Chair of Robotics, Artificial Intelligence and Real-time Systems
TUM School of Computation, Information and Technology
Technical University of Munich

Analysis of Edge Computing Offloading Strategies for Autonomous Mobile Robots

Final Presentation, Master's Thesis

Xiyan Su

June 15, 2023

Supervisor: *Robin Dietrich M.Sc.*
Examiner: *Prof. Dr.-Ing. habil. Alois C. Knoll*

AMRs in Warehouse

- Modules running on the AMRs
  - Perception
  - SLAM
  - Path planning
  - Navigation
  - Control
- Problems with AMR's onboard system
  - Limited space
  - High cost for computation devices

Figure: AMRs in warehouse [Int23]

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Task Offloading

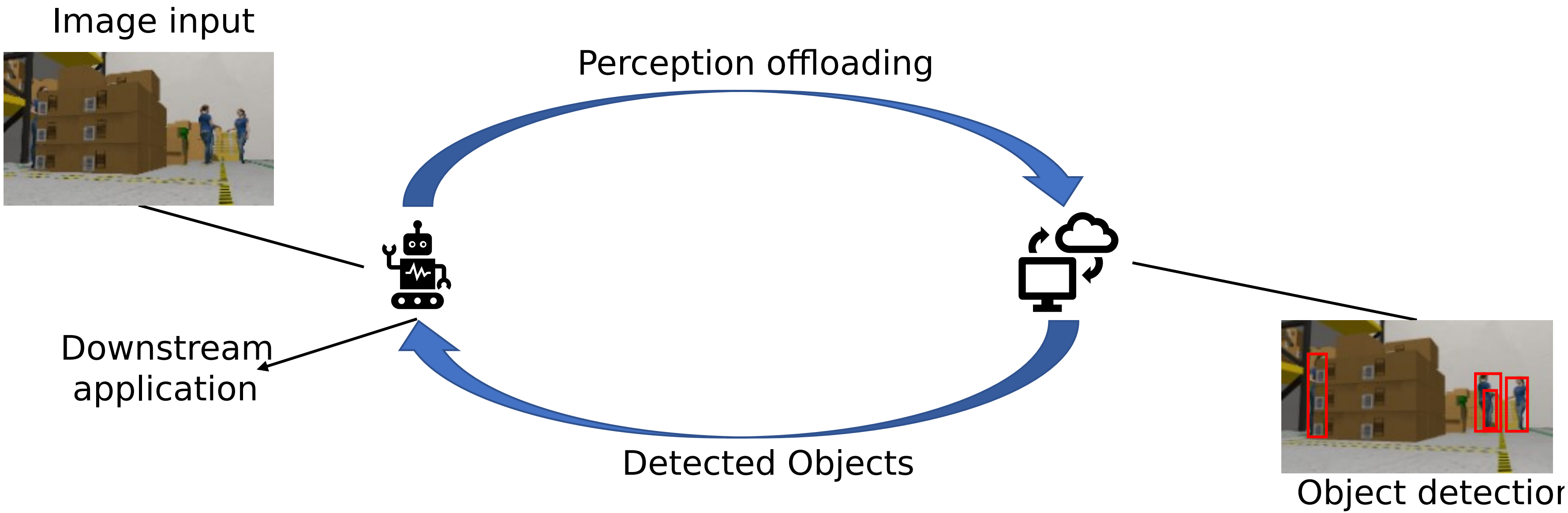

Figure: Robotic computation offloading

Problems

- Why offloading tasks?
  - Reduce onboard resource usage
  - Improve task performance
- Current problems with task offloading
  - Safety issues -> local computation
  - Real-time execution -> edge computing
- When and how to offload?
  - Dynamic network conditions
  - Onboard resources

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Related Work

- Mathematical optimization approaches
  - Formulates an optimization problem with a computational model
  - Minimizes execution latency and/or energy consumption
- Game-theory approaches
  - Formulate the problem as a game
- Deep reinforcement learning approaches
  - Uses deep RL agent to make offloading decisions -> high inference time

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Robot Perception Offloading

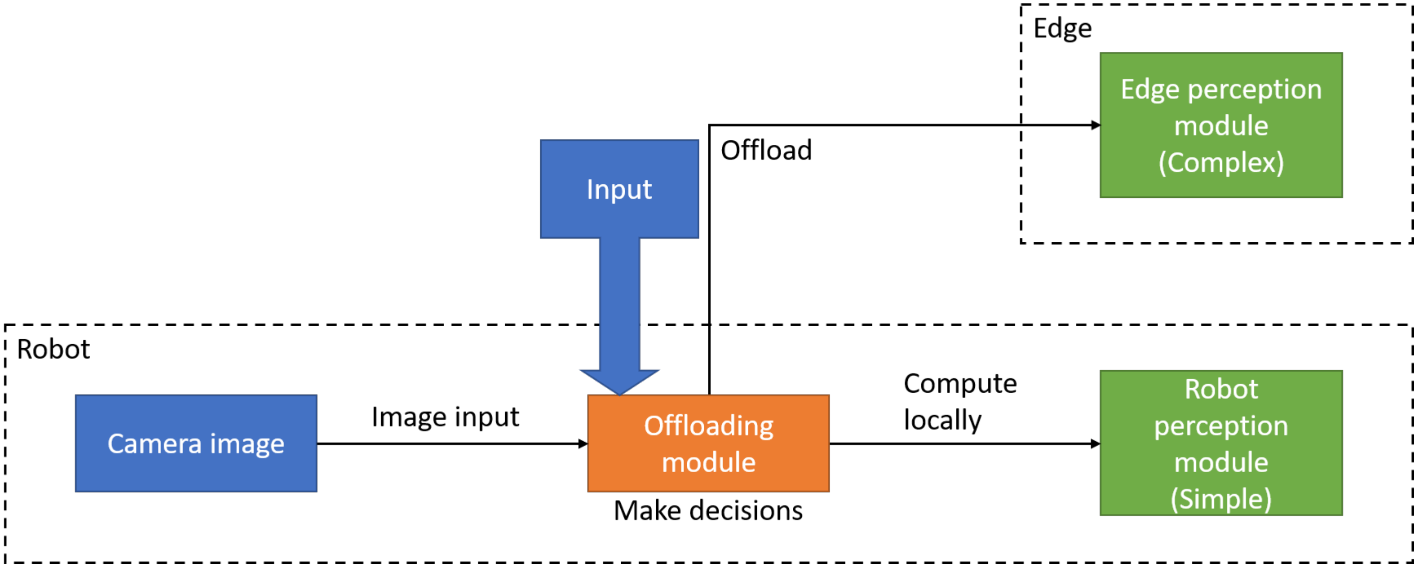
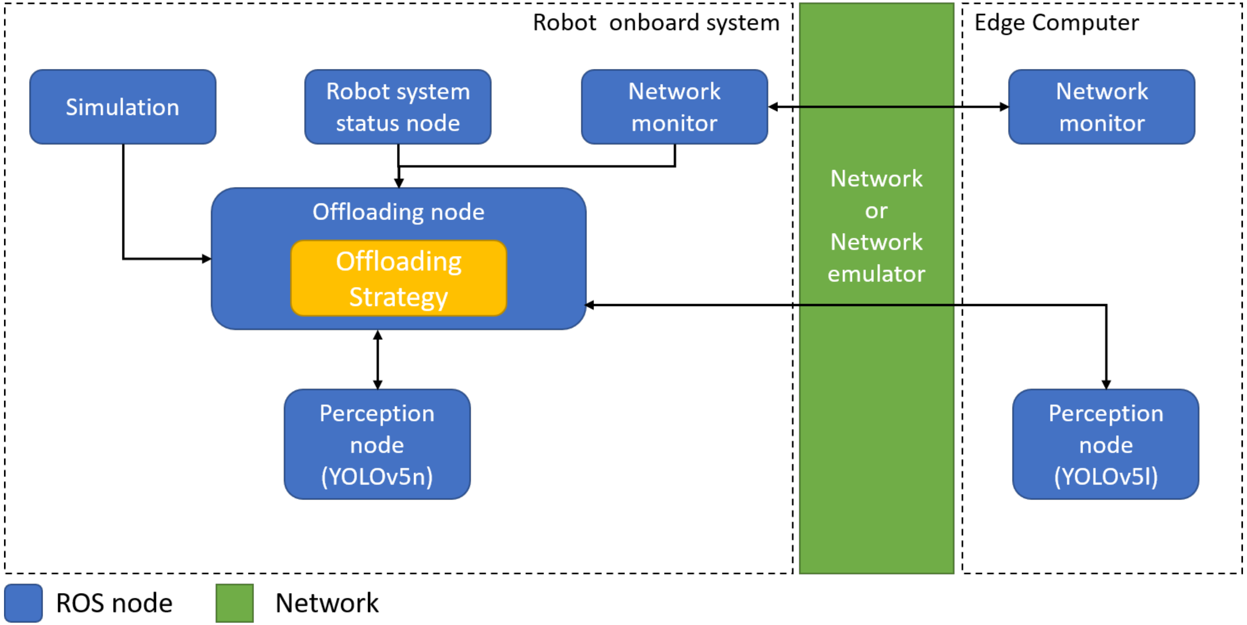


Figure: Robot perception offloading

Offloading Framework



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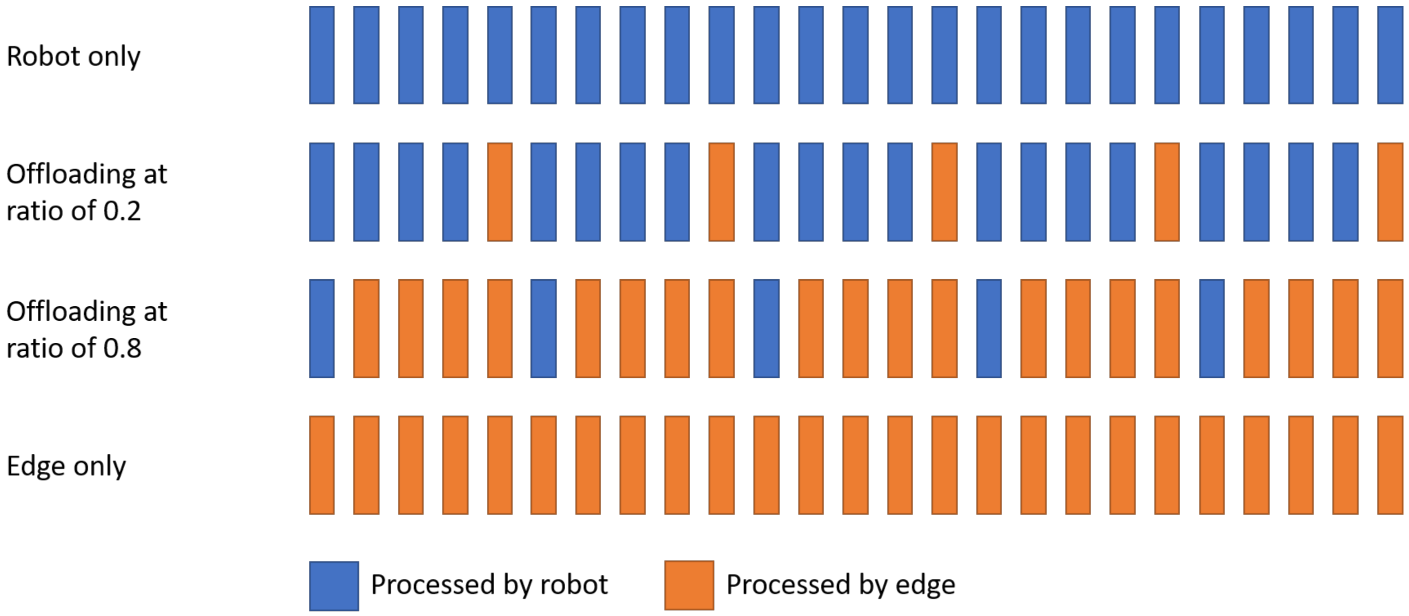
Baseline Strategies



Simulated Scenario

- Environment
  - Industrial warehouse
  - Human and other obstacles
- Robot
  - Equipped with RGB camera
  - Navigation through the scene

Figure: Simulated scenario

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Metrics

- Task performance
  - Average precision
  - Overall processed frames
  - Perception round-trip time
- Resource usage
  - CPU usage
  - CPU power consumption
  - Bandwidth usage

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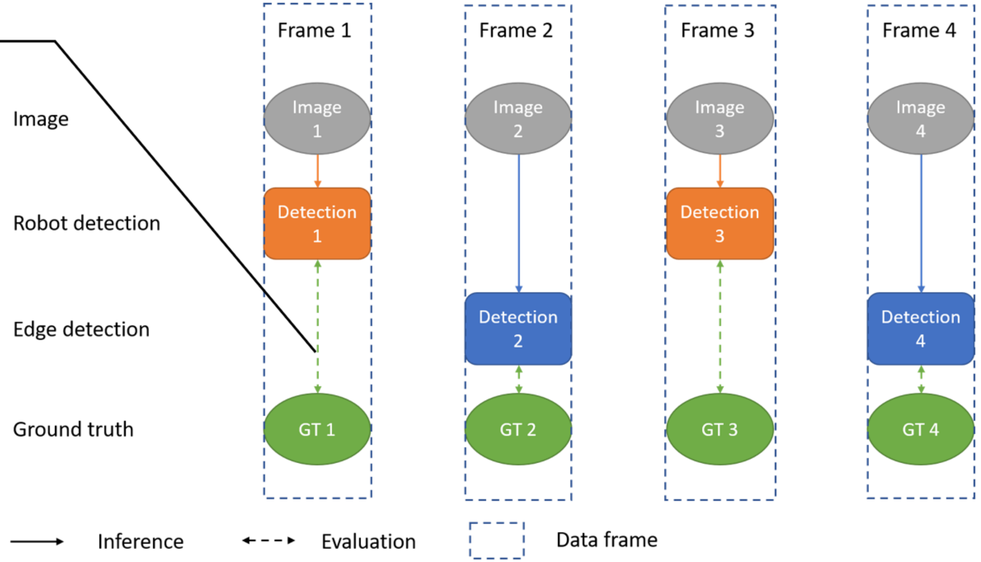
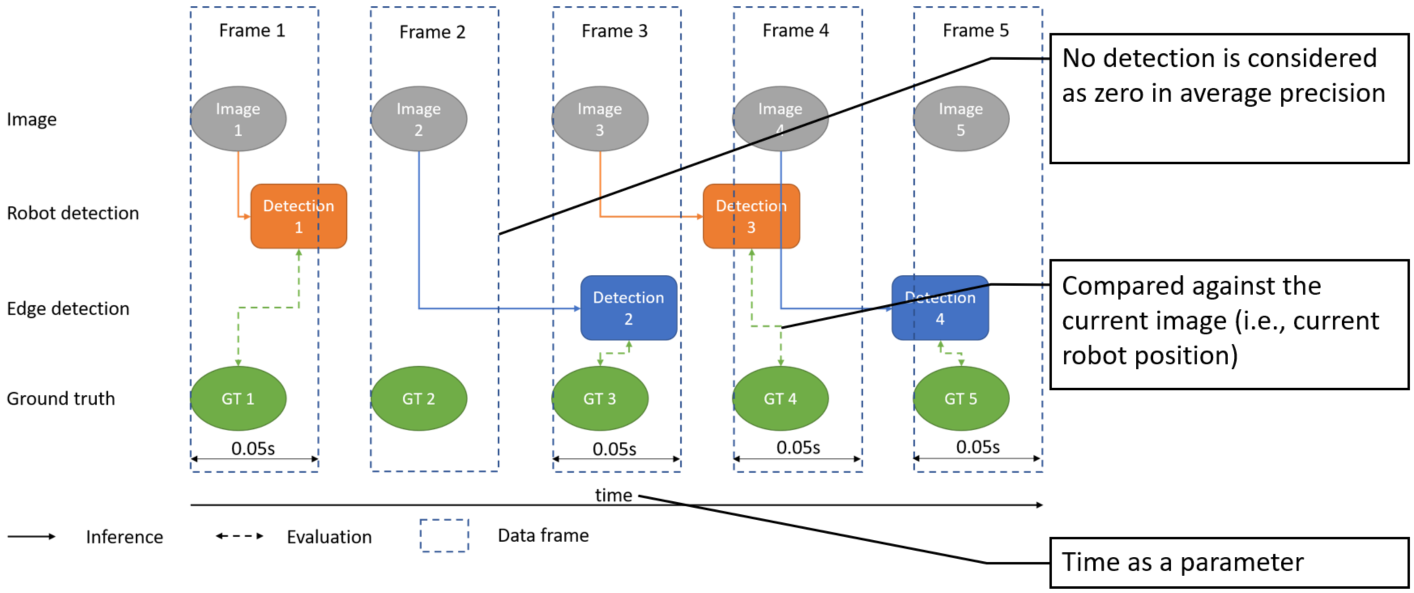
Synchronous Evaluation

- Evaluated against the original image



Asynchronous Evaluation



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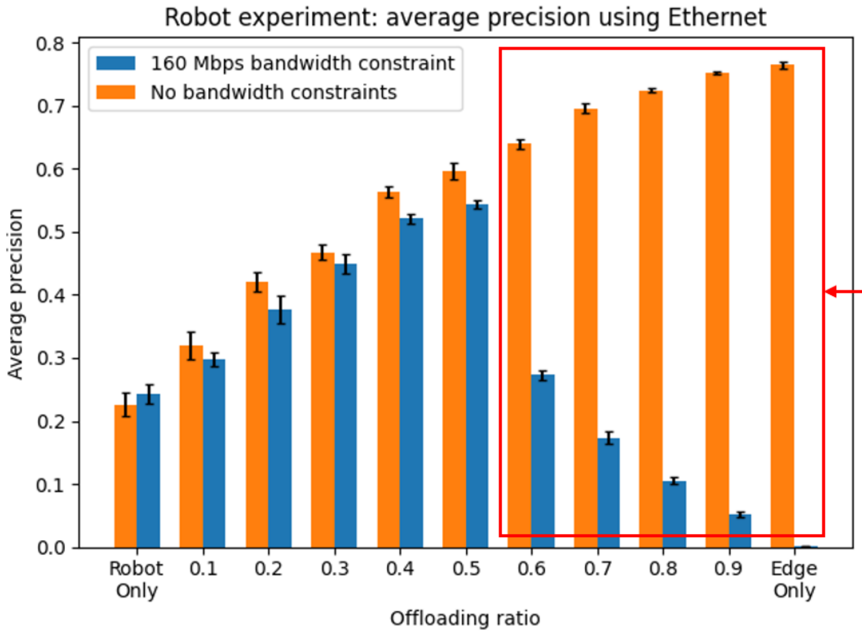
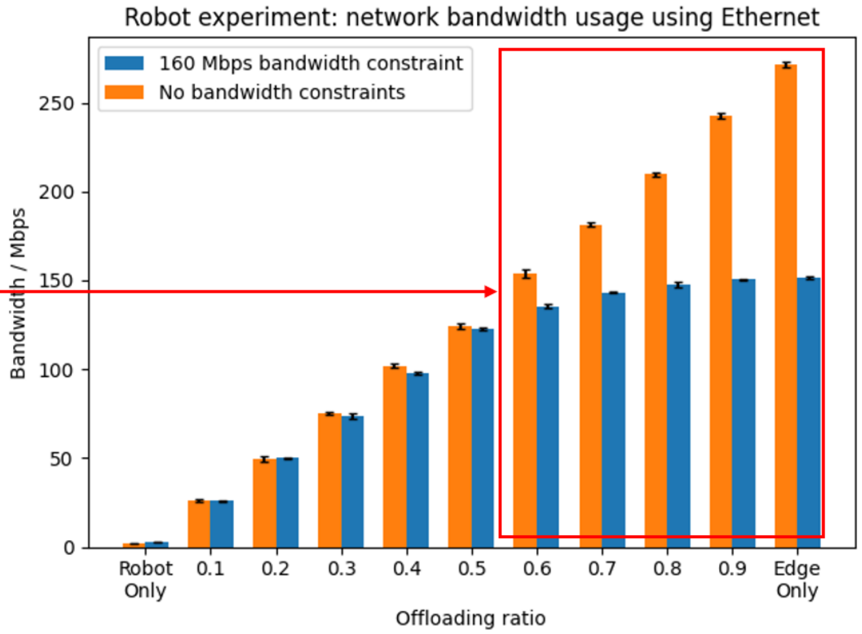
Results of Baseline Strategies





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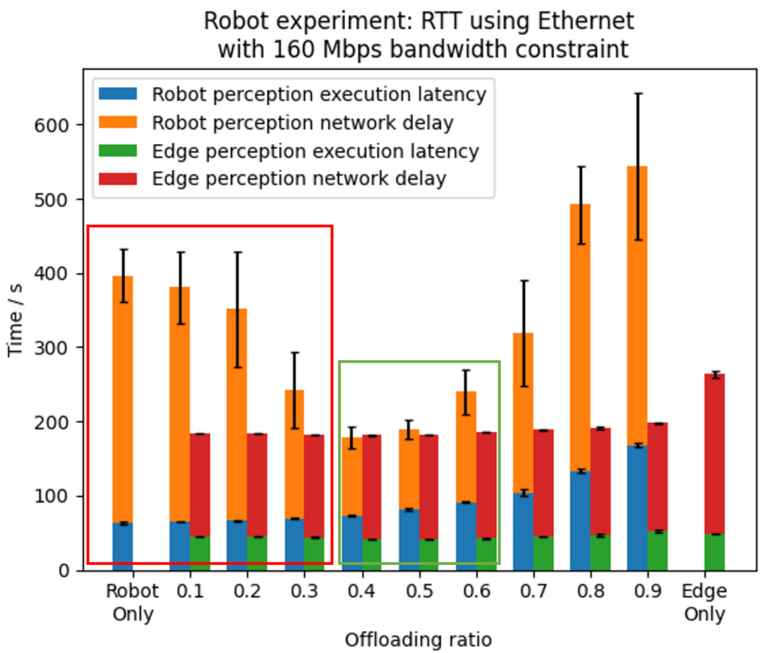

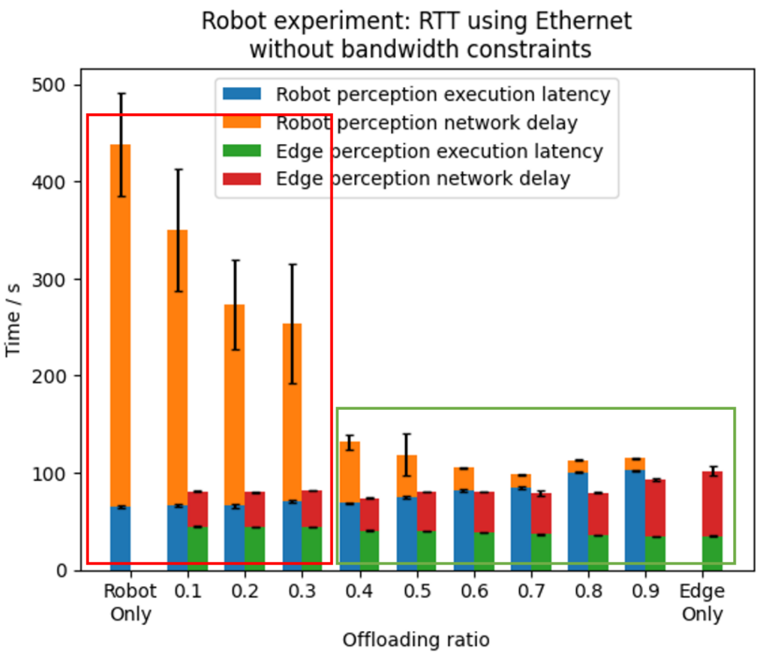

Results of Baseline Strategies

- Network bandwidth is the main constraint of edge task performance -> hard to measure during runtime
- Round-trip time as an indicator for network conditions and onboard computation resources
- Balance between network resources and computation resources

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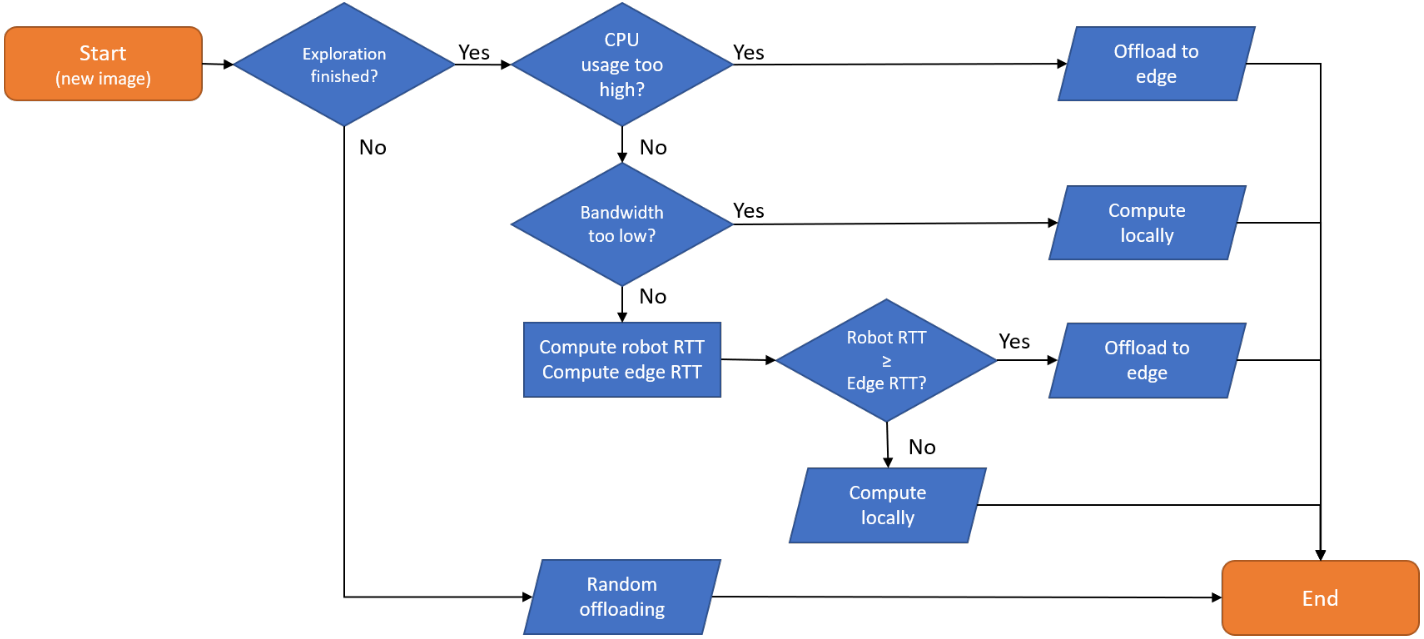
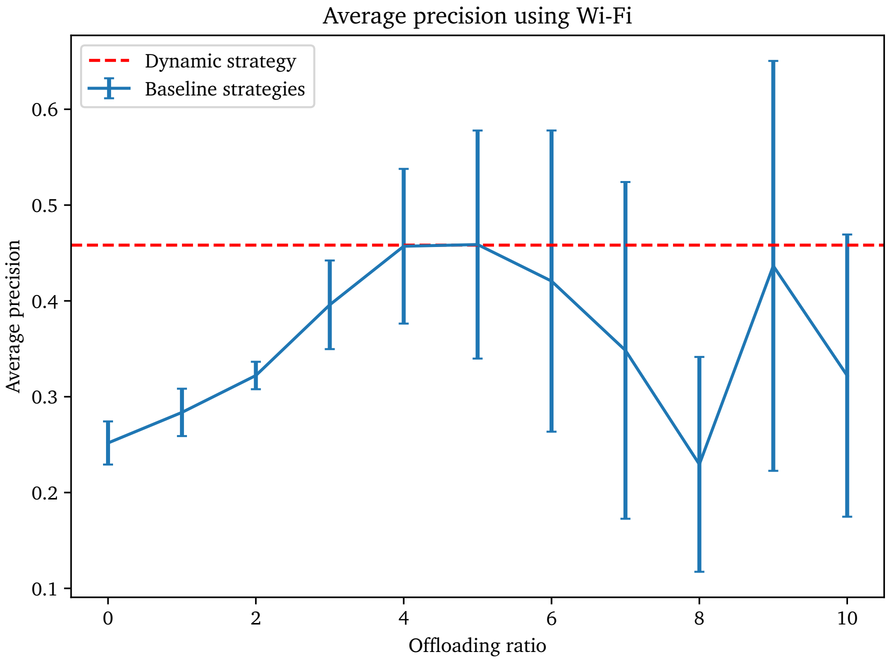
Dynamic Offloading Strategy



Results of Dynamic Offloading Strategy



Results of Dynamic Offloading Strategy

- Improved average precision by 13.61% compared to "edge only" strategy and 23.24% compared to "robot only"
- Comparable performance with the offloading strategy with an offloading ratio of 0.5 (best)
- Able to process 80.31% of all frames
- Less CPU usage and CPU power consumption compared to "robot only" strategy

Summary

- Implement an offloading framework and a simulated scenario
- Set up experiments in simulation and on a robotic system
- Design evaluation framework and define metrics
- Evaluate baseline strategies with different network conditions in simulation and on a robotic system
- Develop and implement the dynamic offloading strategy
- Evaluate dynamic offloading strategy against baselines

Future Work

- Offloading decisions used in downstream application
  - Object detection output used for obstacle avoidance
  - Object detection output used for navigation
  - Resource competition within the onboard system
  - New metrics: safety, efficiency, battery life
- Multi-robot computation offloading
  - Resource competition among multiple robots
  - Centralized offloading decision-making
  - Game-theory approach for decision-making
  - New metrics: joint efficiency

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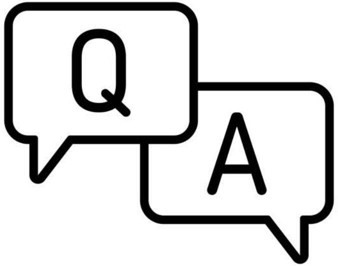
References I

[Int23] Intel. *Robotics Technology Solutions*. June 2023. URL: https://www.intel.com/content/www/us/en/robotics/overview.html.

Q&A



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