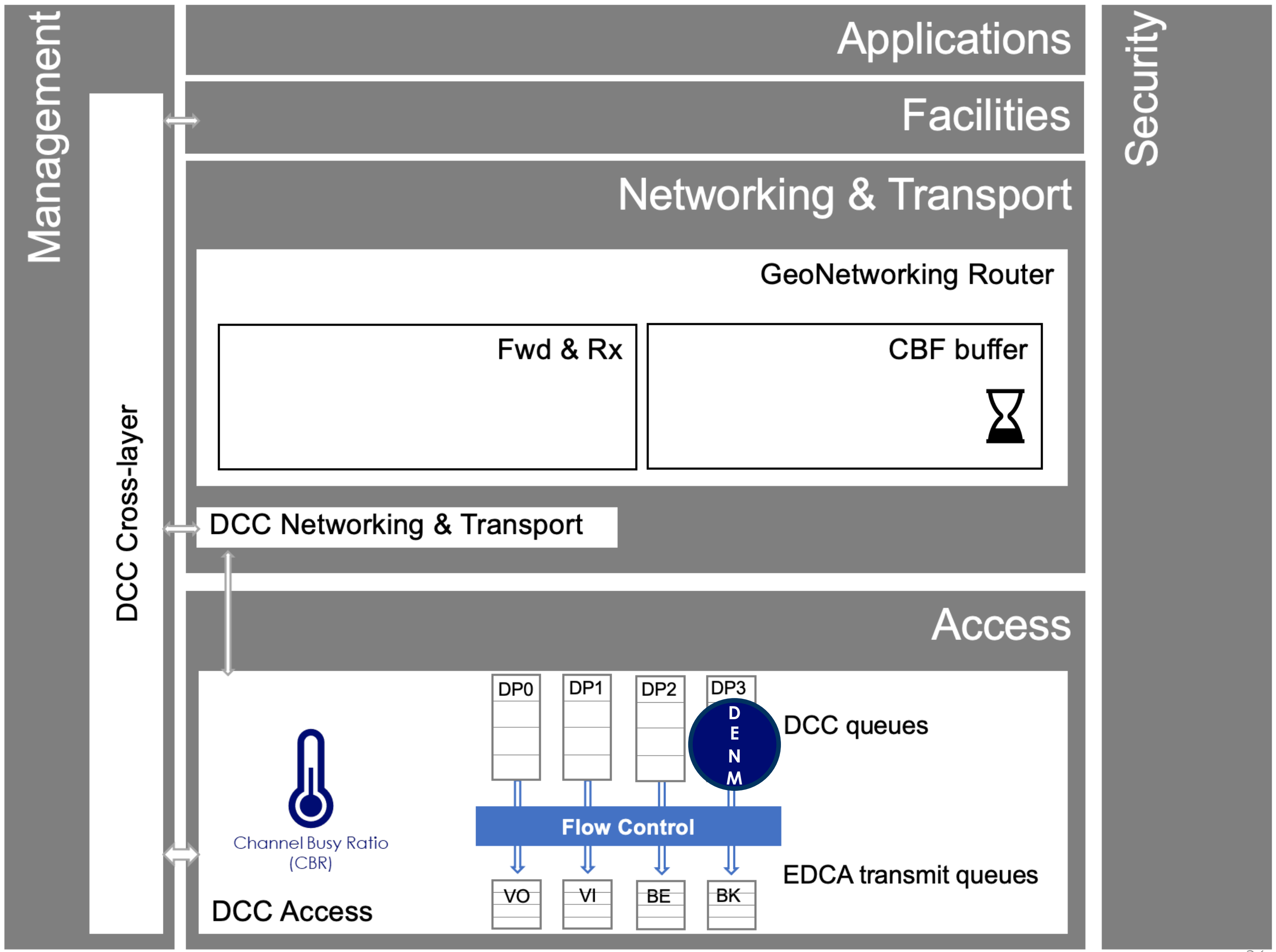


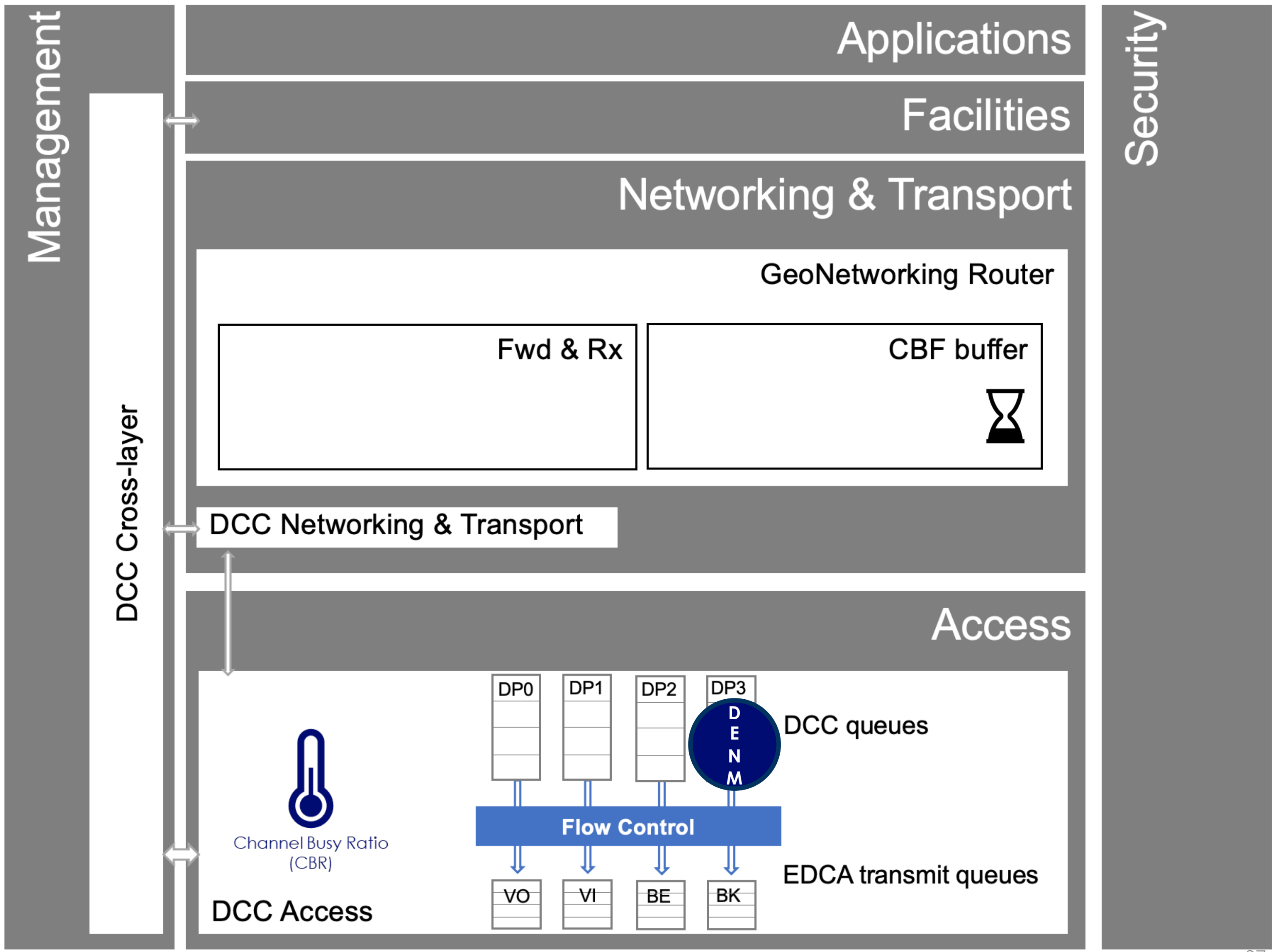

Timer expires

# ETSI CBF and ETSI DCC interaction



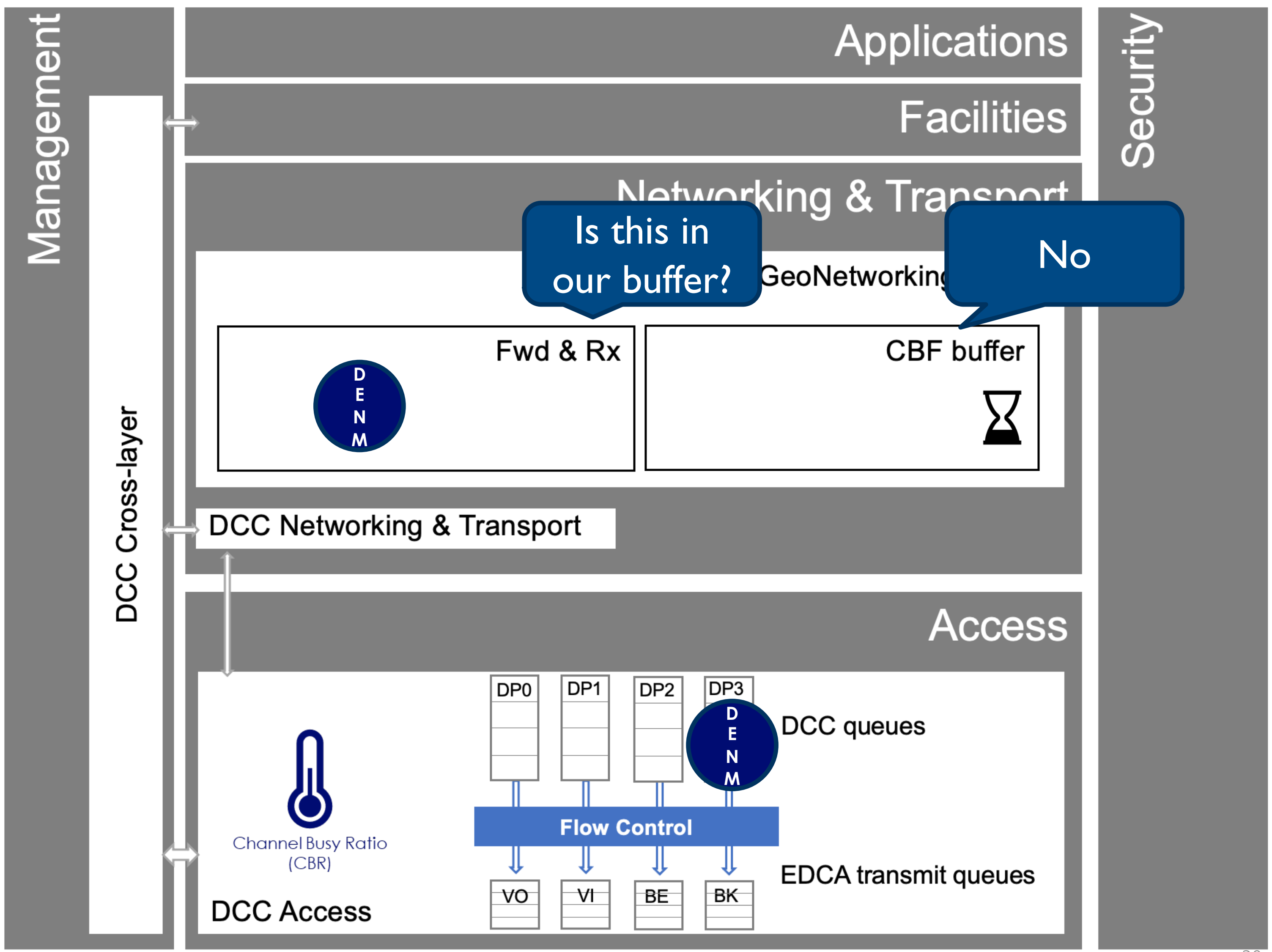

Packet is expected to be transmitted immediately

# ETSI CBF and ETSI DCC interaction




DENM

# ETSI CBF and ETSI DCC interaction




Rel. 1 does not keep a list of duplicate packets

# Forward-on-Time (FoT)

- An addition to ETSI CBF that includes
  - Duplicate packet detection
  - Geographically-aware packet cancellation in the CBF buffer
  - Congestion-aware buffering

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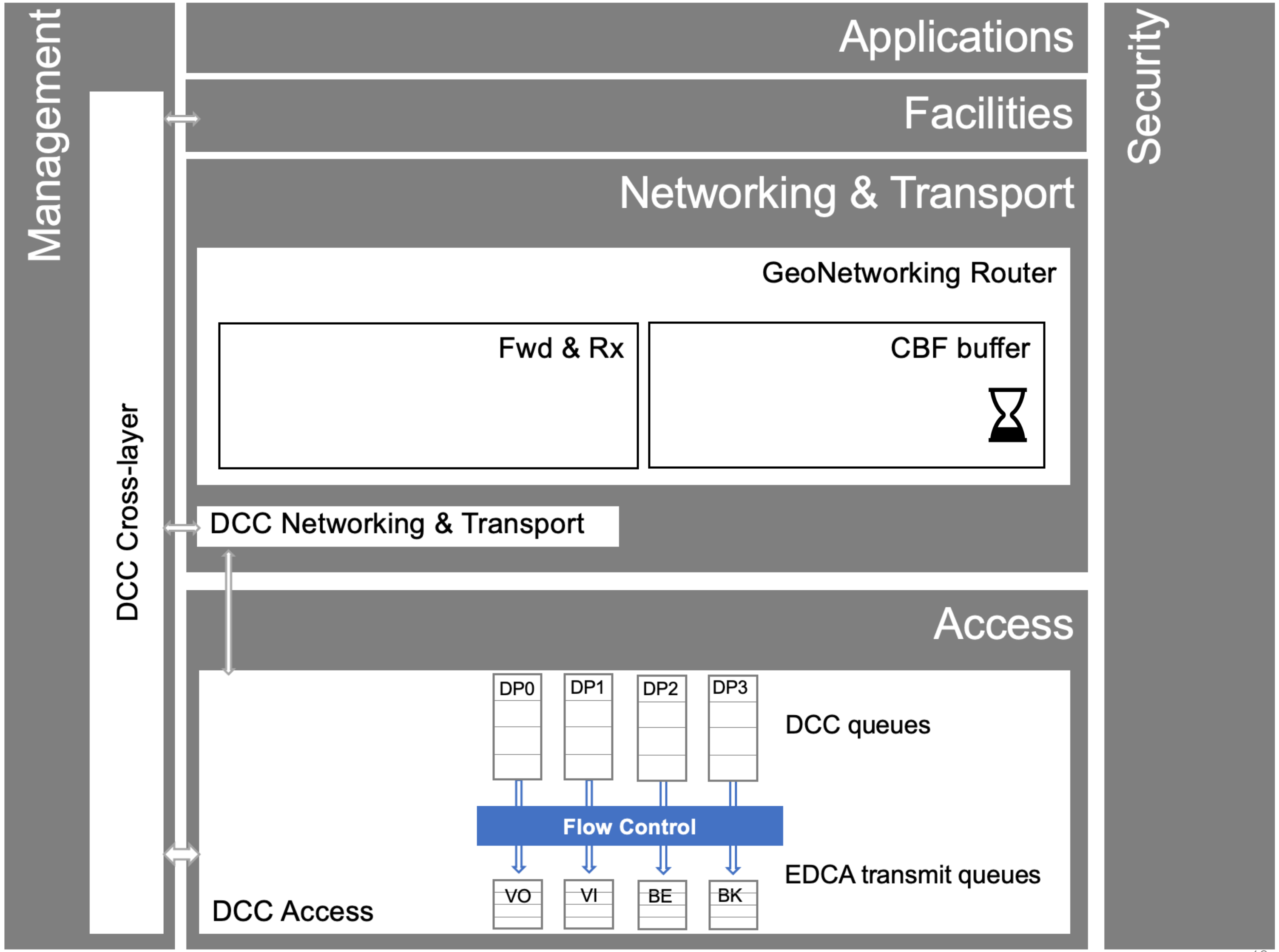


D E N M

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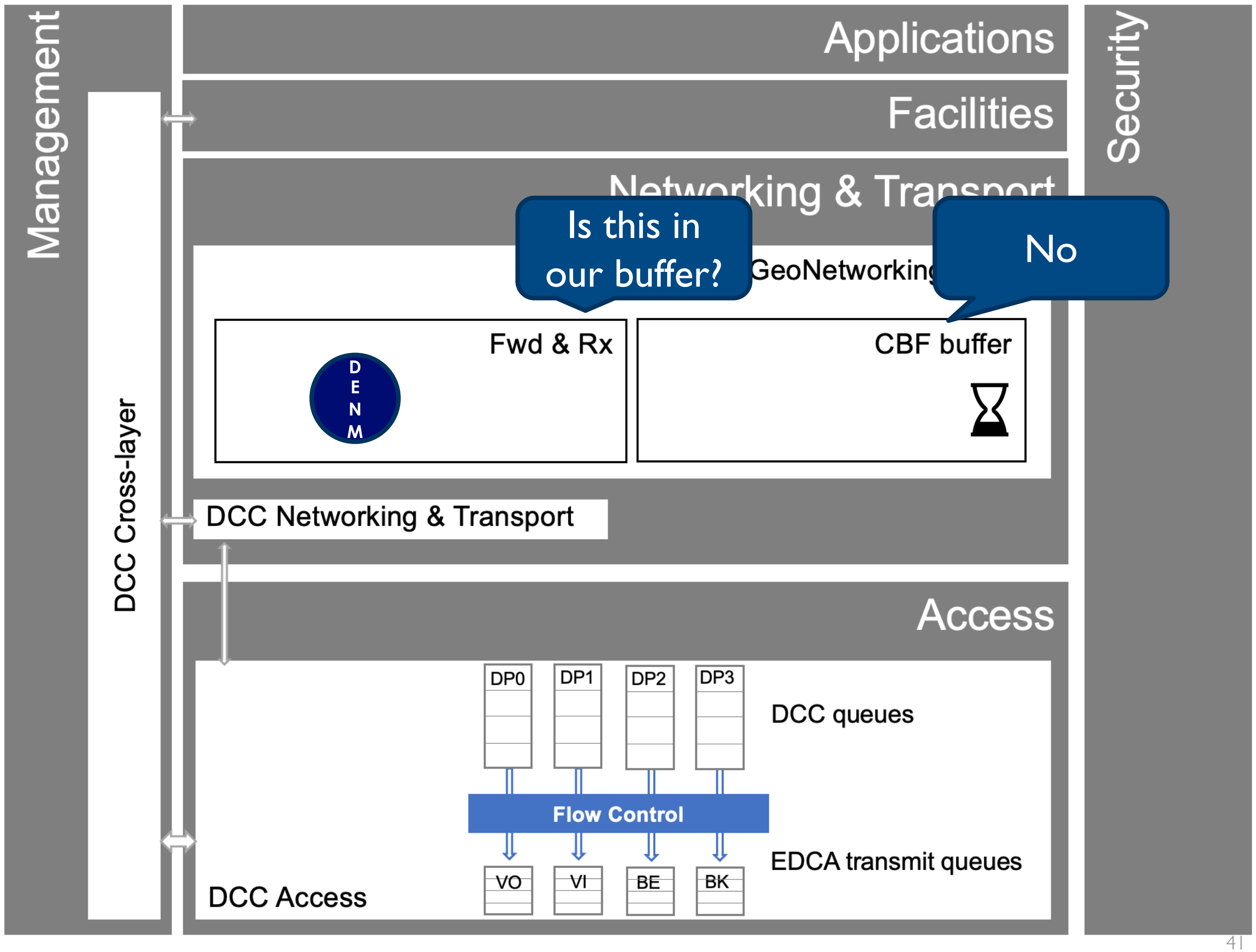

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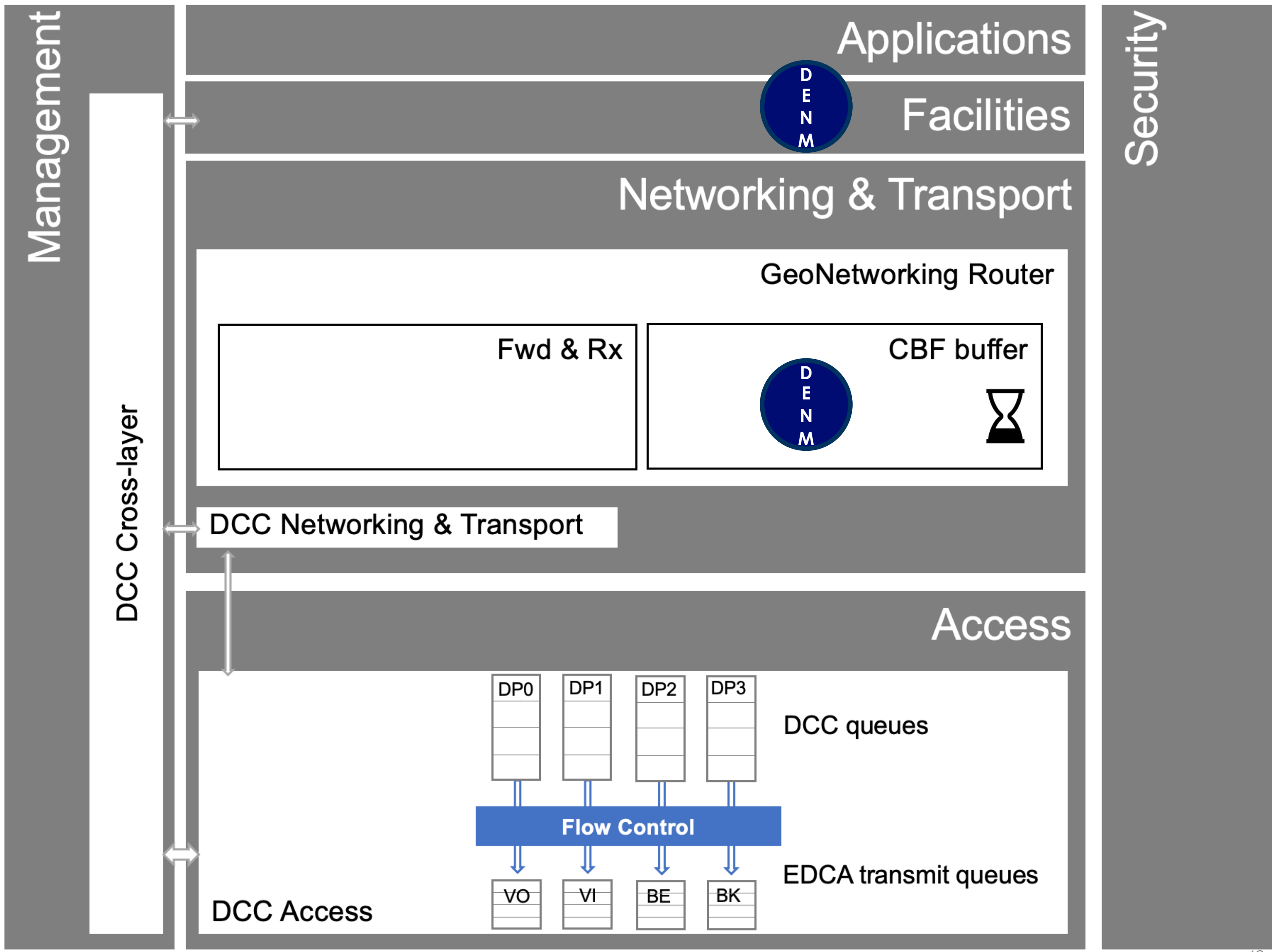

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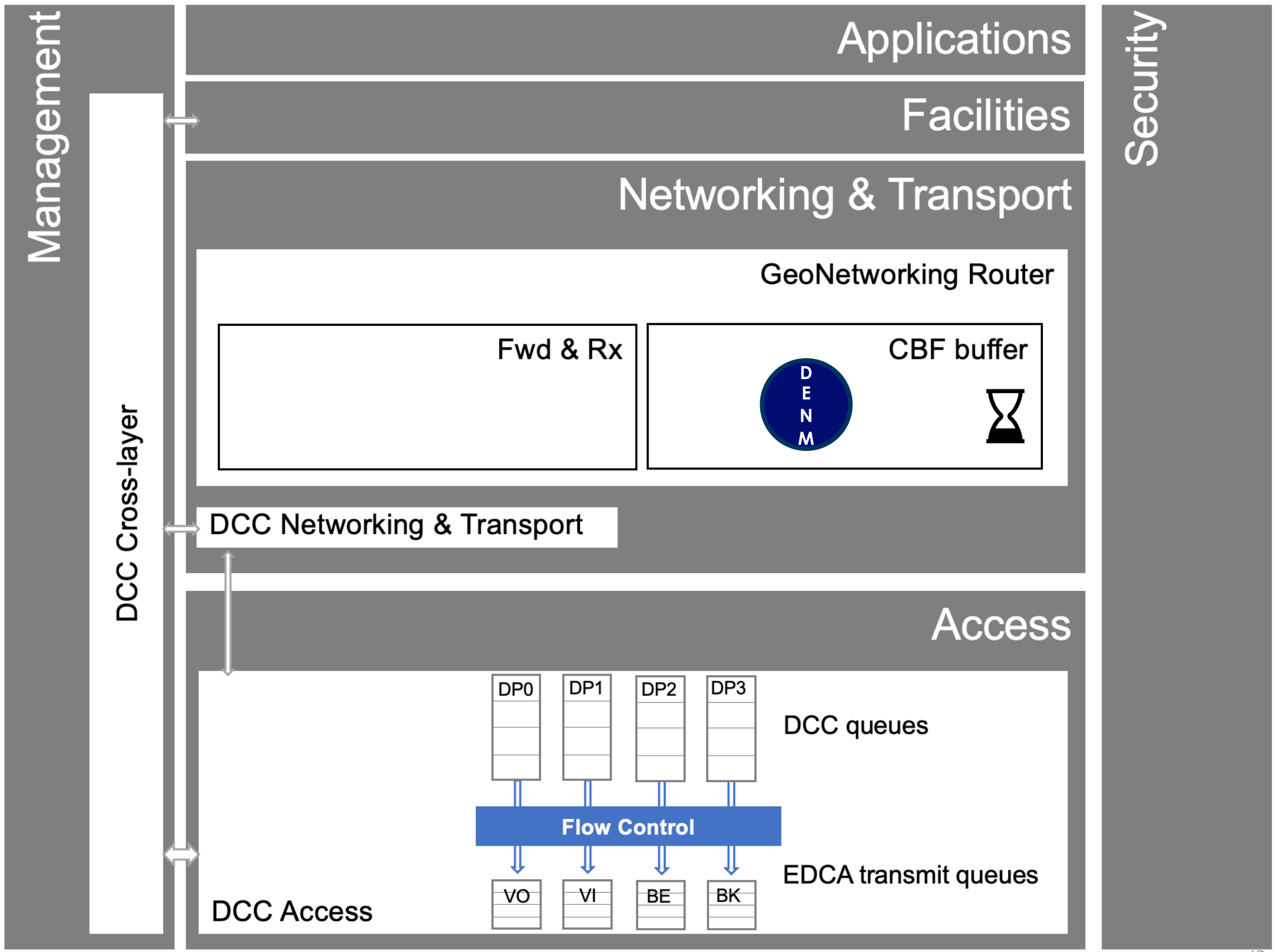


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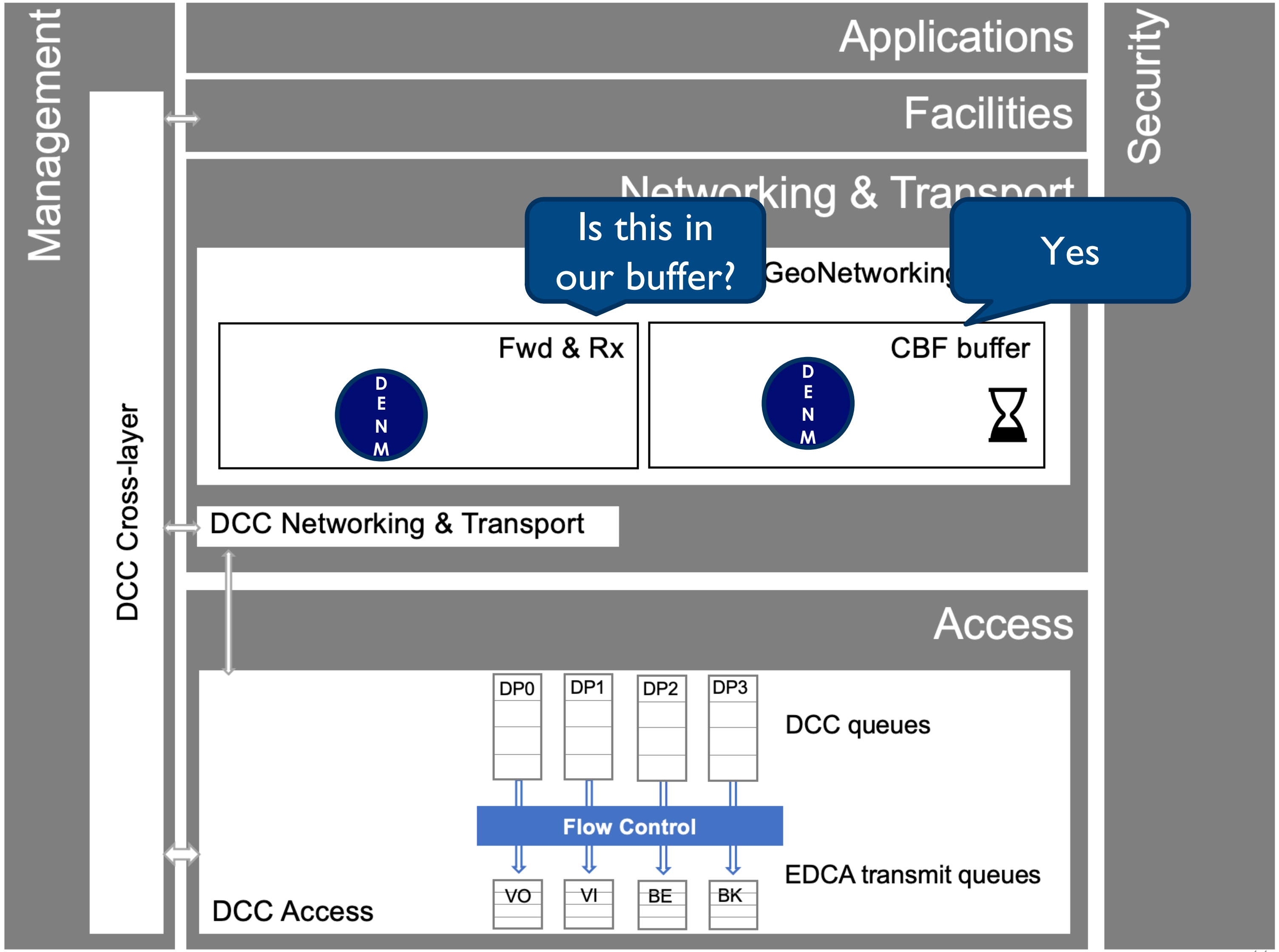

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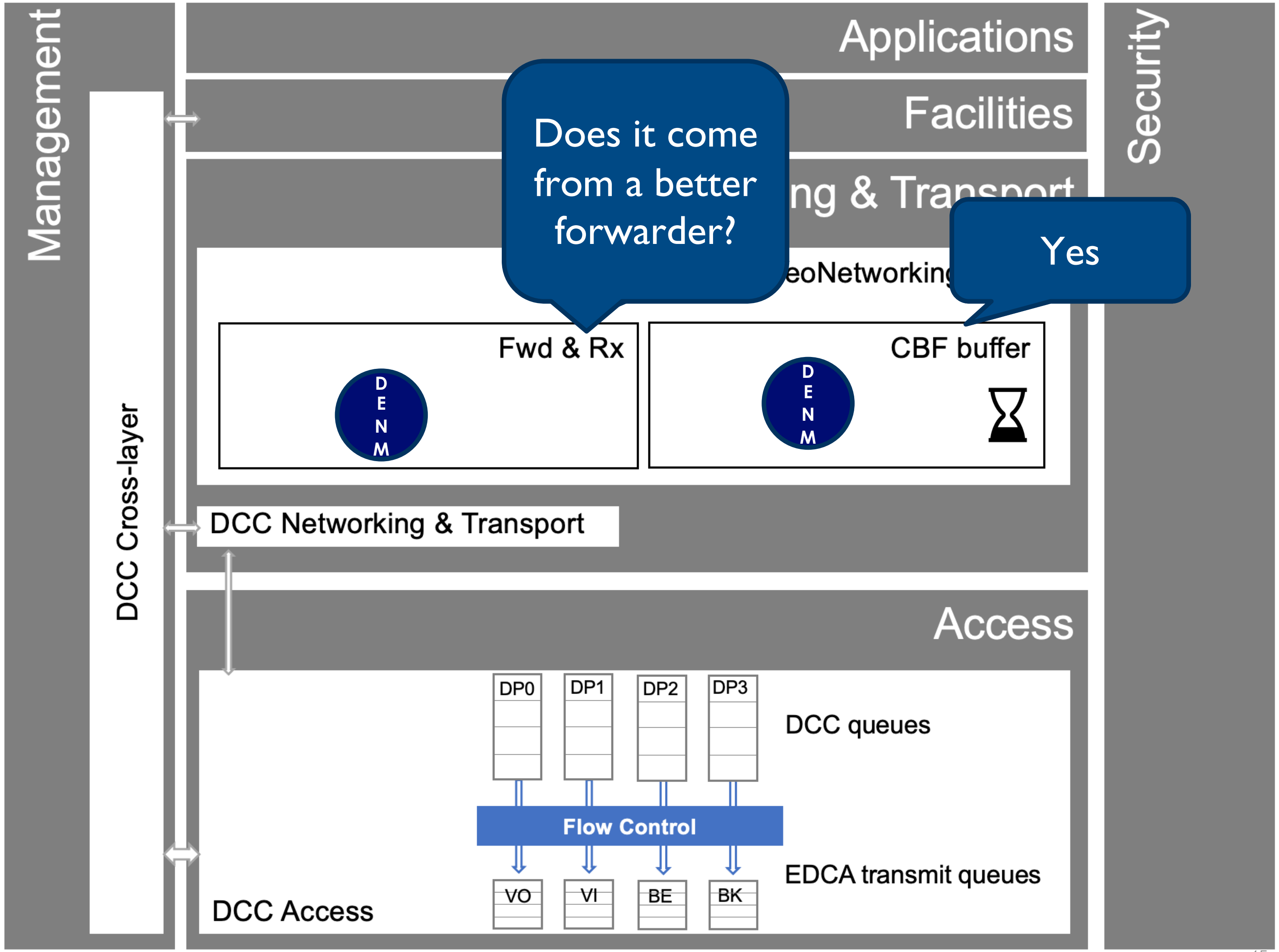
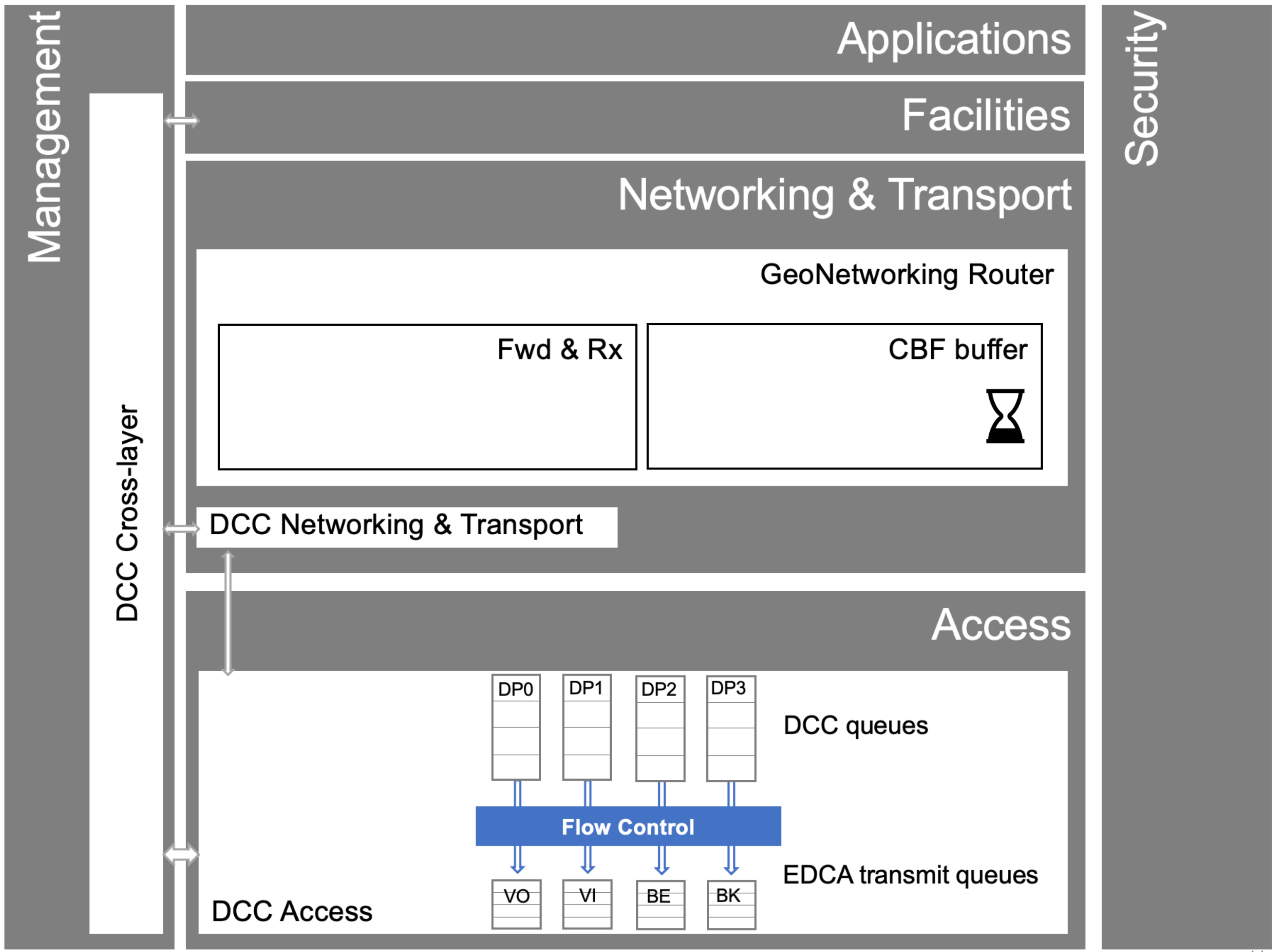
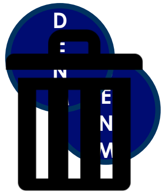


# ETSI CBF – packet cancellation







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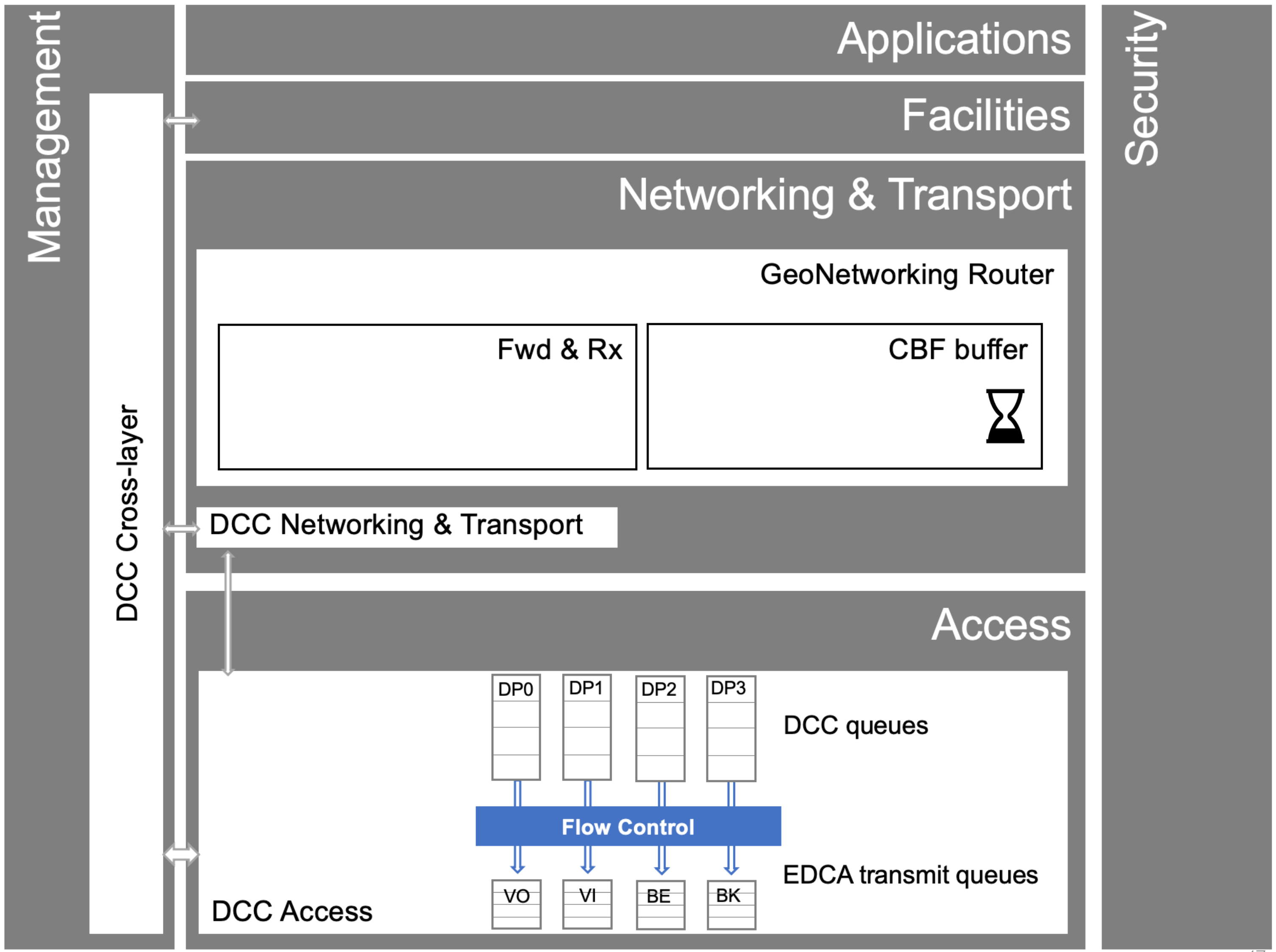
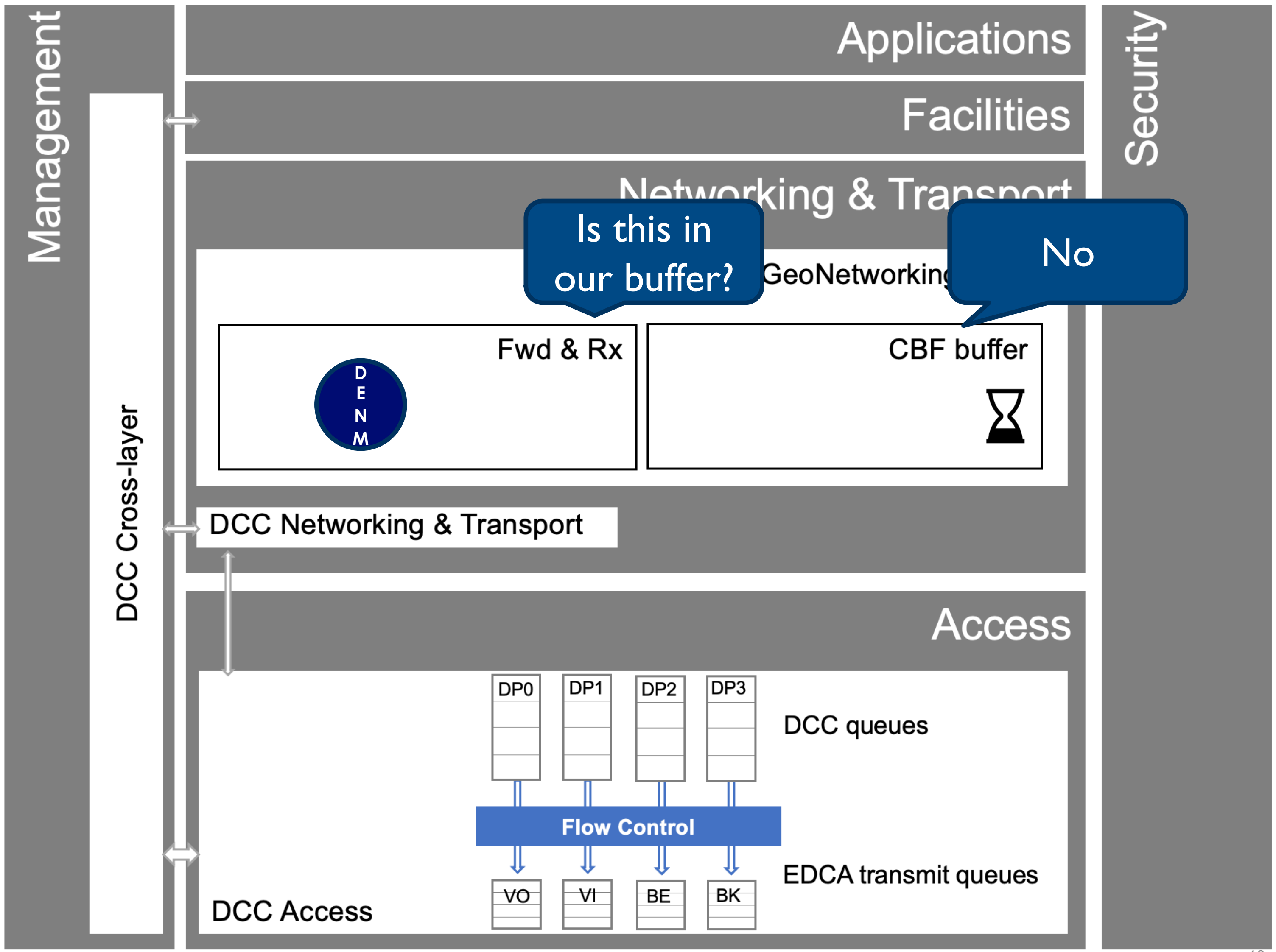



DENM

# Duplicate Packet Detection (DPD)



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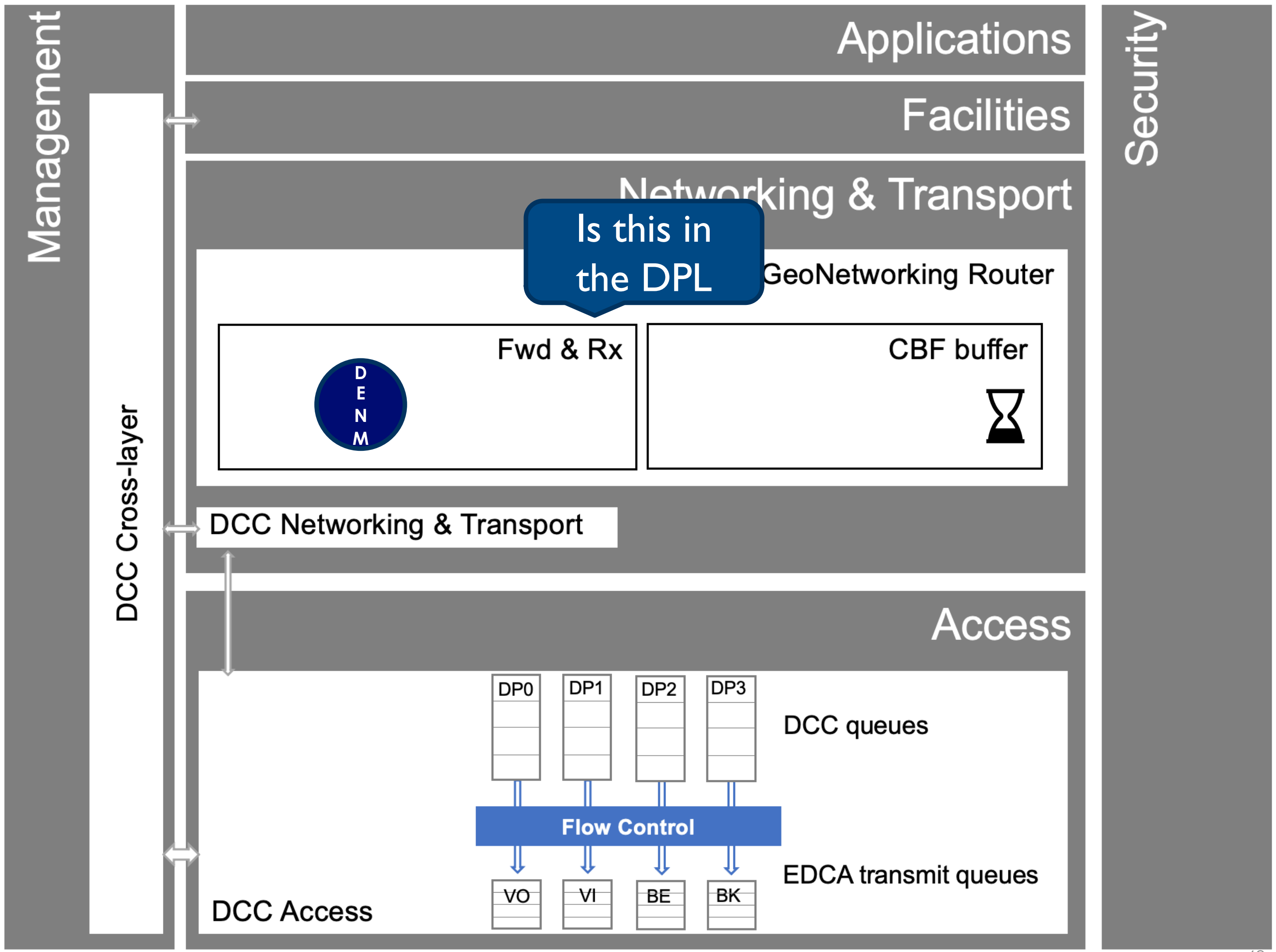


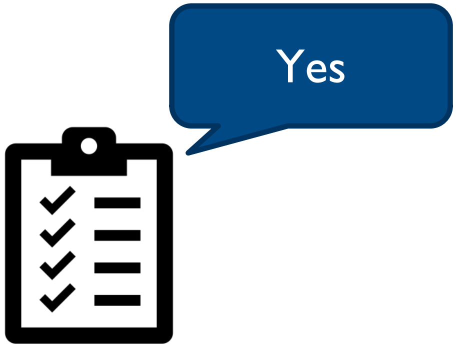




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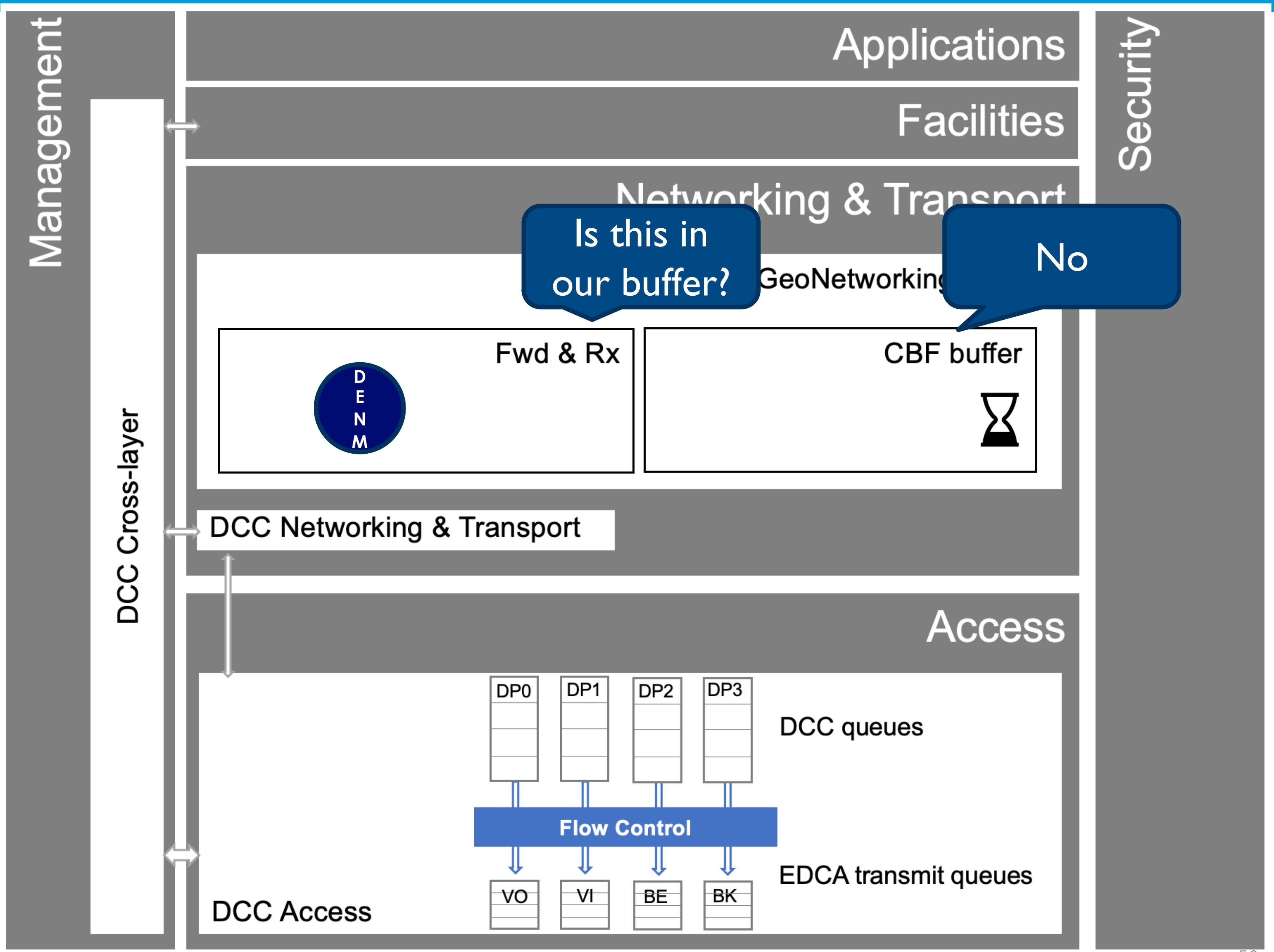
# S-FoT: DCC awareness



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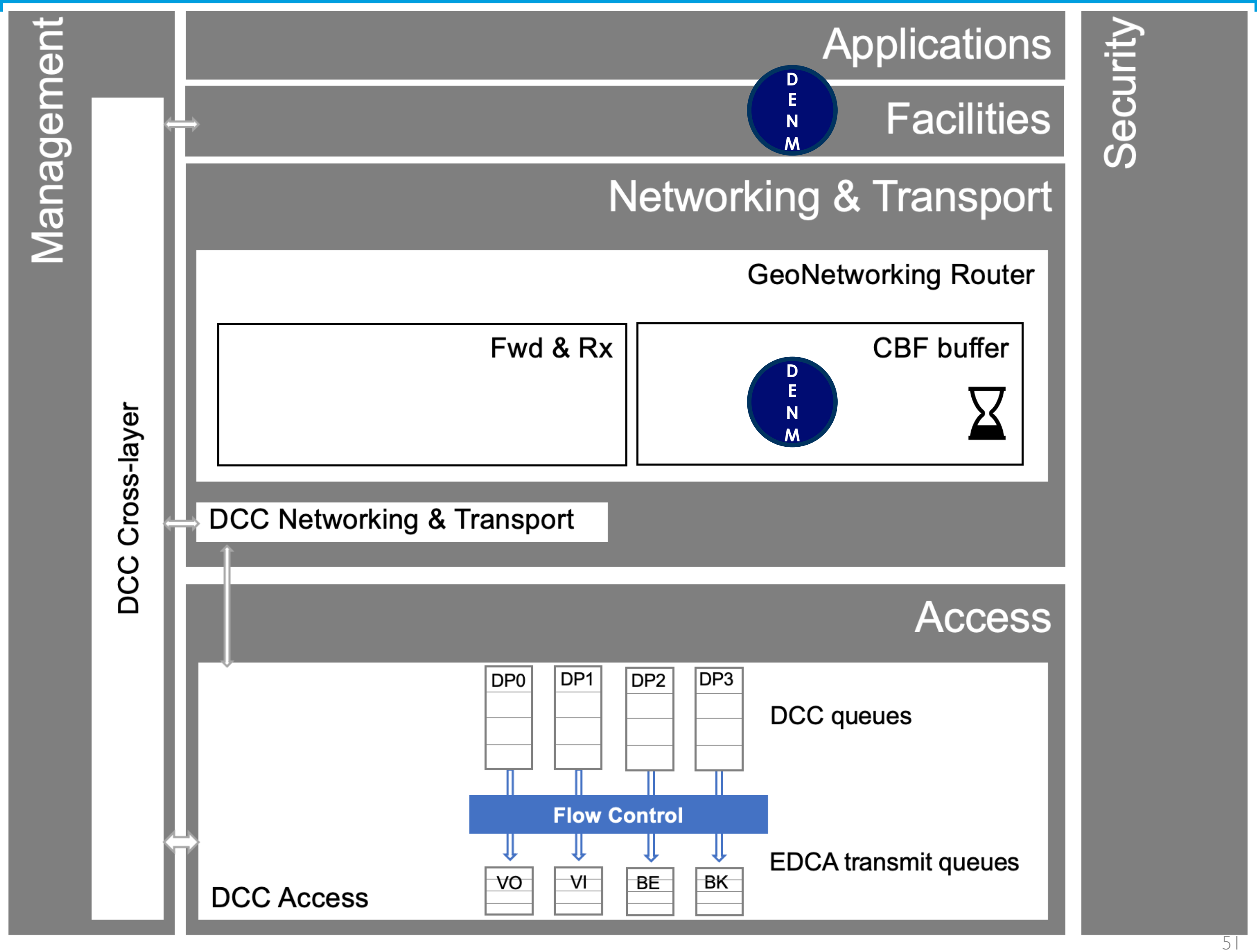
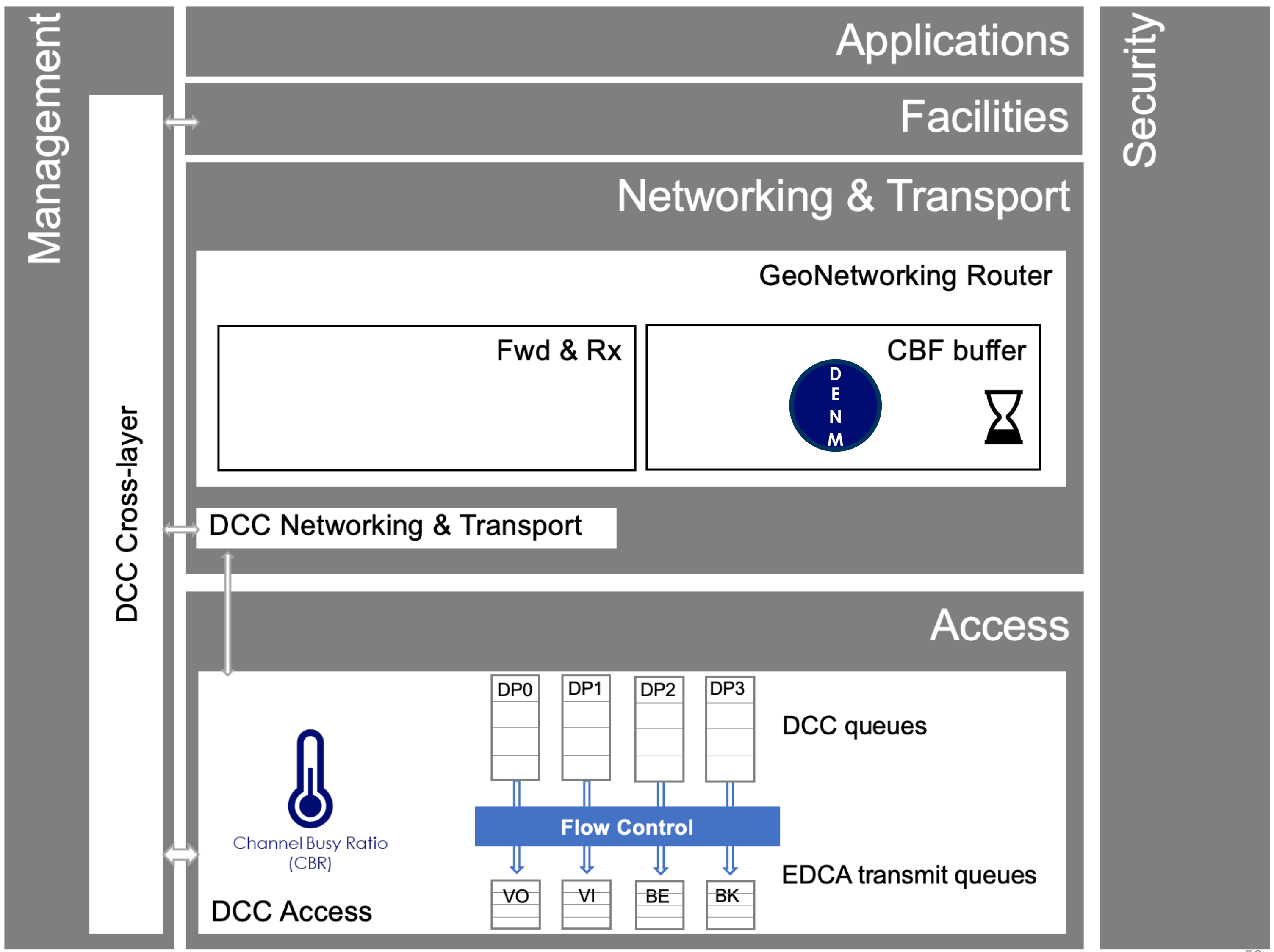


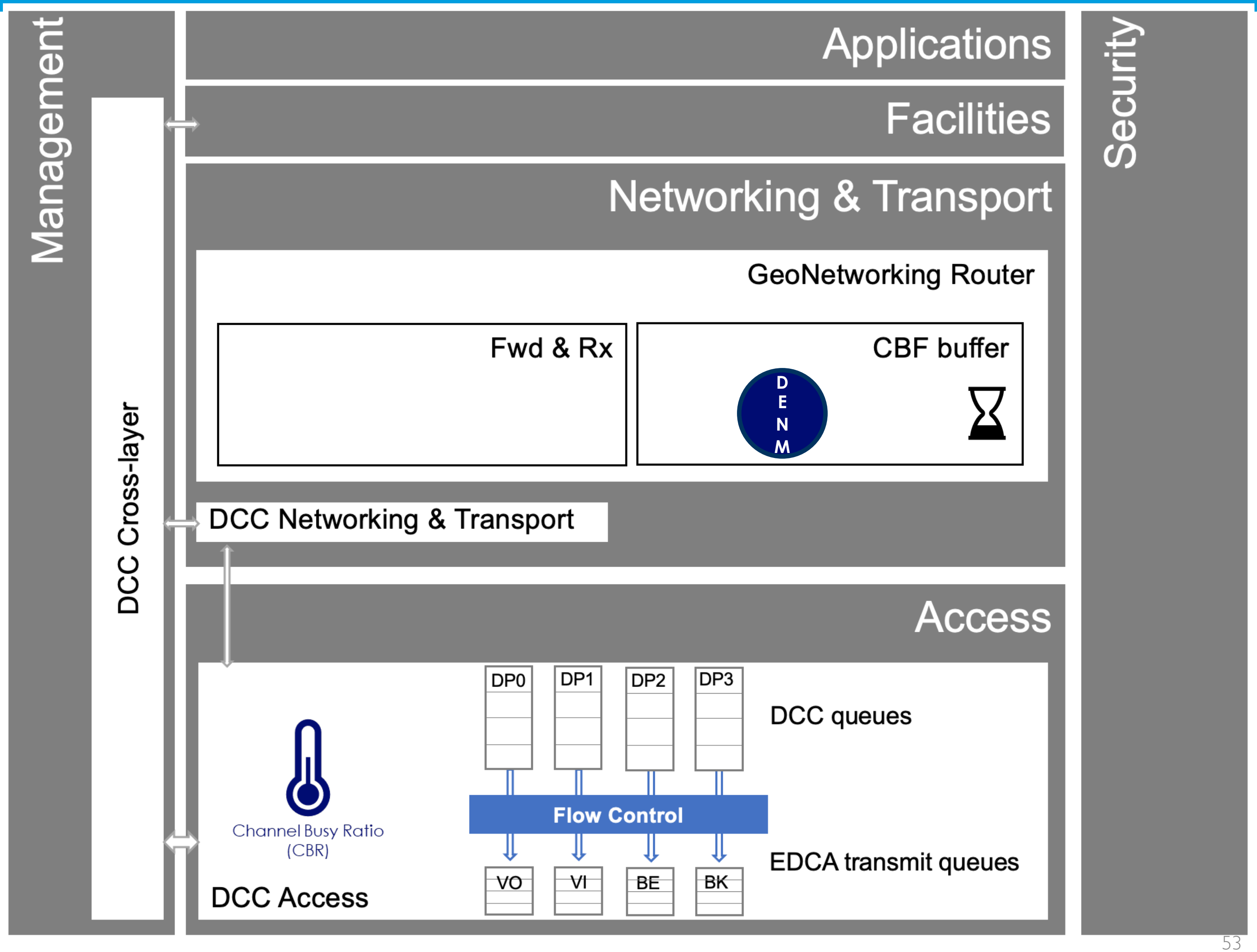

$\max(t_{go}, CBF_{timeout})$

# ETSI CBF and ETSI DCC interaction



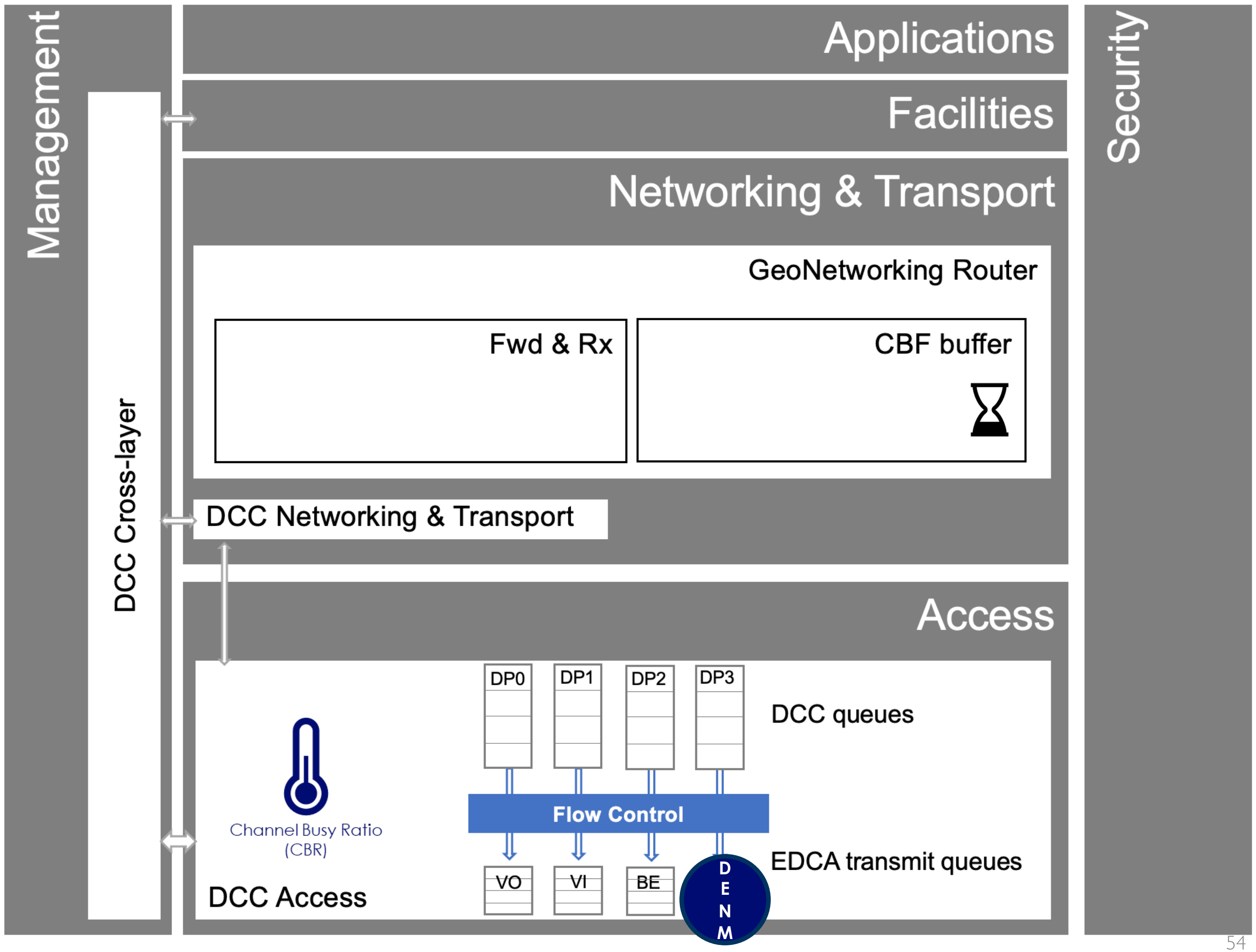

Timer expires.
We check if DCC allows for a transmission.

# ETSI CBF and ETSI DCC interaction




If not, the packet stays in the buffer

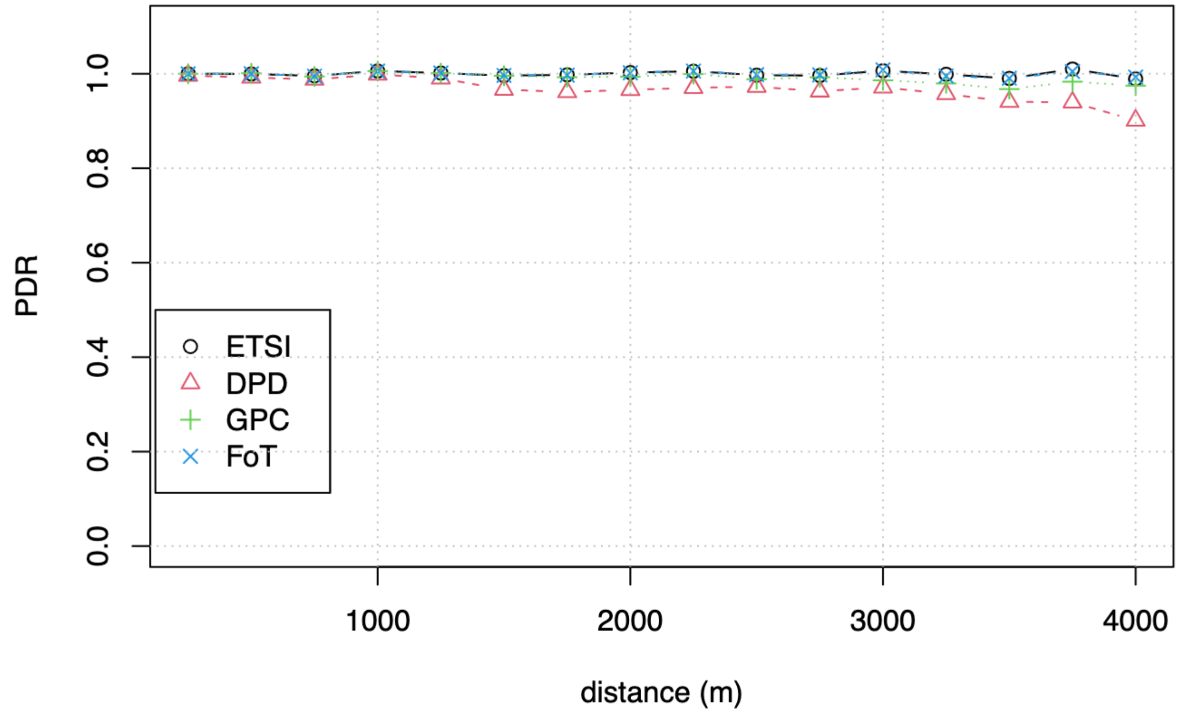
# ETSI CBF and ETSI DCC interaction



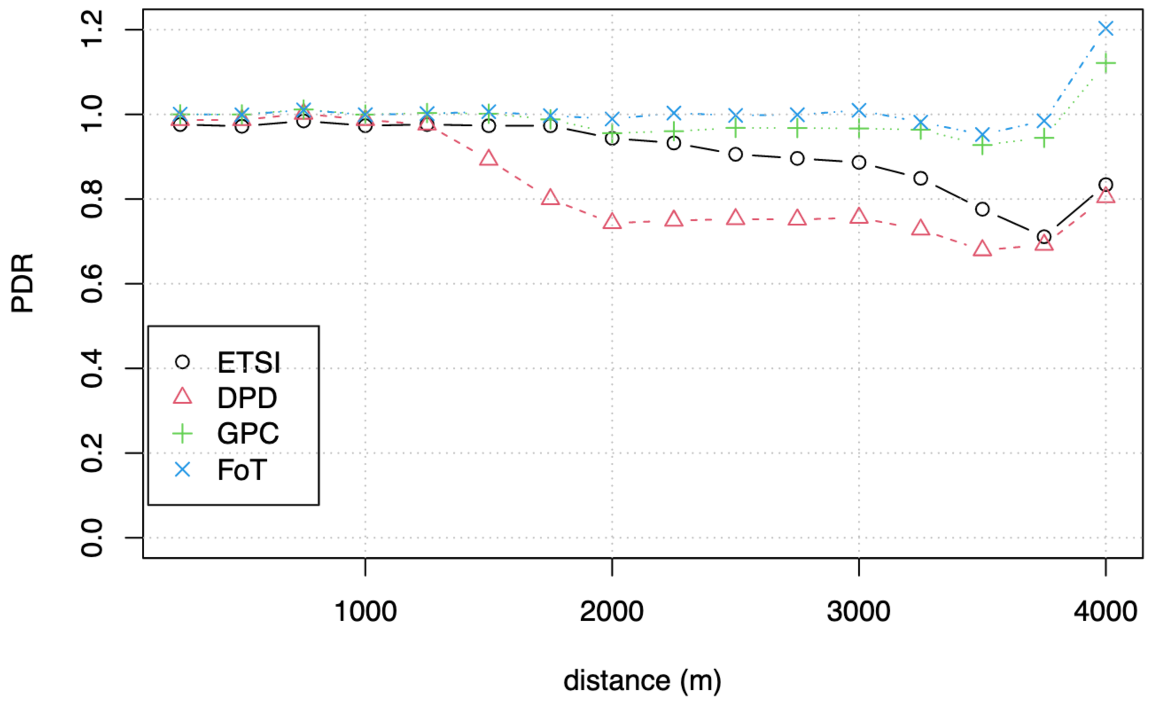

If yes, the packet will get into contention

# ETSI CBF, GPC and FoT in Highway Scenarios

10 veh/km per lane




50 veh/km per lane





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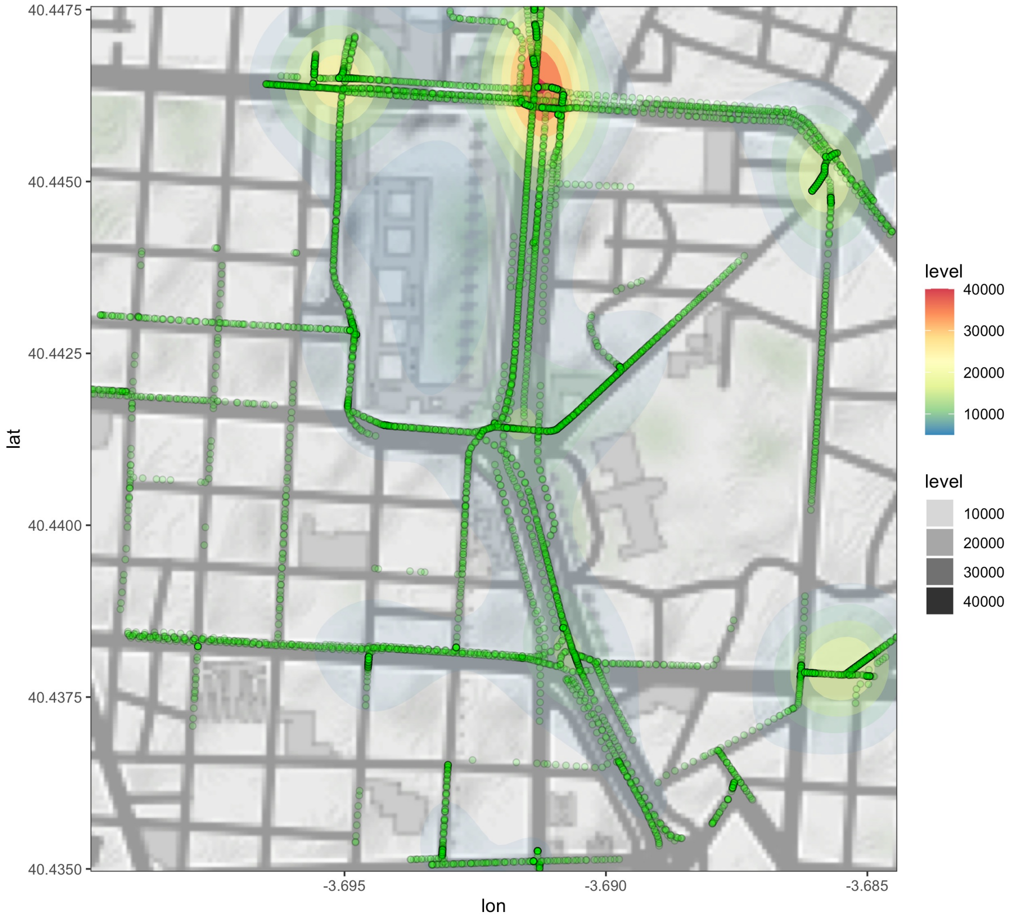
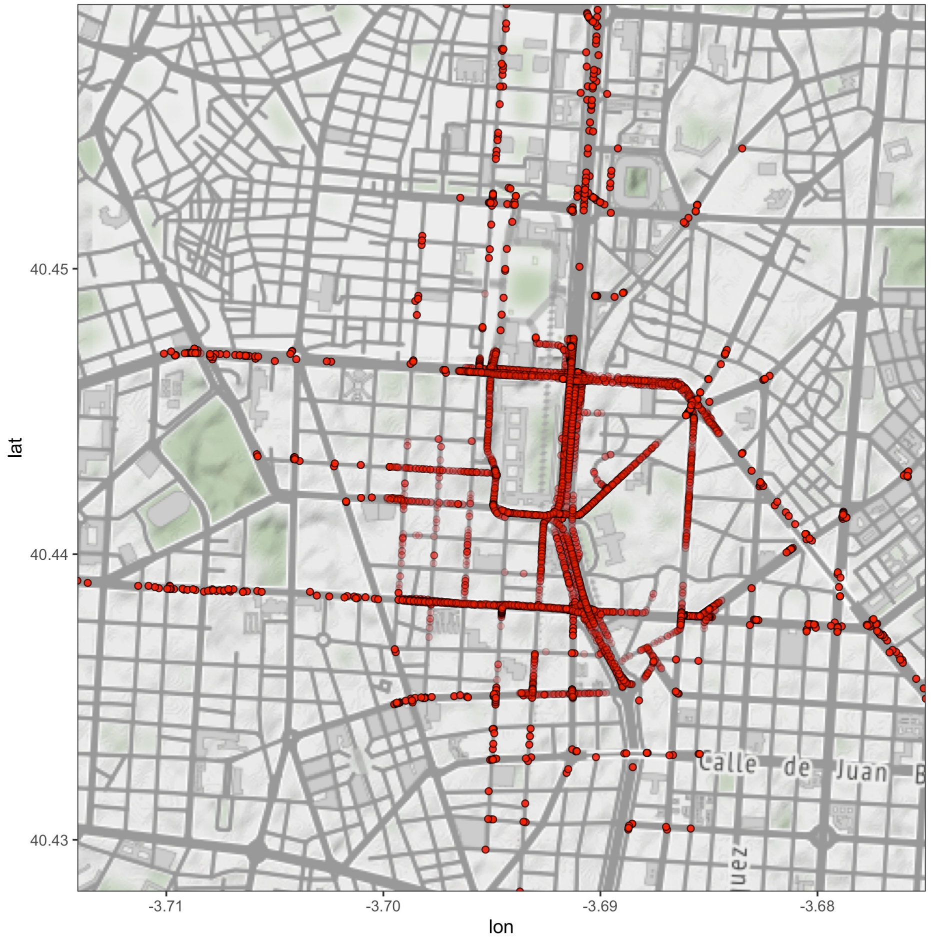
# ETSI CBF in urban scenarios

DENM receptions




DENM transmissions



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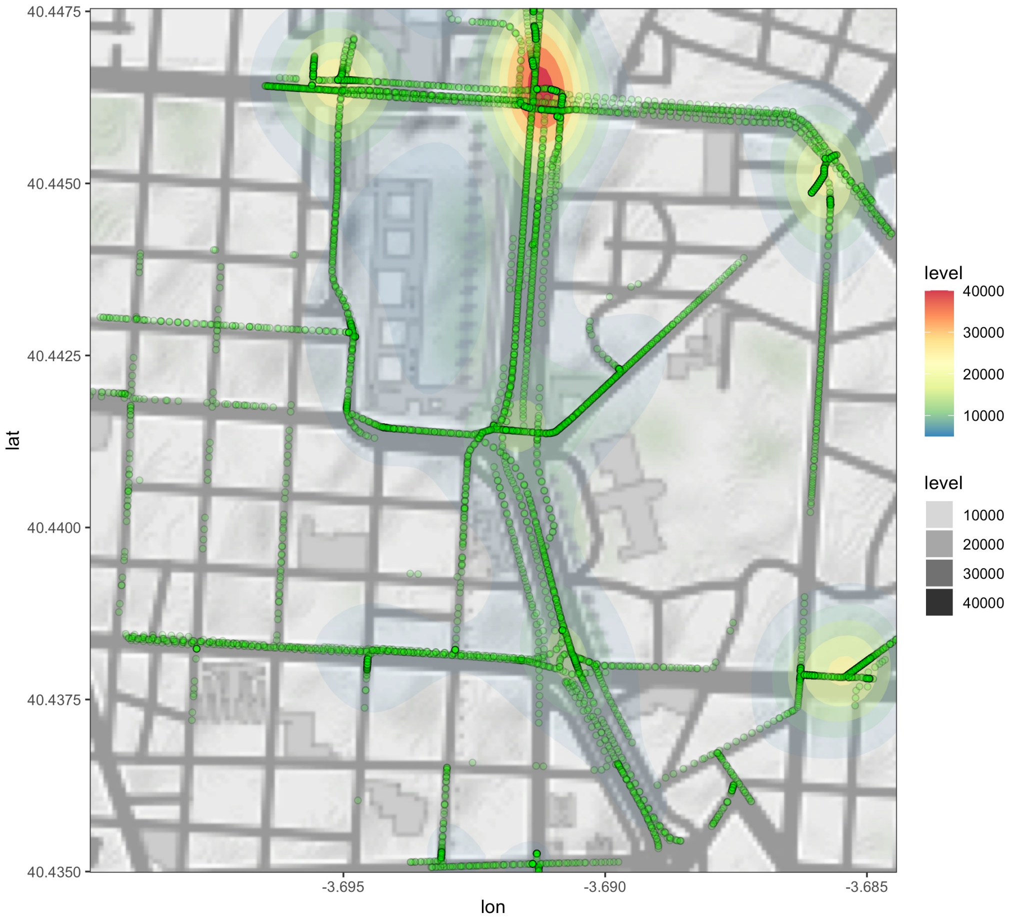
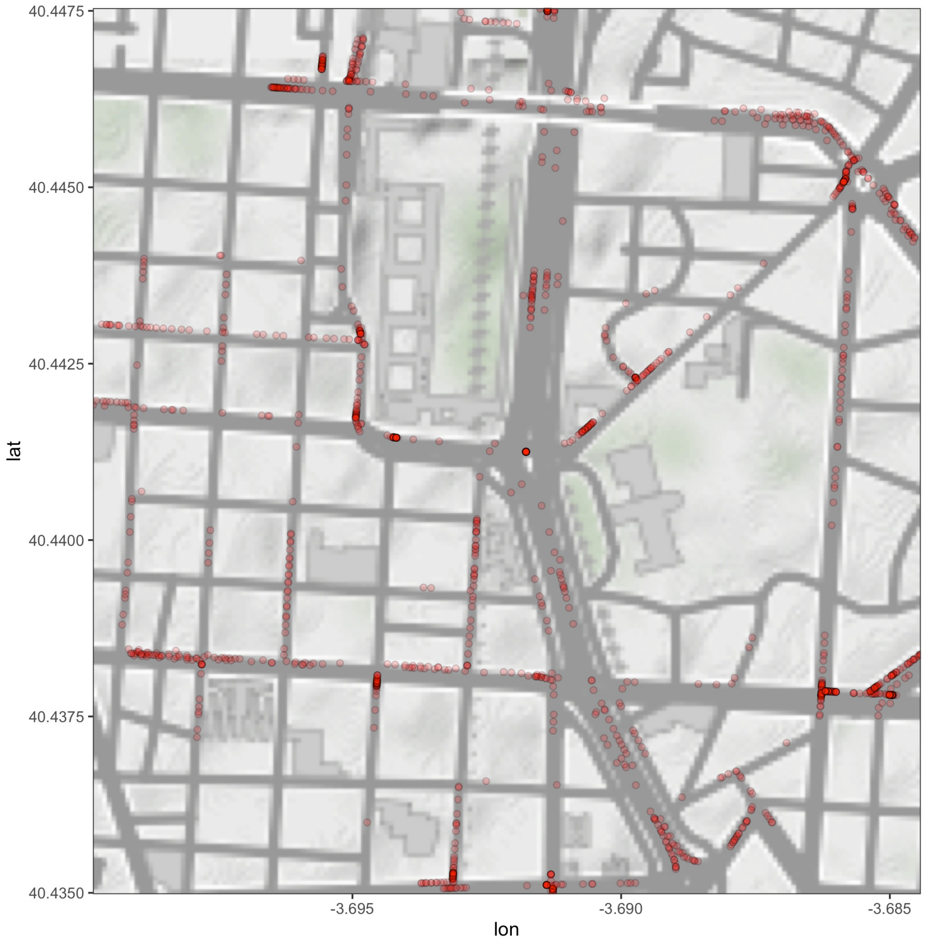
# FoT in urban scenarios

DENM receptions




DENM transmissions



# What is the effect of a “mixed fleet”

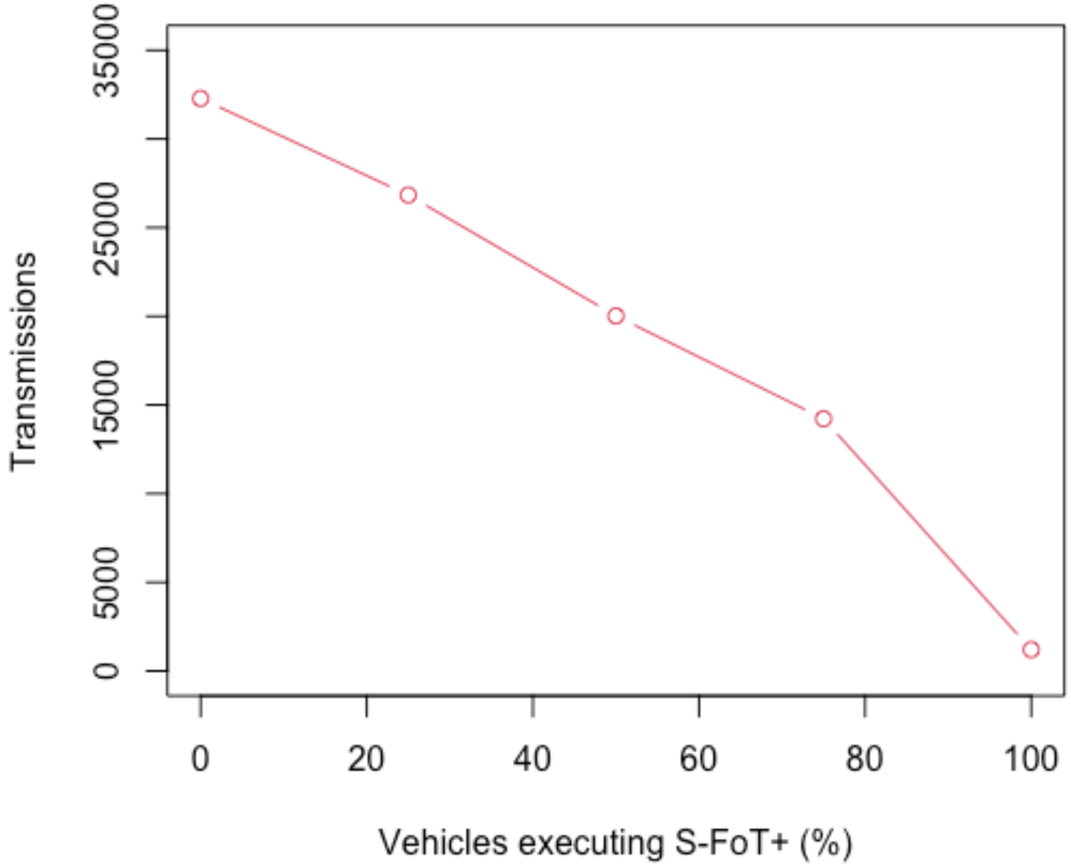
- S-FoT was presented to ETSI in a Change Request for GeoNetworking
  - The CR was supported by Halmstad University (SE), Universidad Politécnica de Madrid (ES), and ASFINAG (AT).
- The CR was accepted for Release 2 of ETSI GeoNetworking, and Release 1 remains unchanged.

- **What is the effect of having vehicles running Rel. 1 coexisting with vehicles running Rel. 2?**
- We measure the number of transmissions and success rate for emergency messages when Release 1 and Release 2 coexist.
- We go for the best-case scenario: everyone understands each other.

# Compatibility Study

- Simulations are run in Artery (with Veins)
- Scenario:
  - 5 km road with four lanes in each direction
  - A stationary vehicle on the west end sends DENMs at 1 Hz
  - Destination area: a 4000 m x 100 m rectangle that covers both directions of the road to the east
  - Density: 30 veh/km per lane
- Measurements are taken for 30 seconds
- Metrics:
  - Number of transmissions (for the 30 messages generated in 30 seconds)
  - Average packet delivery ratio (for the 30 messages)
- Four S-FoT+ penetration rates: 25%, 50%, 75%, and 100% against a benchmark with 0% (i.e., only ETSI CBF)

# Avg. transmissions vs. percentage of S-FoT+ vehicles




| Rate | Avg. Tx |
|---|---|
| 0% | 32283.8 |
| 25% | 26836.4 |
| 50% | 20021.4 |
| 75% | 14222.2 |
| 100% | 1203.8 |

The remainder of vehicles are executing ETSI CBF

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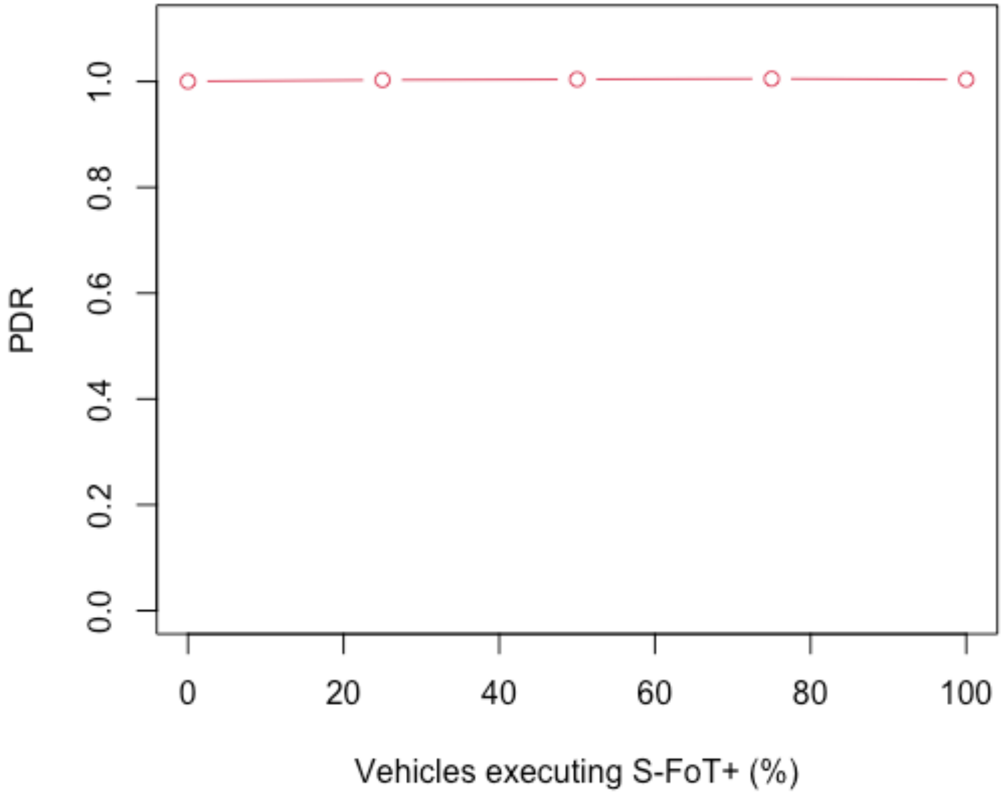
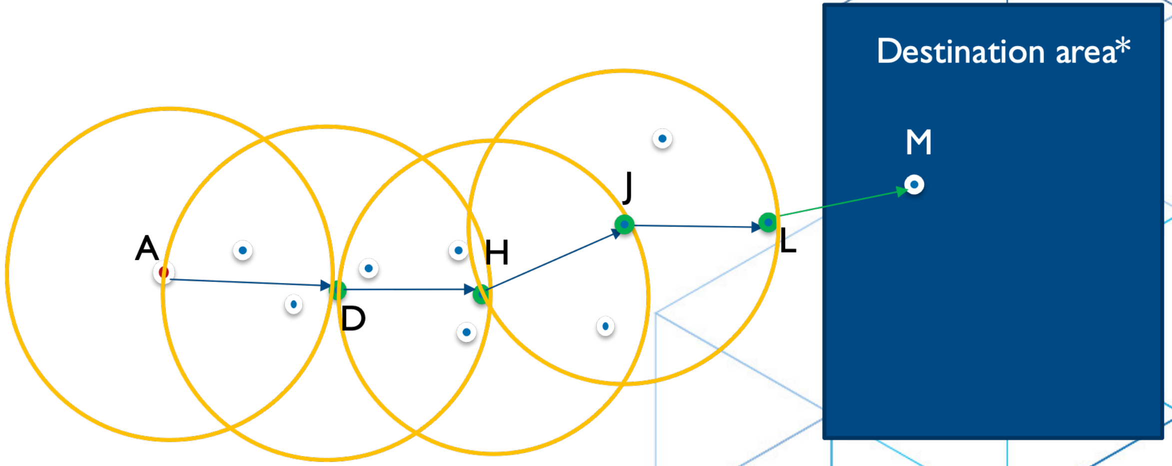
# Packet-delivery ratio vs. percentage of S-FoT+ veh.




- Average PDR stays at 100%
- This result shows that ETSI CBF and S-FoT+ can coexist.

# Remaining Questions

- What happens if Rel. 1 nodes cannot understand Rel. 2 messages?
  - Risks and safety metrics
  - Network performance metrics
- What are feasible solutions to harmonize or homogenize the connected fleet?
- What can we learn from past experiences in evolving network technologies?

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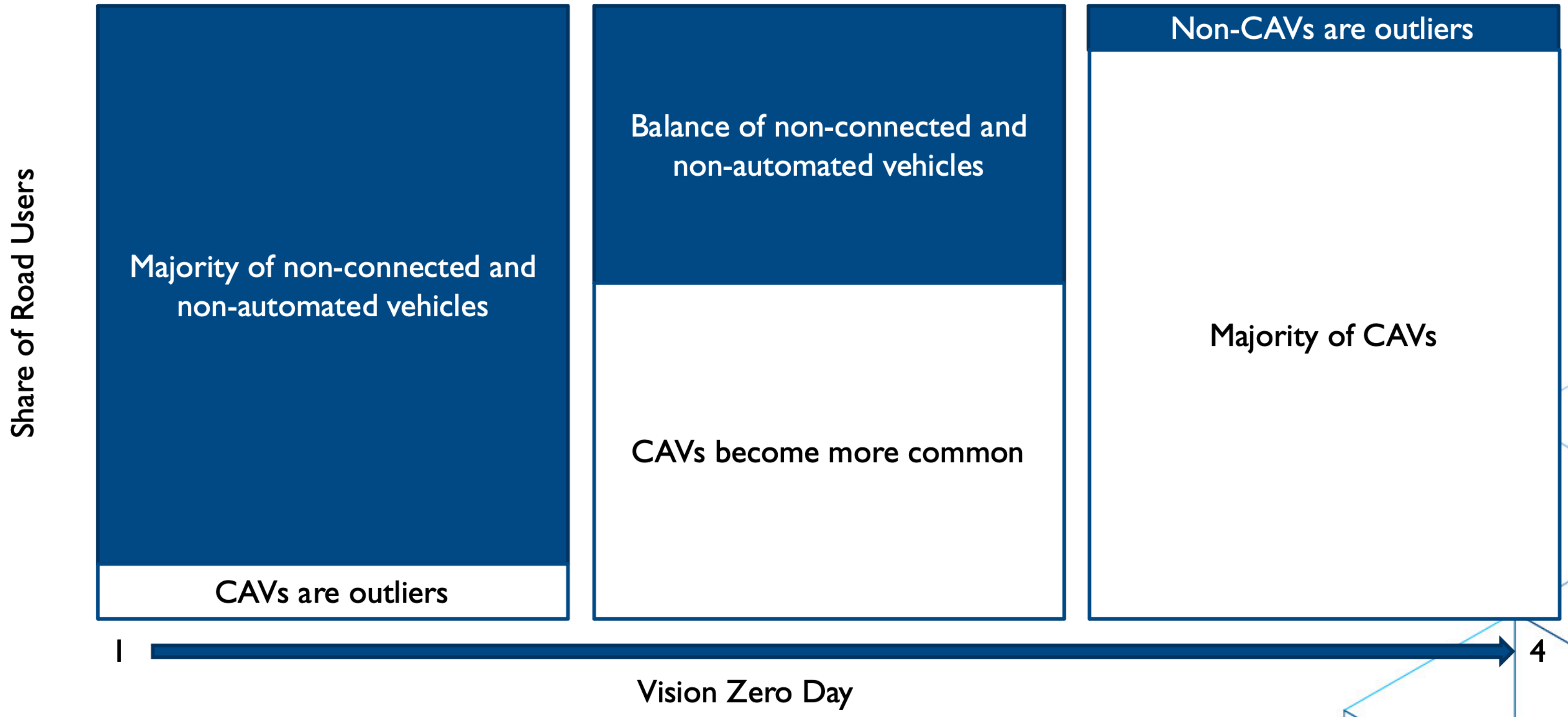
# Ongoing Work

- SAFER (SE) pre-study on risk metrics and system performance

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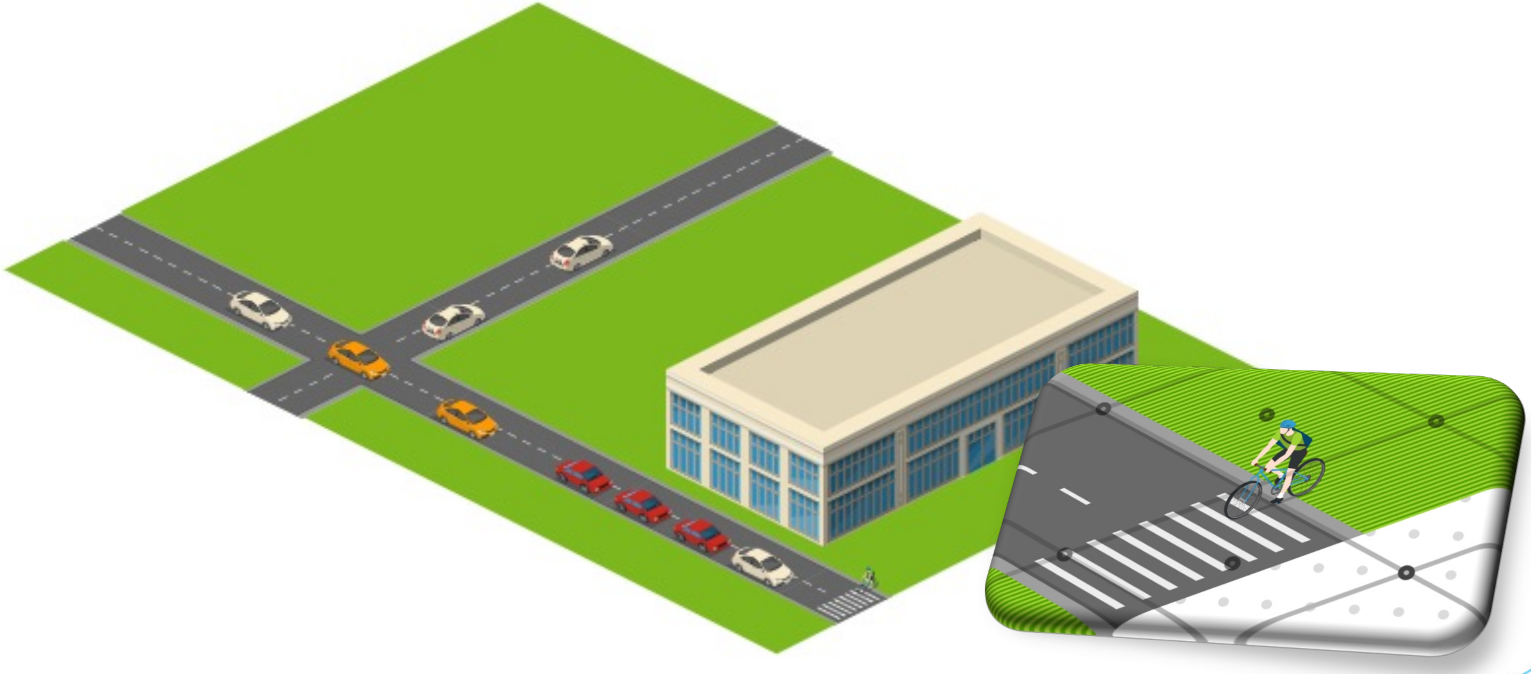
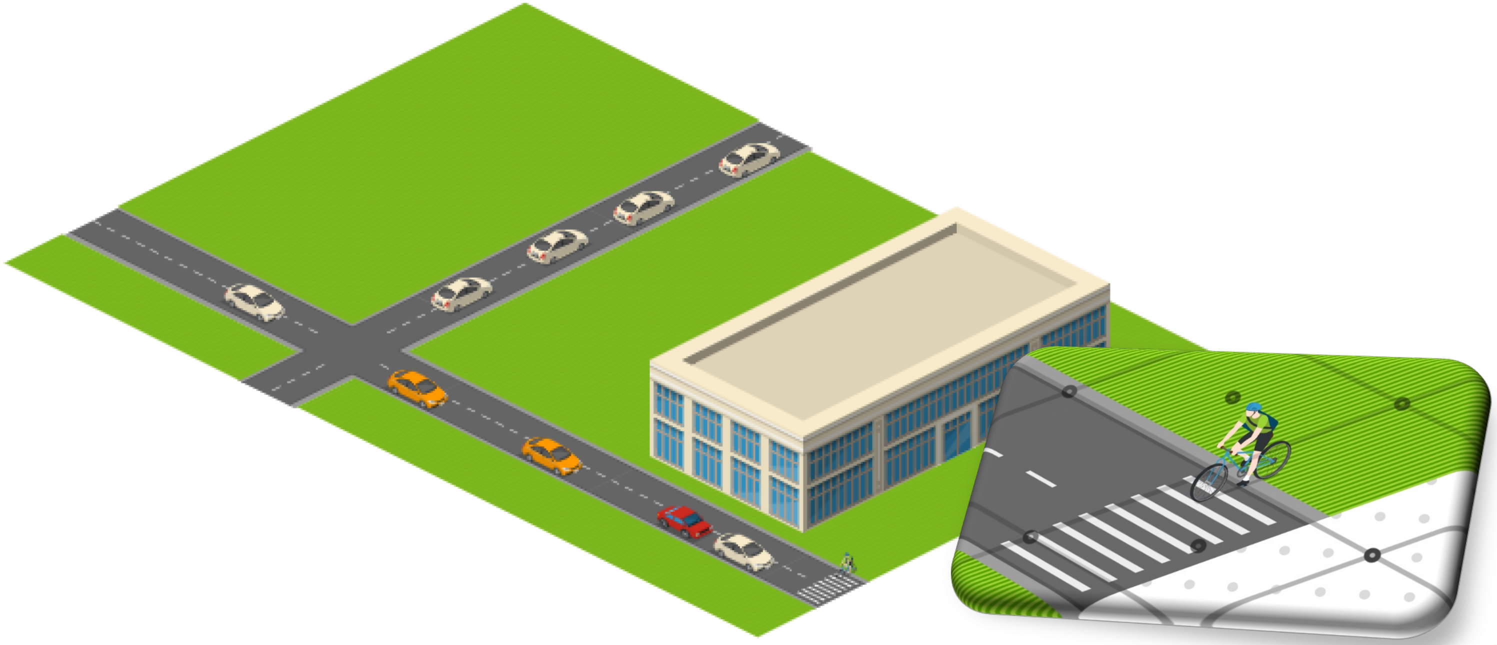
# High heterogeneity



# High homogeneity



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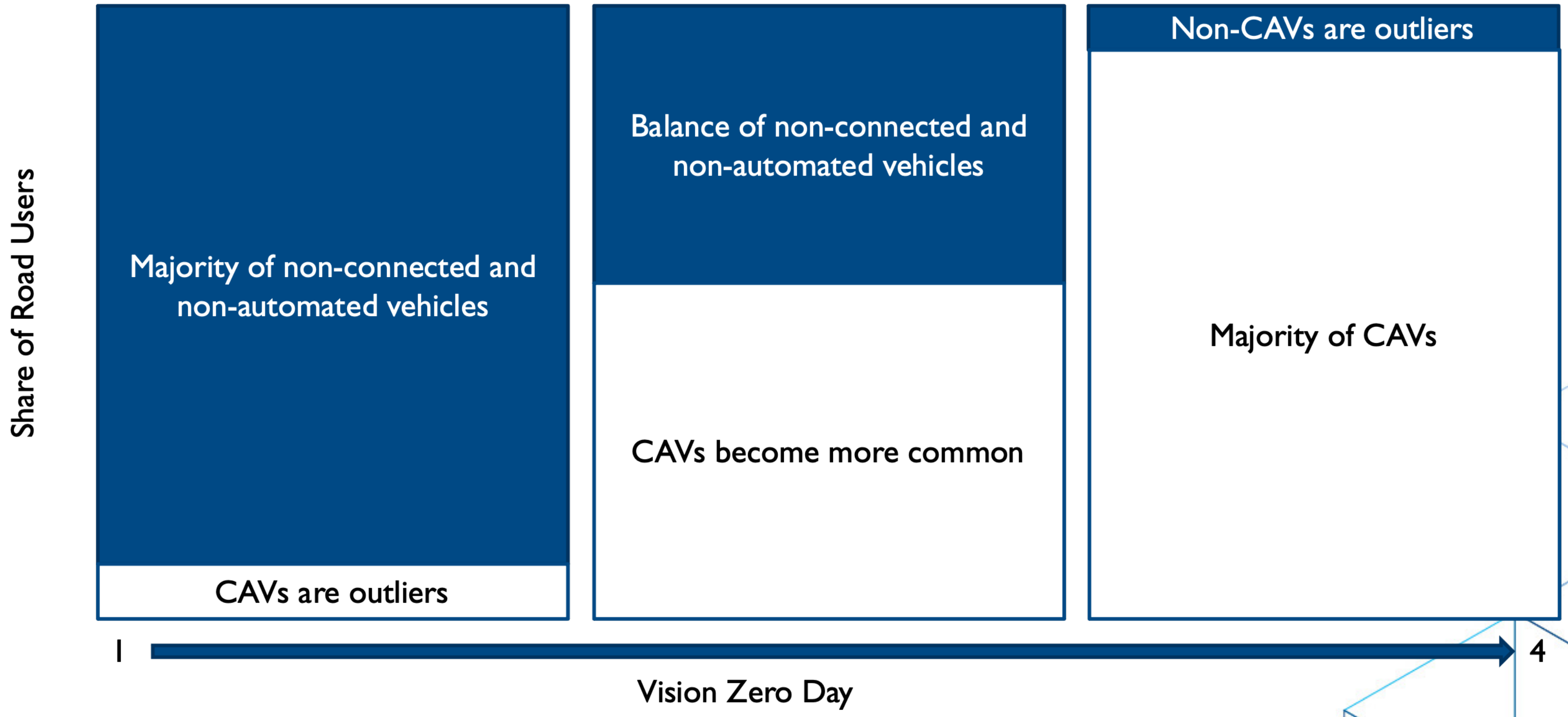
# Ongoing Work

- SAFER (SE) pre-study on risk metrics and system performance

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