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# Scheduling at the Edge for Assisting Cloud Real-Time Systems

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TOPIC 2018

2018



# Introduction

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- Cloud computing



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  - Offloading computation from battery powered devices
  - Very scalable



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  - Cloud functionality at smaller scale
  - Located in proximity of the controlled system
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- Sensor network
  - Duty-cycled for energy saving

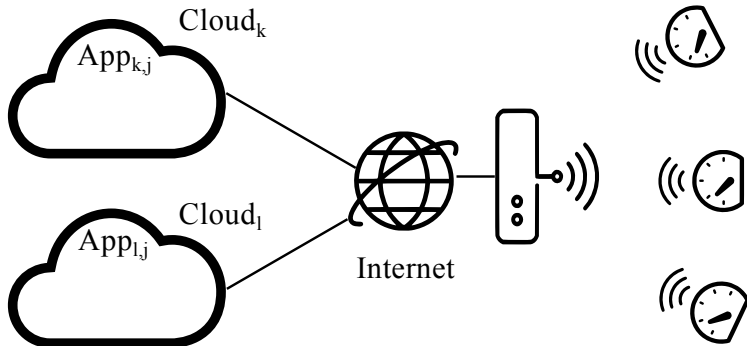


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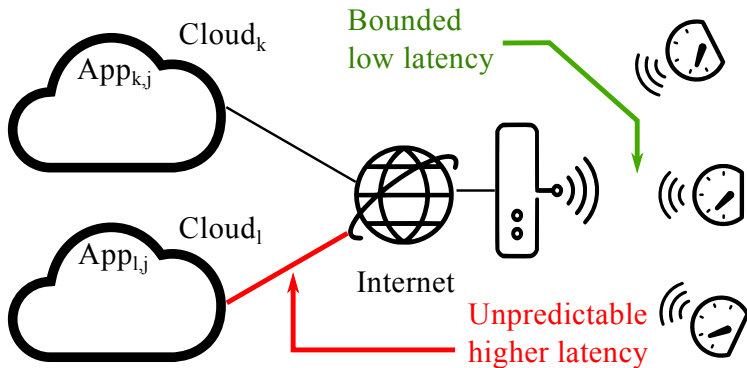
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- Real-Time applications
  - Have timing requirements
  - Run in a cloud-hosted environment

# Cloud-Edge-Sensor architecture

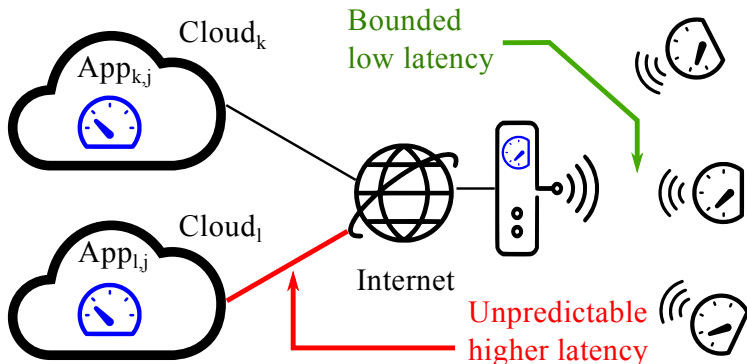




# Cloud-Edge-Sensor architecture



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A “digital twin” sensor is a cached copy of the most recent sensor update.



# Research question

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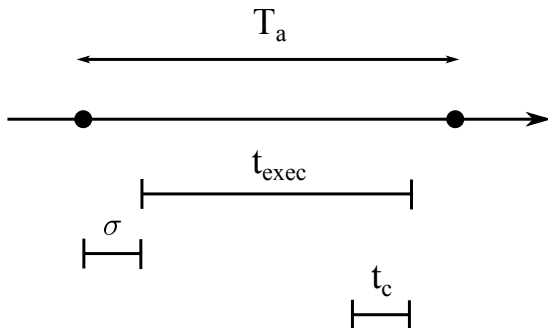
Can we use an edge device for helping real-time applications in fulfilling their timing requirements?



# Real-time model

We introduce additional parameters at application side:

- $t_{exec}$ : application execution time
- $\sigma$ : delay before starting of  $t_{exec}$
- $t_c$ : minimum required execution time for computation
- $\tau_\Delta$ : Age of Information requirement





# Age of Information (Aol)

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Age of Information is a metric that measures data freshness.

## Definition

$\Delta(t) = t - u(t)$ , where  $t$  is the current time and  $u(t)$  is the generation time of the latest sensor update.



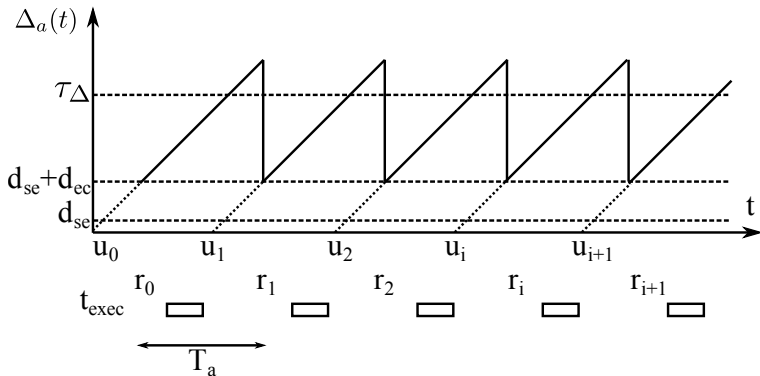
# Validity of sensor update

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## Definition

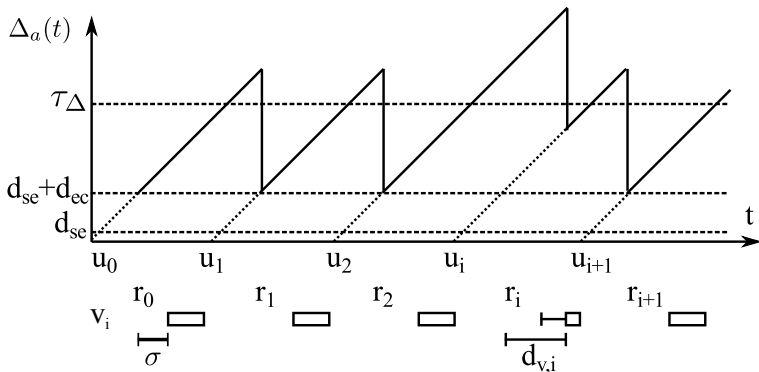
The validity of the  $i$ :th sensor update,  $v_i$ , is defined as the intersection between execution time interval and AoI (when smaller than  $\tau_\Delta$ ).

# Execution time: $t_{exec}$ (1/3)



**Figure:** Execution time and Age of Information in a scenario with no communication delay variability.

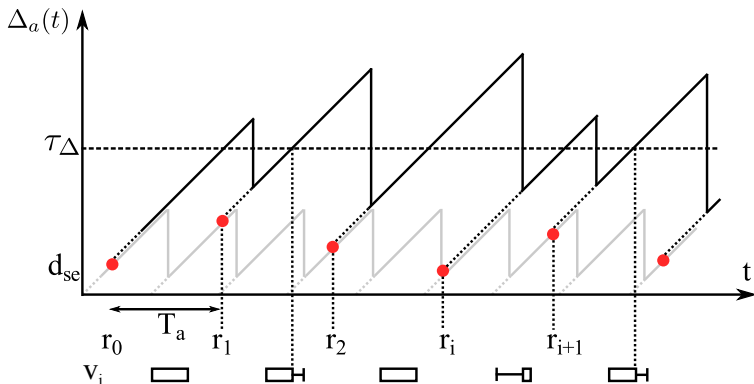
# Execution time: $t_{exec}$ (2/3)



**Figure:** Age of Information and reduced execution time due to communication delay variability  $d_{v,i}$ .



# Execution time: $t_{exec}$ (3/3)



**Figure:** Age of Information and reduced execution time due to communication delay variability  $d_{v,i}$  and AoI constraint  $\tau_\Delta$ .



# Scheduling policies

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We propose two scheduling policies performed at the edge device:

- **AITE**: Age in the Edge. The edge pushes sensor updates towards the digital twin in the cloud according to application period.



# Scheduling policies

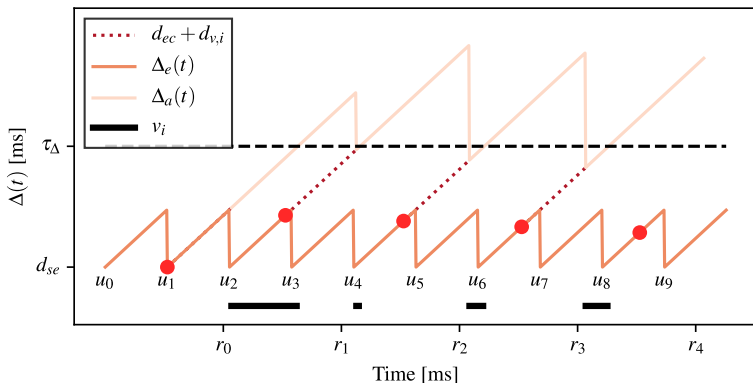
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We propose two scheduling policies performed at the edge device:

- **AITE**: Age in the Edge. The edge pushes sensor updates towards the digital twin in the cloud according to application period.
- **AITC**: Age in the Cloud. The edge pushes sensor updates upon reception as close as possible to the application period.

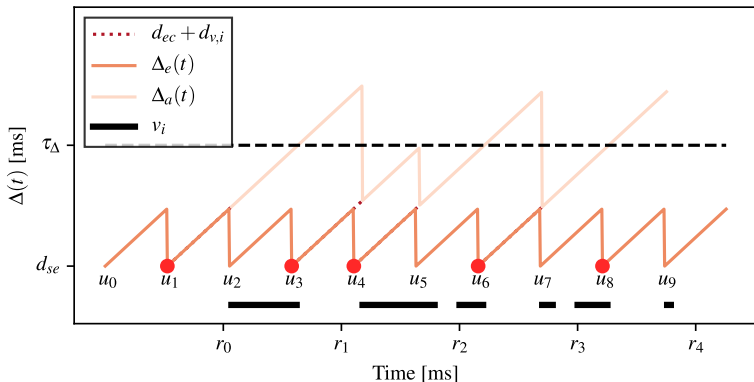
We will analyze both of them and decides which is most suitable for reaching our objectives.

# AITE: Age in the Edge



**Figure:** Execution time and Age of Information for AITE.

# AITC: Age in the Cloud



**Figure:** Execution time and Age of Information for AITC.



## Evaluation setup

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We evaluate the aforementioned scheduling policies through simulation. We choose the following parameters:

- Latency sensor-edge,  $d_{se} = 1\text{ms}$
- Latency edge-cloud,  $d_{ec} = 100\text{ms}$
- Application deadline,  $\tau_{\Delta} = 210\text{ms}$
- Sensor update period,  $T_s = 100\text{ms}$
- Application period,  $T_a = 190\text{ms}$
- Application execution time,  $t_{exec} = 152\text{ms}$
- Communication delay variability: Pareto distribution with maximum value 161ms and average value 14ms.



## Evaluation setup

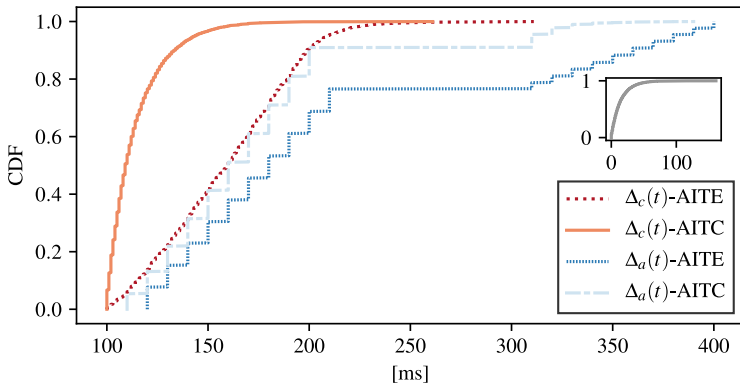
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We collected 5000 samples both at the cloud and the application for every simulation instance.

# Aol at the cloud and at the application

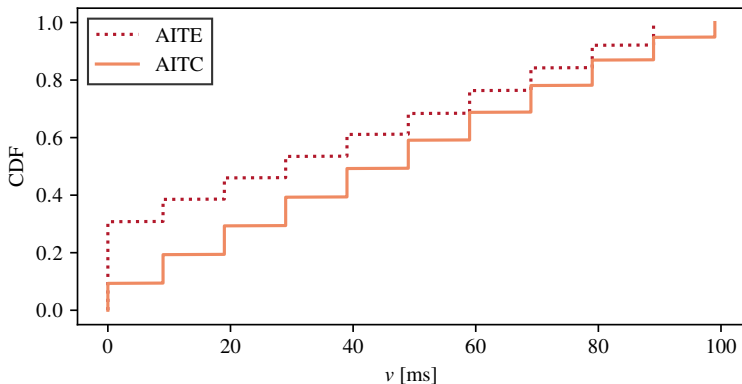


**Figure:** Age of Information at the cloud and at the application, respectively,  $\Delta_a(t)$  and  $\Delta_c(t)$  for AITE and AITC.





# Validity $v$



**Figure:** Validity of the updates at the application,  $v$ .



# Results

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- Percentage of real-time misses
  - $AITE \approx 34\%$
  - **$AITC \approx 9\%$**
- Validity of sensor updates
  - **$v_{AITC} > v_{AITE}$**



# Results

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- Percentage of real-time misses
  - $AITE \approx 34\%$
  - **$AITC \approx 9\%$**
- Validity of sensor updates
  - **$v_{AITC} > v_{AITE}$**

**AITC** outperforms AITE in both the metrics!



# Conclusion

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- We propose to use Age of Information and validity in periodic real-time cloud assisted applications



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# Conclusion

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- We propose to use Age of Information and validity in periodic real-time cloud assisted applications
- We propose to use an edge device to schedule sensor updates in order to fulfill application requirements
- We propose and evaluate two scheduling policies at the edge device



# Thank you!

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Any questions?