Falcon: Live Reconfiguration for Stateful Stream Processing on the Edge

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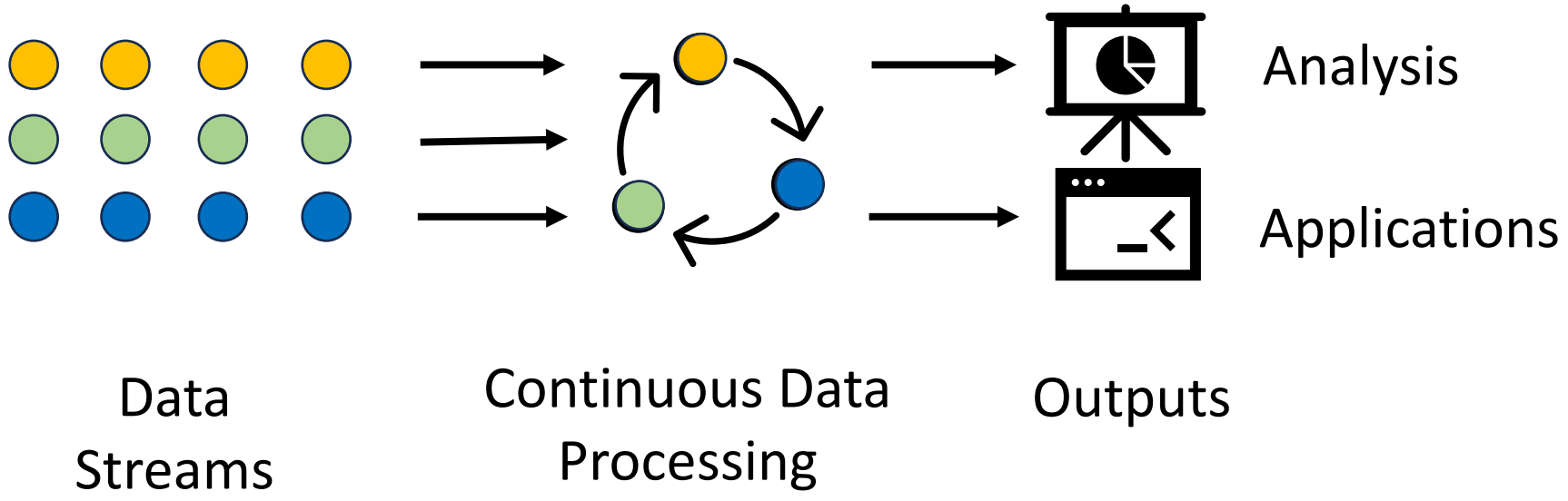
Best Paper Award, ACM/IEEE Symposium on Edge Computing (SEC) 2024

UNIVERSITY OF TORONTO

McGill UNIVERSITY

NOKIA BELL LABS

What Is Stream Processing?



Stream Processing Is Popular

Popular Stream Processing Frameworks

Real Time Analysis

Optimize search rankings in real time

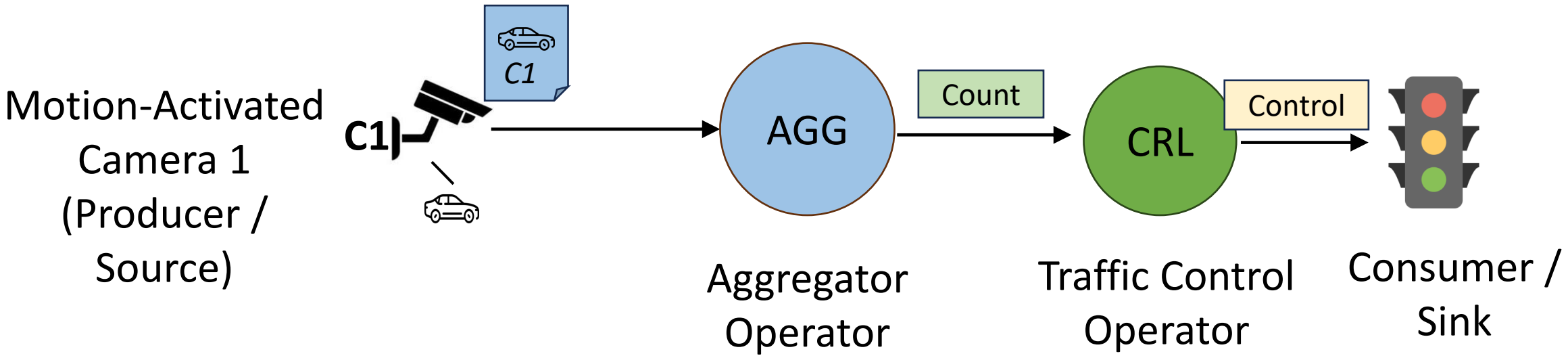
Process and analyze streaming data

Real-time monitoring

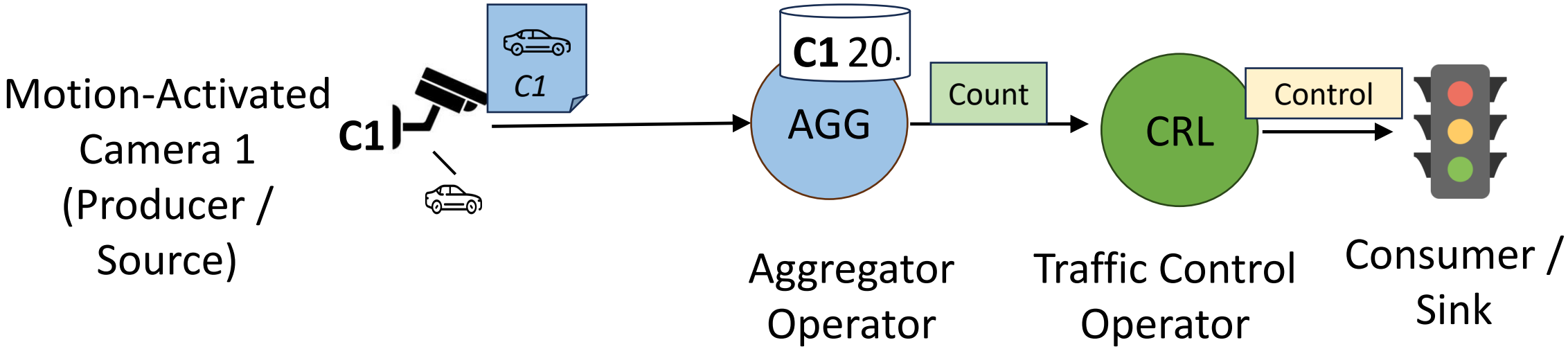
Organizations using these frameworks[1]

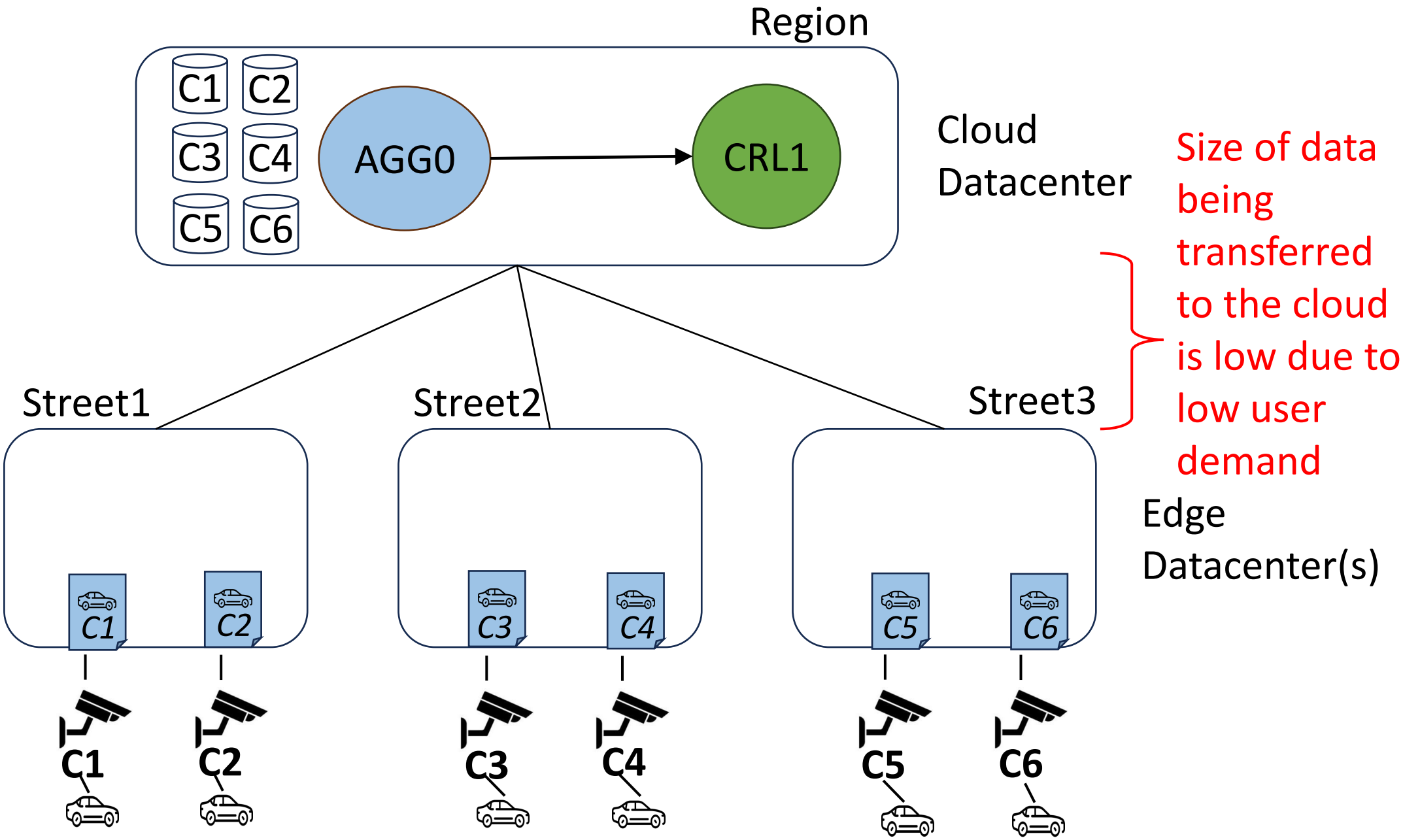
1. https://flink.apache.org/what-is-flink/powered-by/

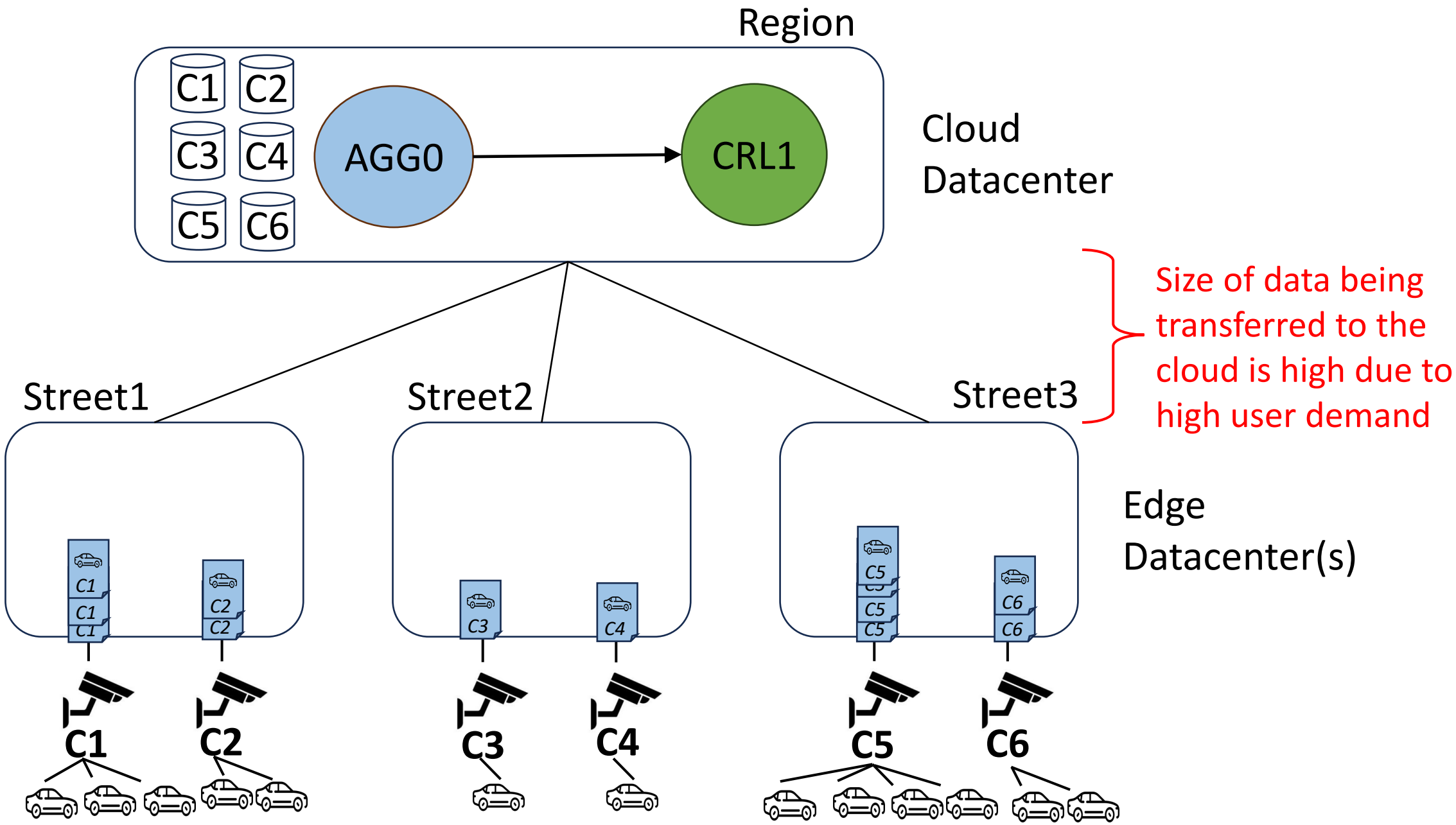
Stateful Stream Processing - Basics



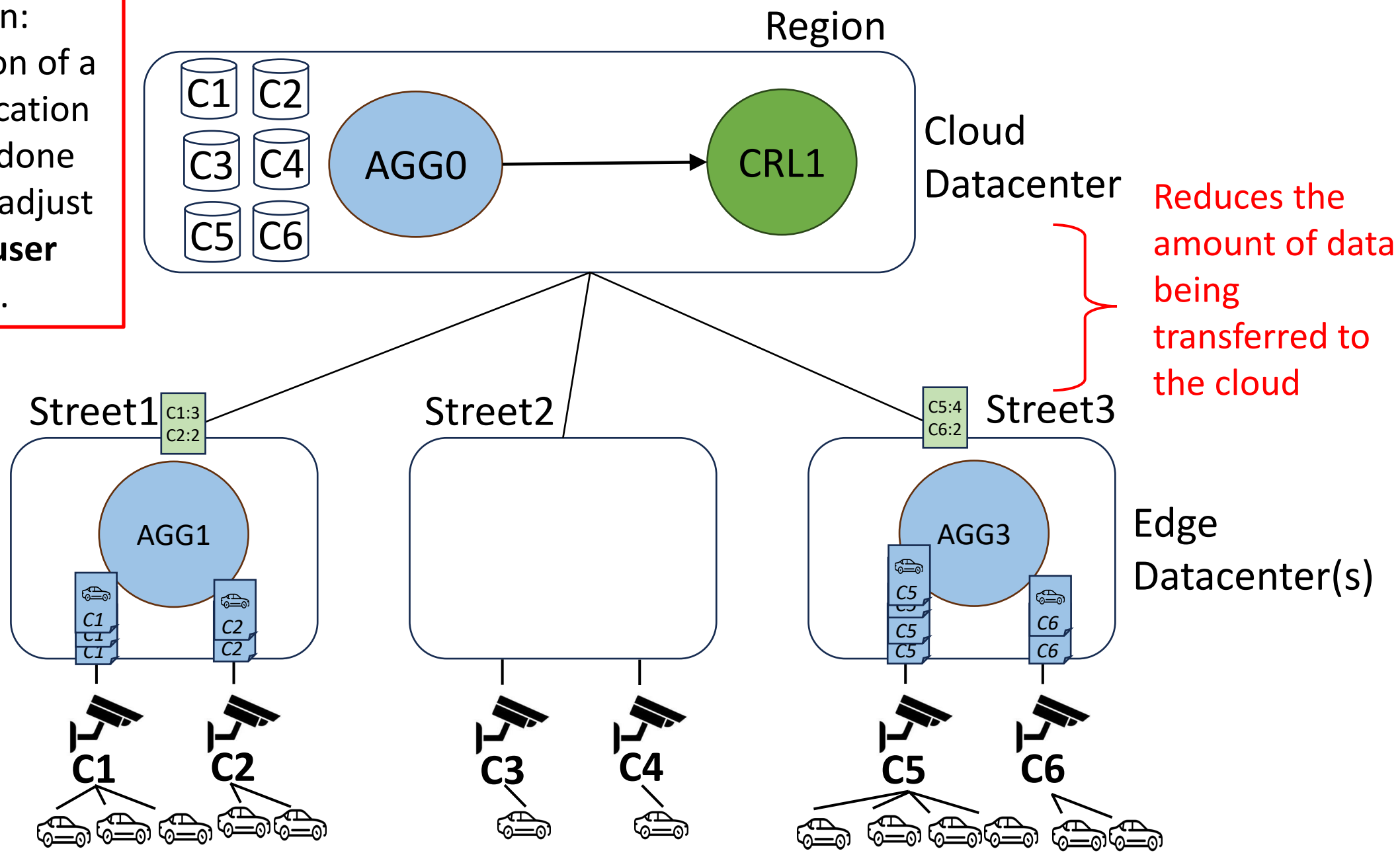
Stateful Stream Processing - State



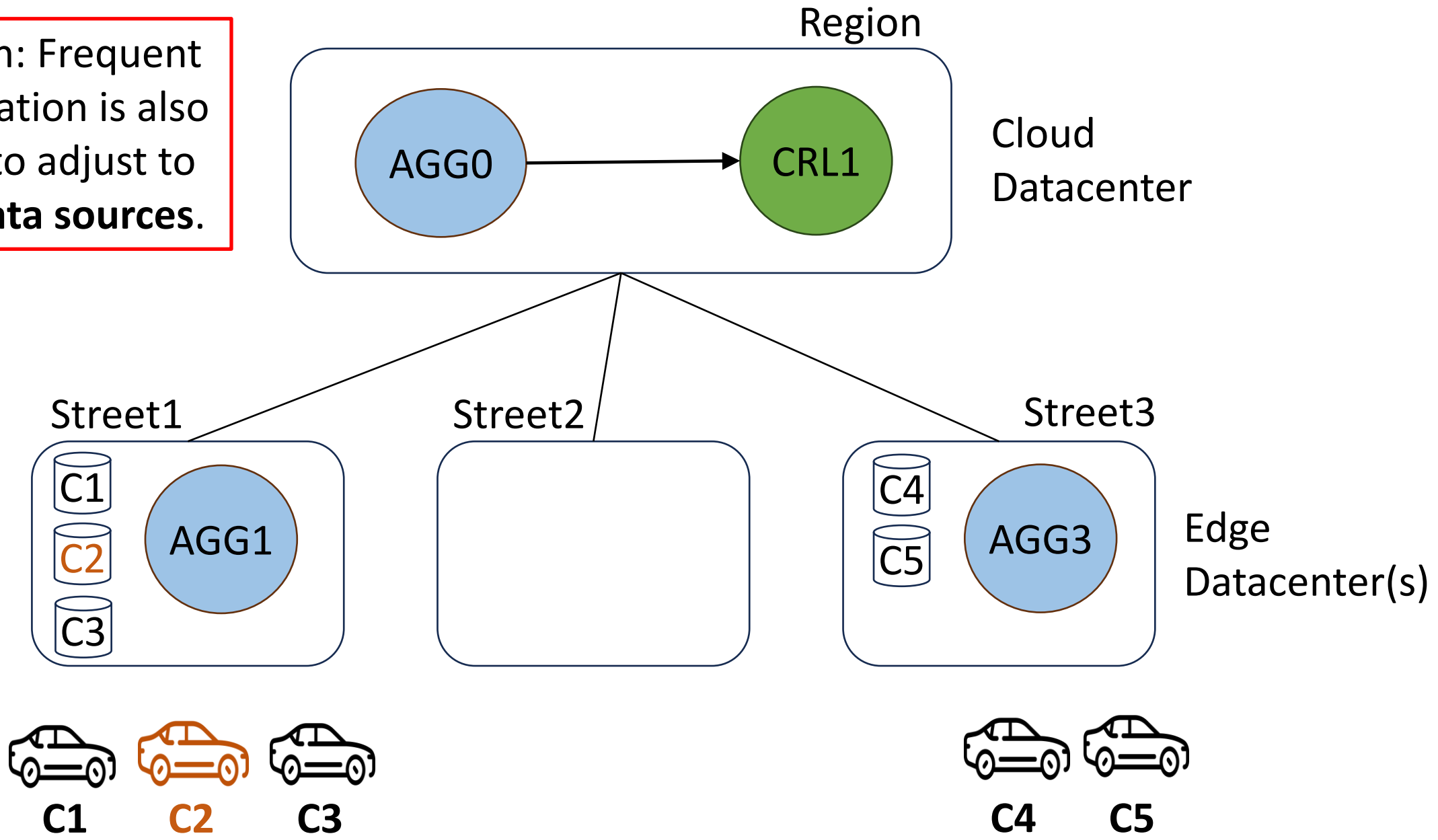

Region
C1
C2
C3
C4
C5
C6
AGG0
CRL1
Cloud Datacenter
Size of data being transferred to the cloud is low due to low user demand
Street1
Street2
Street3
C1
C2
C3
C4
C5
C6
C1
C2
C3
C4
C5
C6
Edge Datacenter(s)


Region
C1
C2
C3
C4
C5
C6
AGG0
CRL1
Cloud Datacenter
Size of data being transferred to the cloud is high due to high user demand
Street1
Street2
Street3
Edge Datacenter(s)
C1
C2
C3
C4
C5
C6

Conclusion: Reconfiguration of a running application needs to be done frequently to adjust to **varying user demand**.



Conclusion: Frequent reconfiguration is also required to adjust to **moving data sources**.



Existing Systems

Full-restart

Stops the entire application, performs reconfiguration and then restarts the application

Systems: **Flink**

Partial-pause

Stops only the affected operators and Use fine-grained transfer and on-demand fetch to spread the impact of application disruption

Systems: **Trisk**, **Meces**

Hot backups

State is replicated periodically to all possible locations where reconfiguration could occur

Systems: **Rhino**

Existing Solutions Fail For The Edge-Cloud!

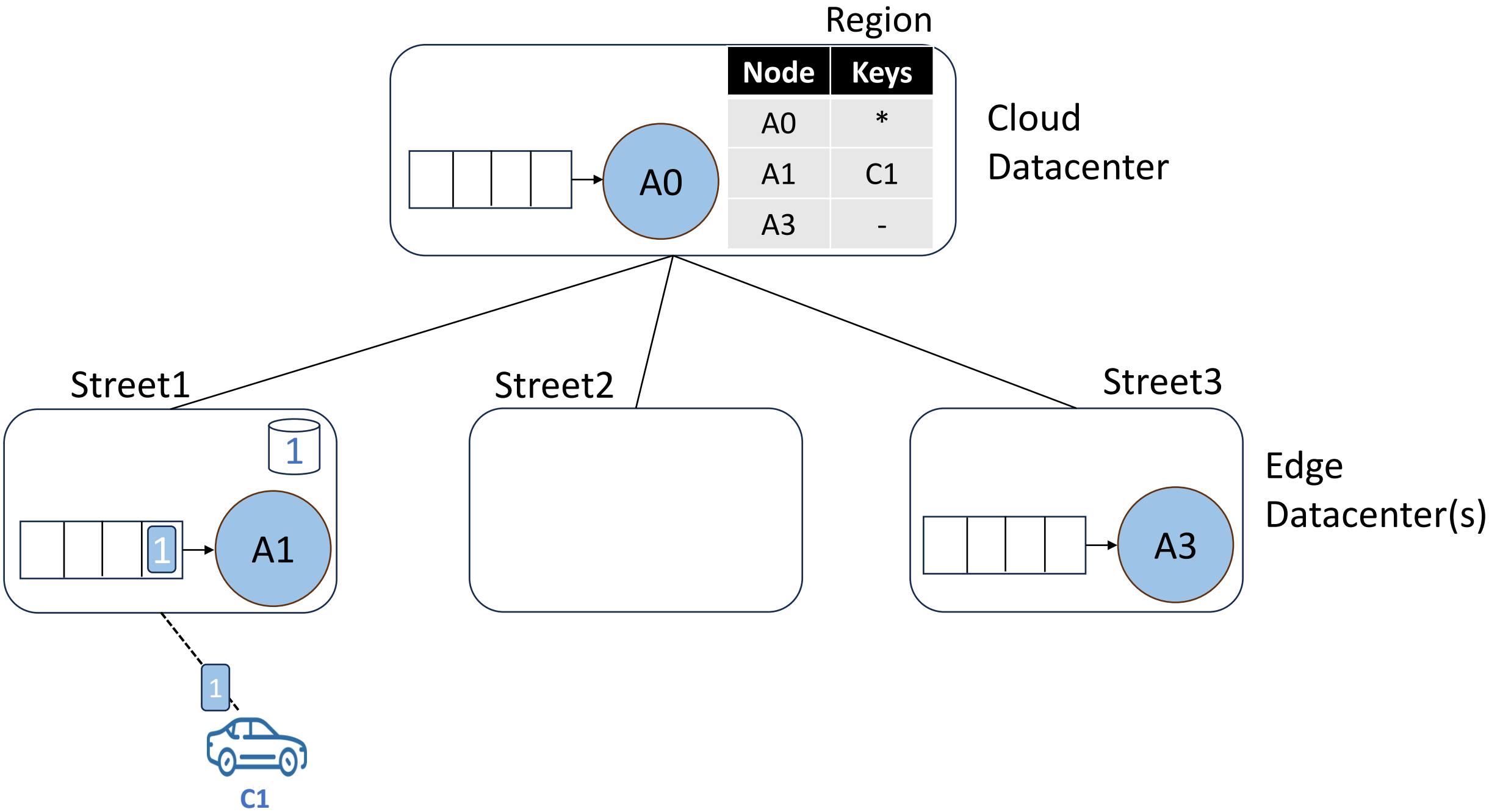
- Reconfiguration has significant stoppage time.
  - Apache Flink
- Inefficient state migration.
  - Meces
  - Rhino
  - Trisk
- Do not handle source mobility.

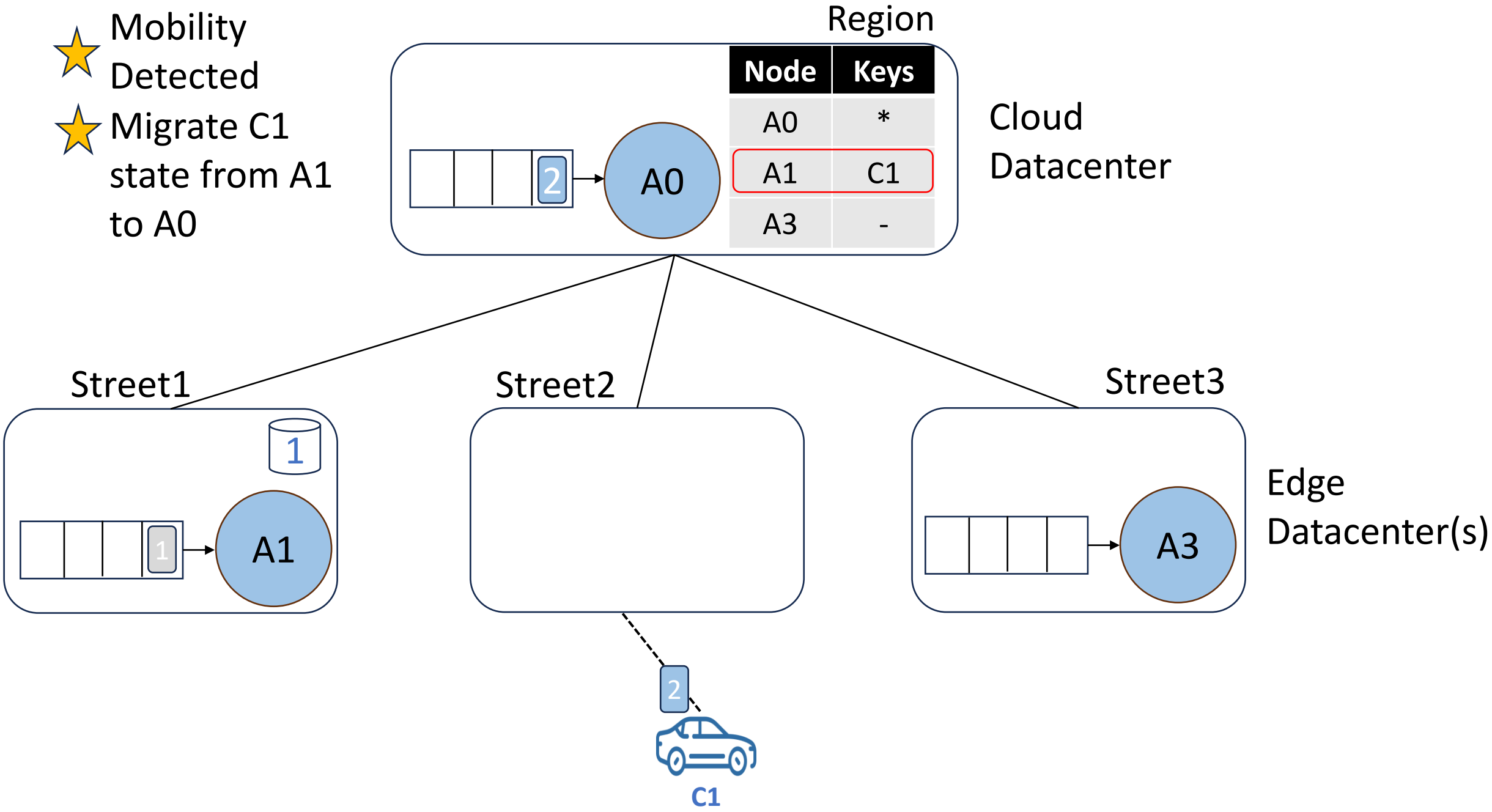
Falcon System: seamless reconfiguration, minimal stoppage time, state and mobility support

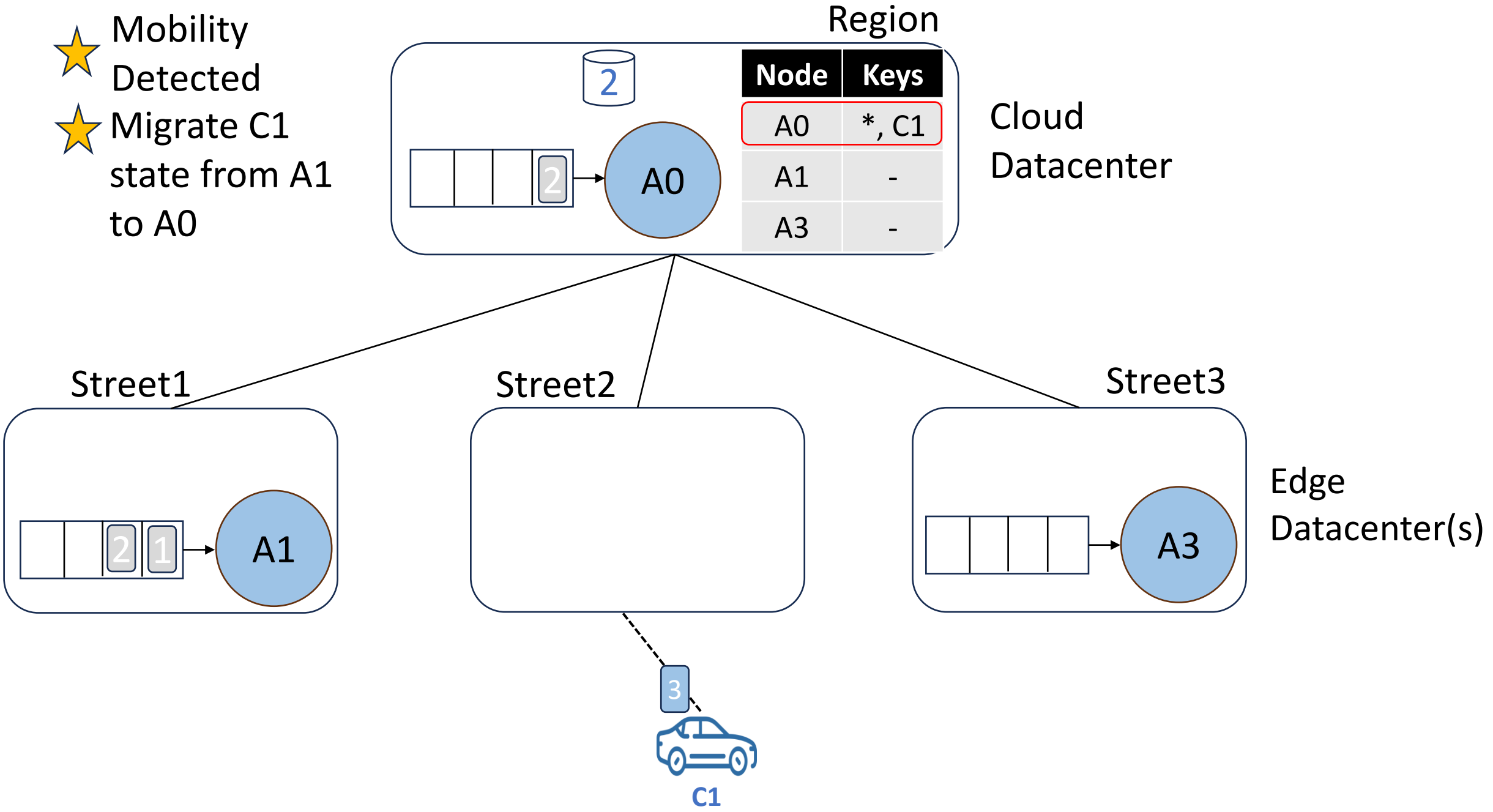
Challenges Of Performing Reconfiguration

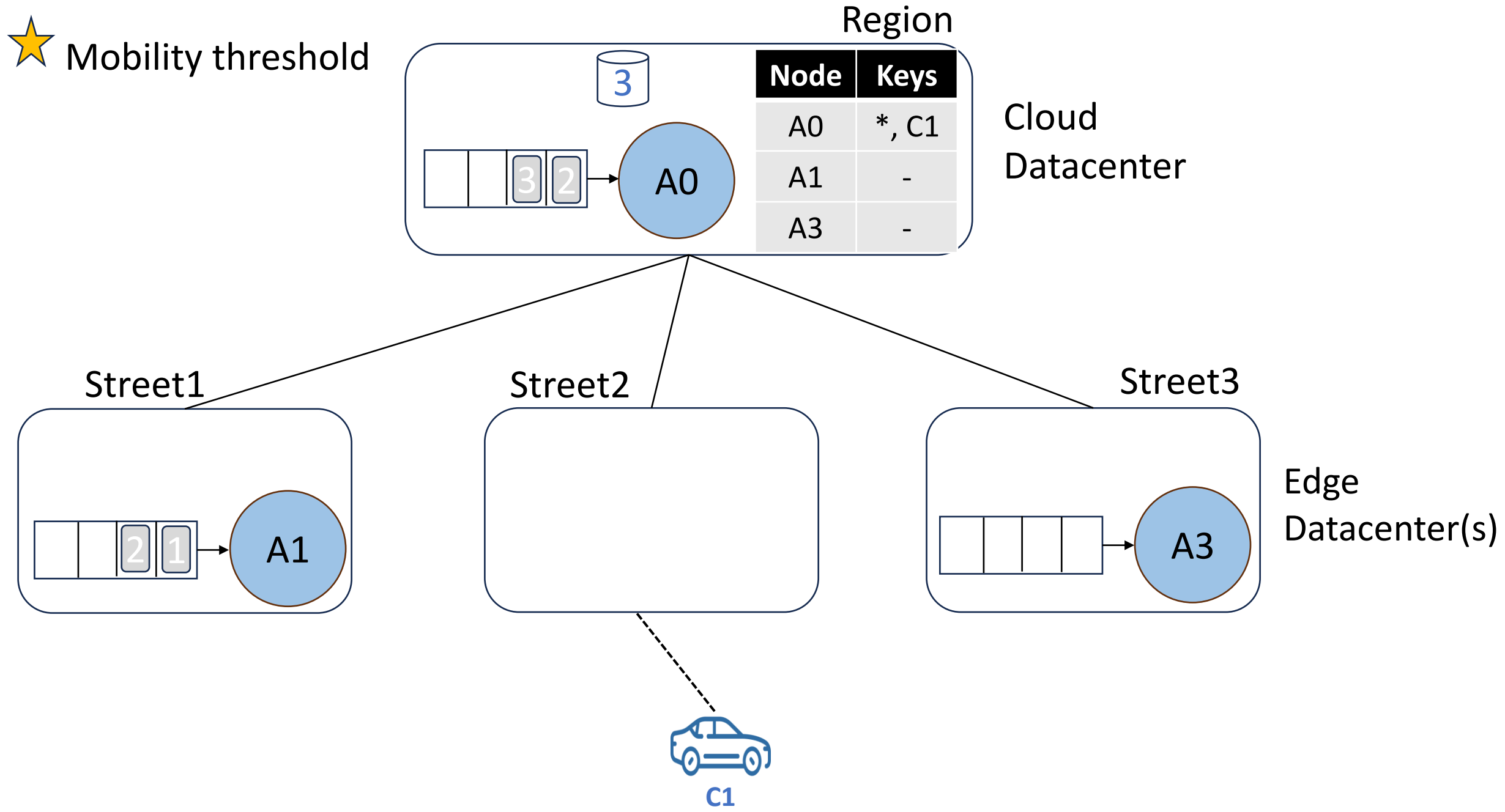
1. **Global coordination**
2. **Long state transfer time**
3. **State correctness guarantees**
4. **In-order and Exactly-once Tuple Processing**

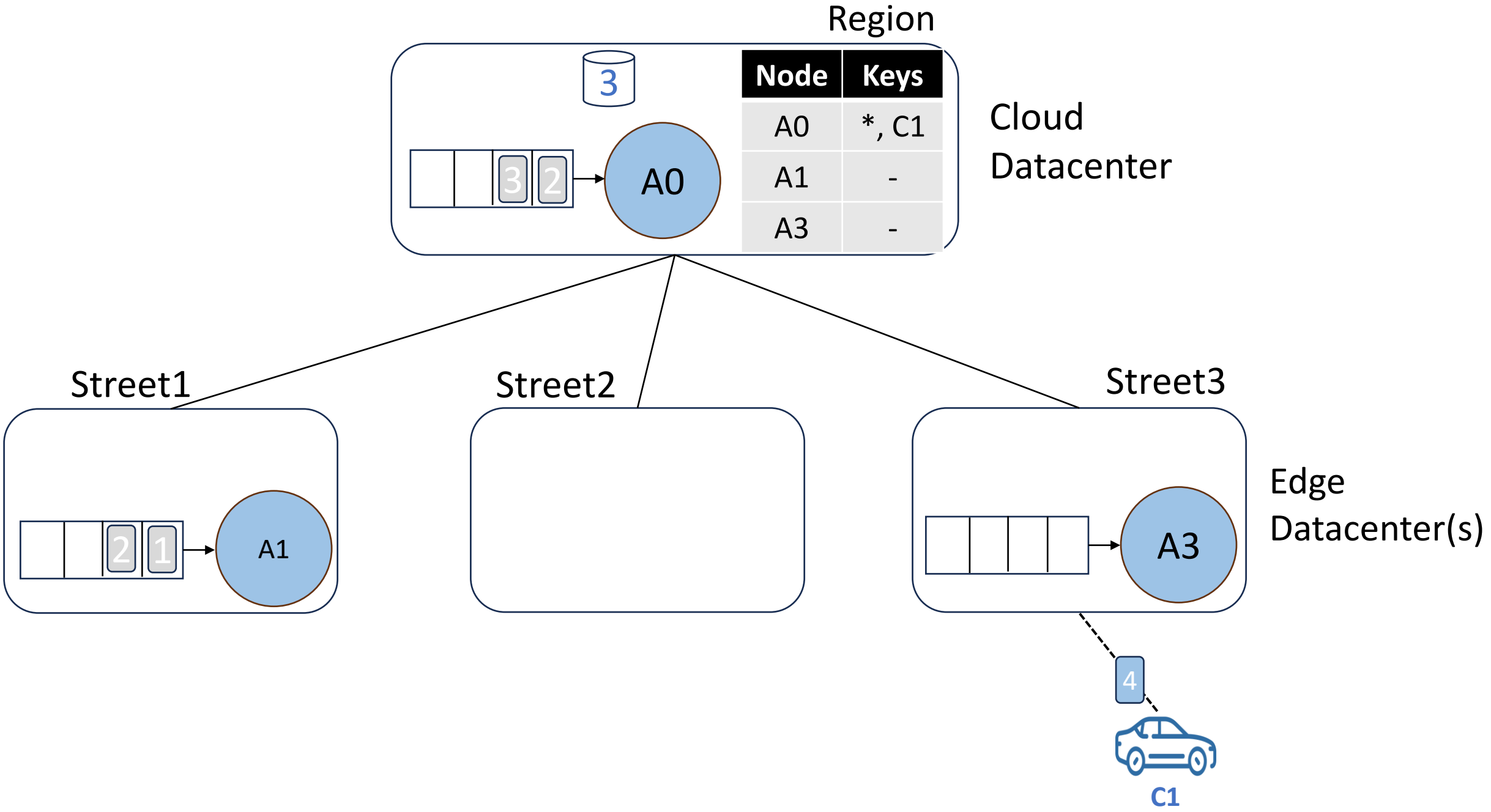
1. **Late Binding Routing System**
2. **Duplicate processing of tuples during reconfiguration**
3. **The source processes while the destination transfers and replays tuples to sync its state**
4. **Emit filter and Marker-based synchronization**

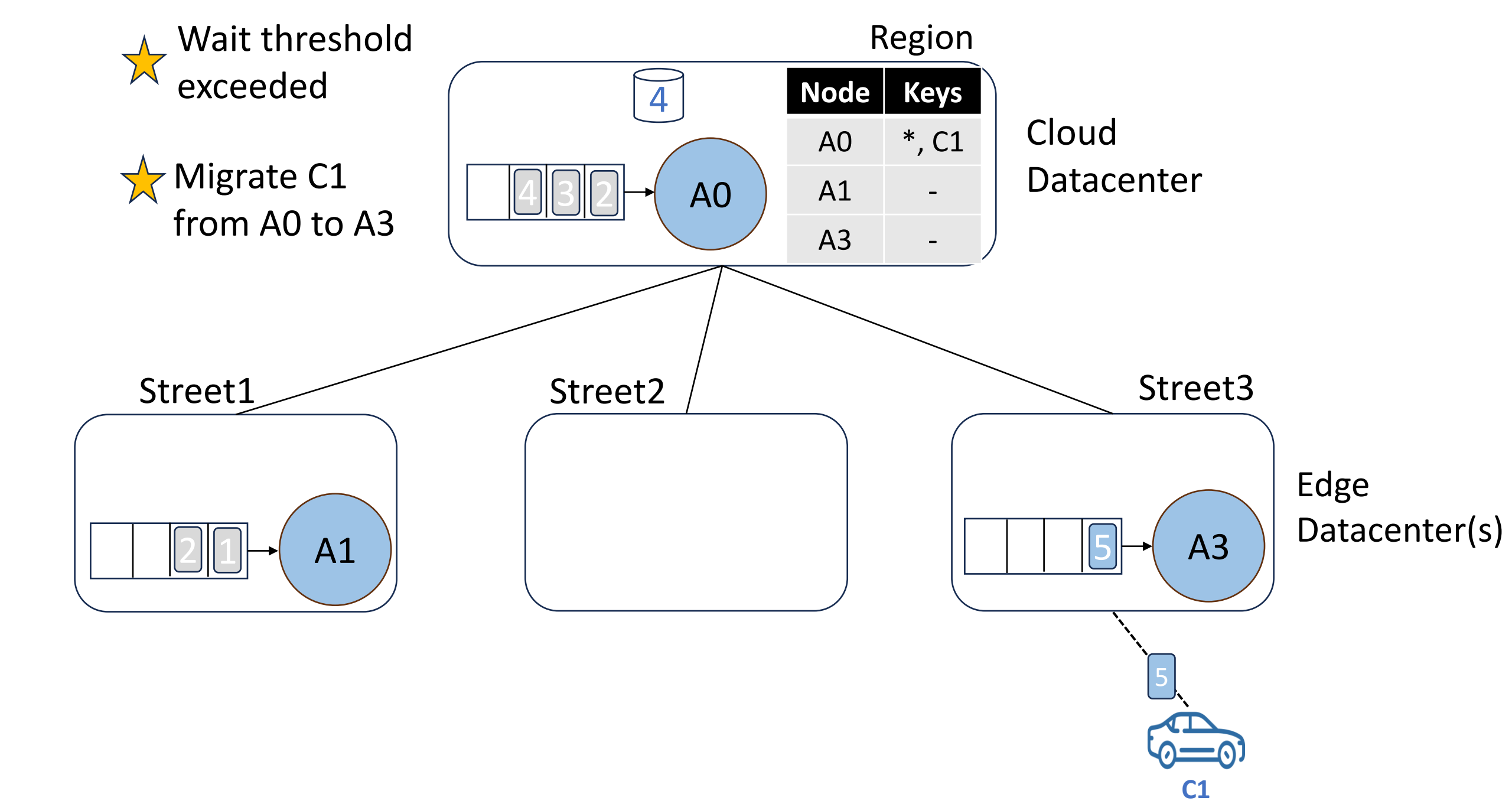

Region
Node
Keys
A0
*
A1
C1
A3
-
A0
Cloud
Datacenter
Street1
Street2
Street3
1
1
A1
A3
Edge
Datacenter(s)
1
C1

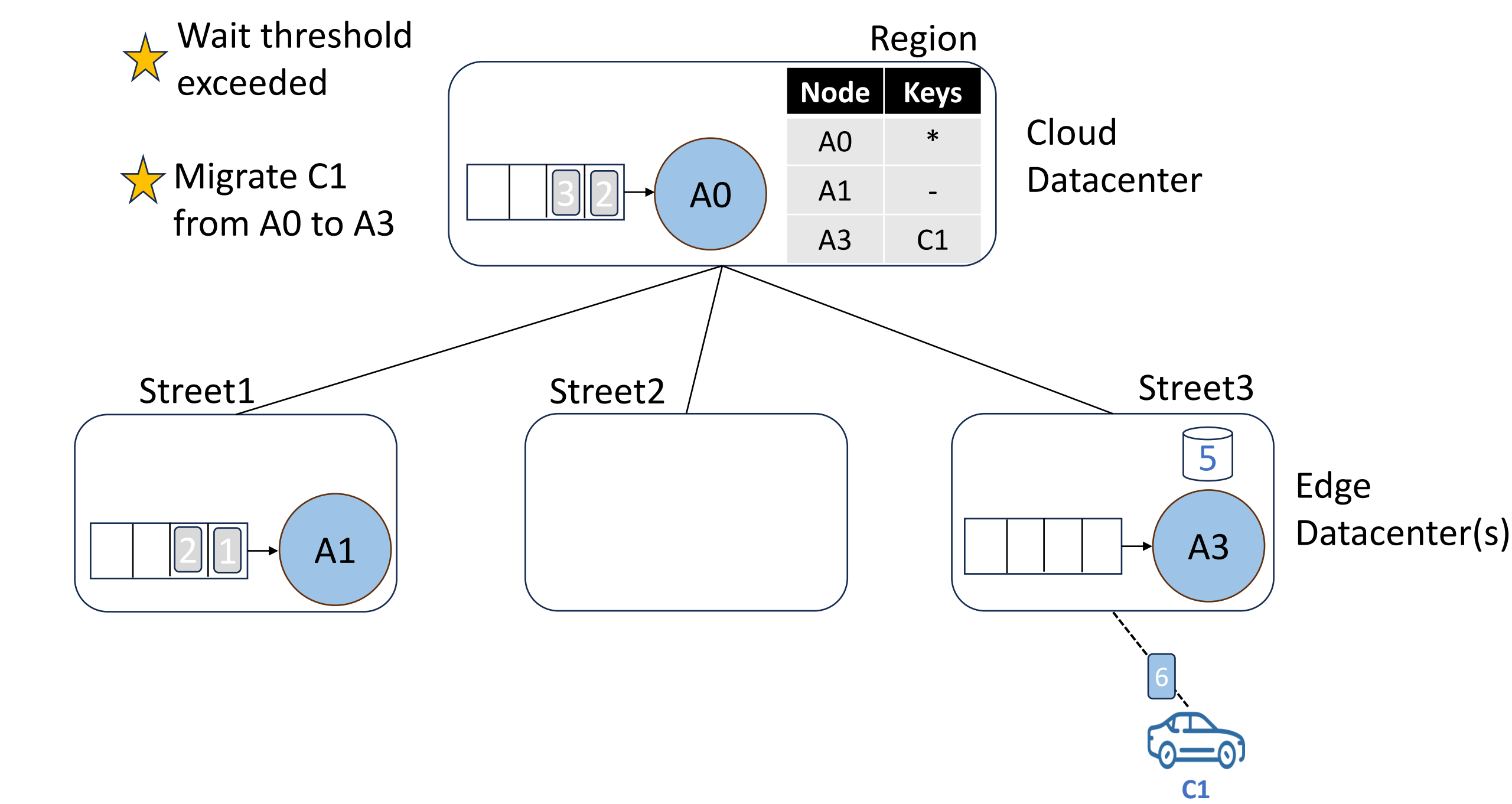

Mobility Detected
Migrate C1 state from A1 to A0
Region
Node
Keys
A0
*
A1
C1
A3
-
2
A0
Cloud Datacenter
Street1
Street2
Street3
1
1
A1
A3
Edge Datacenter(s)
2
C1

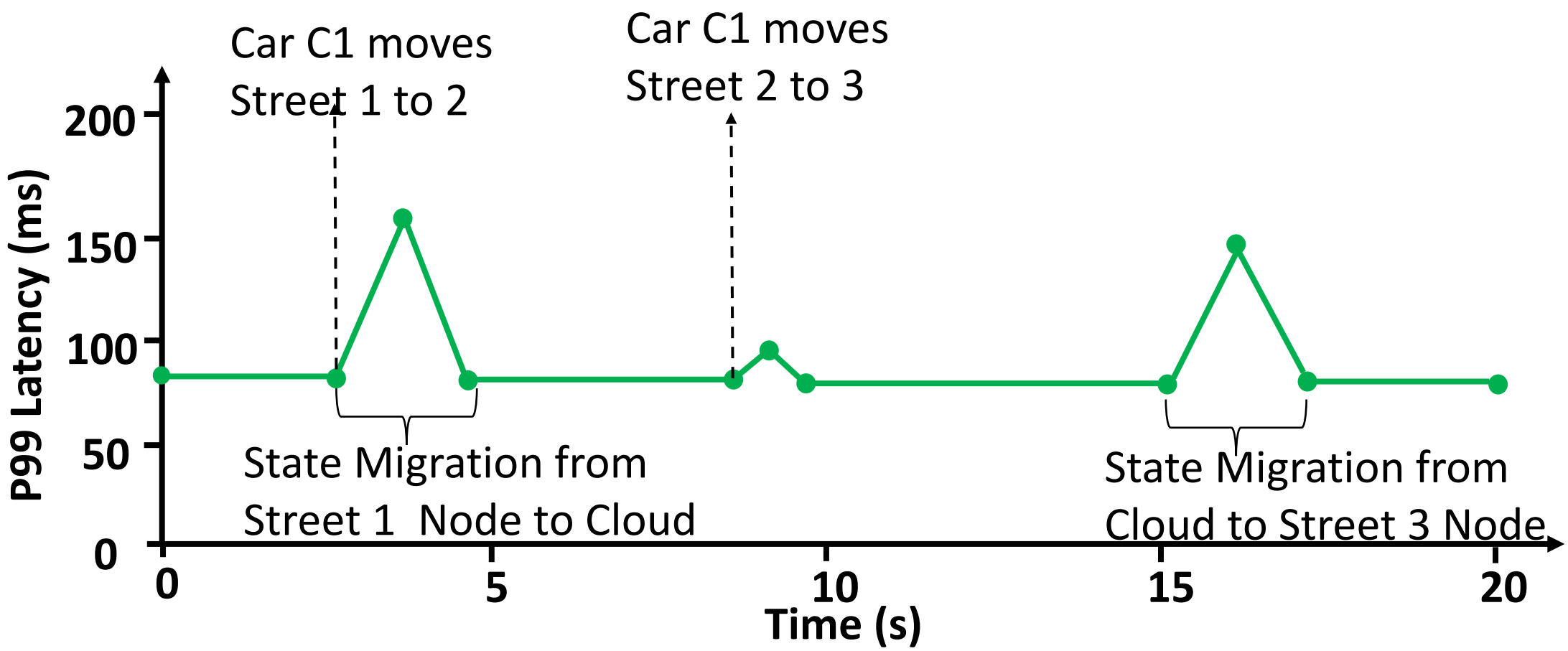

Mobility Detected
Migrate C1 state from A1 to A0
Region
2
Node
Keys
A0
*, C1
A1
-
A3
-
2
A0
Cloud Datacenter
Street1
Street2
Street3
2
1
A1
A3
Edge Datacenter(s)
3
C1


Mobility threshold
Region
3
Node
Keys
A0
*, C1
A1
-
A3
-
3
2
A0
Cloud
Datacenter
Street1
Street2
Street3
2
1
A1
A3
Edge
Datacenter(s)
C1


Region
3
Node
Keys
A0
*, C1
A1
-
A3
-
3
2
A0
Cloud
Datacenter
Street1
Street2
Street3
2
1
A1
A3
Edge
Datacenter(s)
4
C1

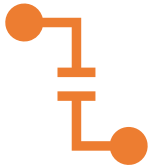

Wait threshold exceeded
Migrate C1 from A0 to A3
Region
4
Node
Keys
A0
*, C1
A1
-
A3
-
4 3 2
A0
Cloud Datacenter
Street1
Street2
Street3
2 1
A1
5
A3
Edge Datacenter(s)
5
C1


Wait threshold exceeded
Migrate C1 from A0 to A3
Region
Node
Keys
A0
*
A1
-
A3
C1
3
2
A0
Cloud Datacenter
Street1
Street2
Street3
2
1
A1
5
A3
Edge Datacenter(s)
6
C1



Car (C1) moves from Street 1 Edge Node to Street 3 Edge Node

Evaluation Baselines



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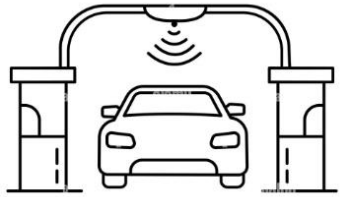
Systems: **Rhino (Falcon-HB)**

Benchmark Apps

Traffic Monitoring

Detects speeding vehicles using a running average

Allows for easy control of number of keys, state size



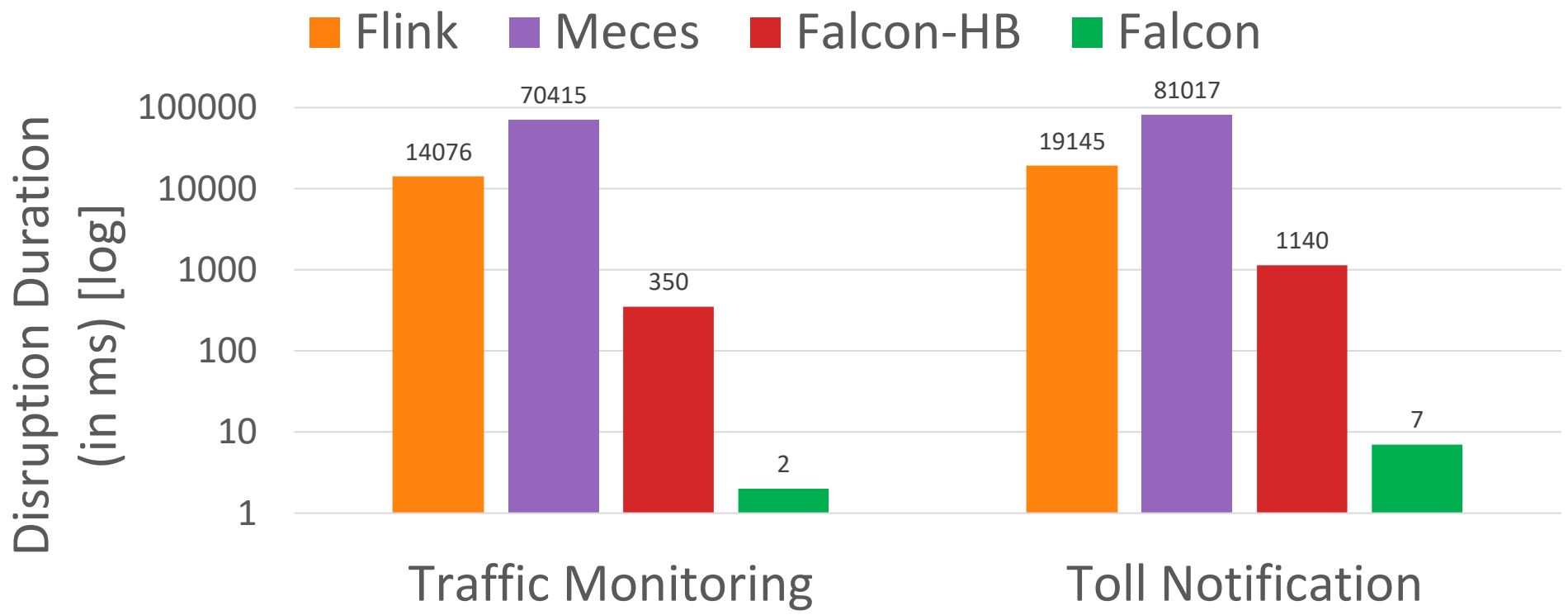
Toll Notification

Smart toll computation and real-time accident detection

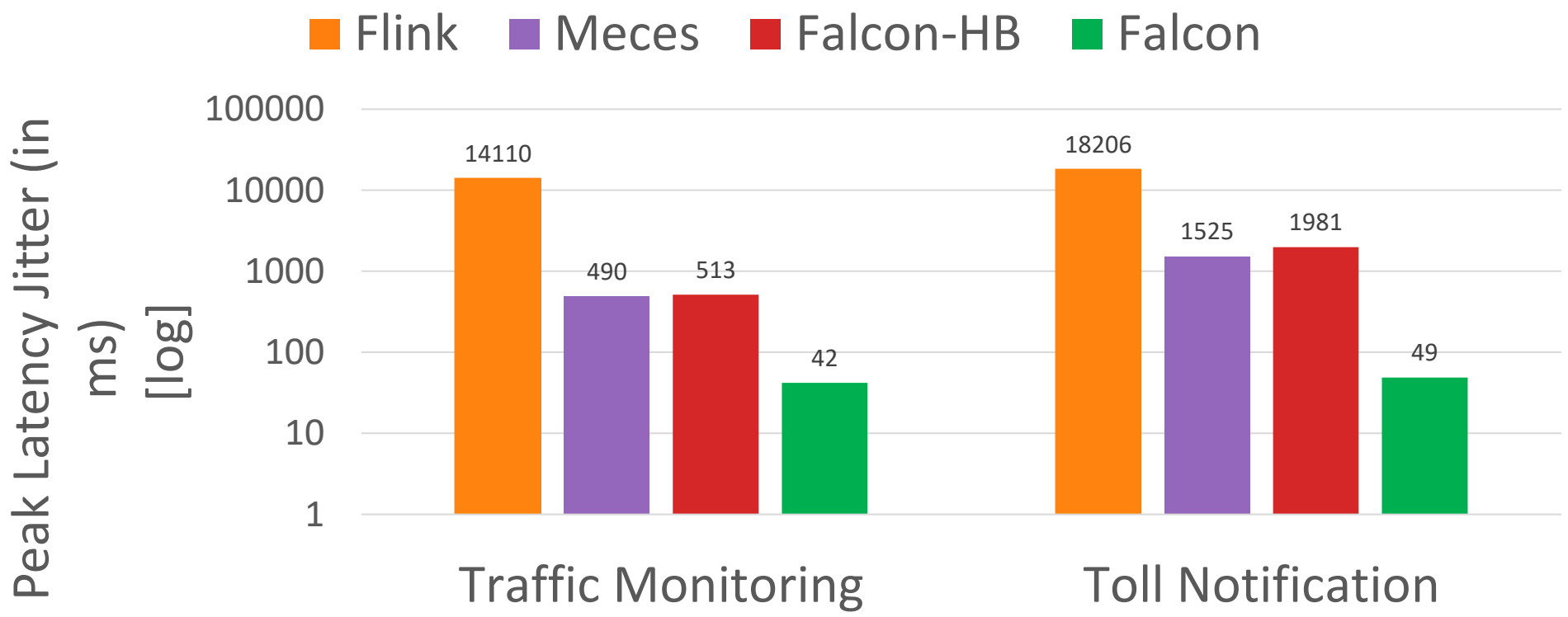
Road Segments - 101
Cars (Keys) – 124K

Uses event and count-based sliding windows

Disruption Duration



Peak Latency Jitter



Summary & Conclusions

- Falcon minimizes reconfiguration disruption with live key migration.
- Cuts interruption time to 40-45 ms, far below existing frameworks.
- Guarantees in-order, exactly-once processing and mobility awareness.
- More in the paper:
  - ➢Baselines, results and protocol details!

Download the paper

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https://github.com/delara/falcon