PTC: Pick-Test-Choose to Place Containerized Micro-services in IoT

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Introduction

- **Cloud Computing and Internet of Things (IoT) applications:** Short bursty flows generated by the IoT applications increase the response time in cloud.
- **Fog Computing** [1]**:** Fog computing delivers user desired quality of service for IoT applications.
- **Micro-service architecture** [2]**:** In this architecture, each application is developed in the form of a bunch of loosely coupled lightweight services.
- **Containers:** It is a lightweight virtualization technology that provides service isolation, lightweight migration.
- **Pick-Test-Choose (PTC) framework**: PTC uses bayesian optimization [3] based iterative reinforcement learning algorithm.

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Challenges

- How can we cater to the primary workloads of the fog devices?
- How to provide micro-service isolation?
- How can we handle migration of micro-services?
- How to make the deployment and migration framework lightweight?
- How to monitor the highly dynamic in-network processing architecture?

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Objective

- Given the communication graph and available resources, the micro-service placement problem finds an allocation schedule for each micro-service with required instructions and resources such that the maximum response time taken by the applications is minimized.

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Related Works

- Saurez et al., ACM DEBS 2016 [4]: Developed a programming infrastructure which launches the application modules and performs the migration of these modules as containers.
- Souza et al., FGCS 2018 [5]: Developed a micro-service offloading framework by exploiting traditional memory allocation strategies (best-fit,first-fit).
- Goncalves et al., IEEE ISCC 2018 [6]: Provided a VM placement and migration framework to maximize the number of applications placed in fog while reducing the overall application latency.
- Wang et al., IEEE CloudNet 2017 [7]: Placed the applications as virtual machines in the edge or fog devices.

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Related Works (contd.)

- Ahmed et al., IEEE EDGE 2018 [8]: Proposed a container driven framework to speed-up application deployment procedure.
- Yigitoglu et al., IEEE AIMS 2017 [9]: Proposed task scheduling mechanisms using containers in fog computing architecture.
- Taneja et al., IFIP/IEEE IM 2017 [10]: Proposed a module mapping algorithm for efficient utilization of resources in Fog-Cloud infrastructure.
- Elgamal et al., IEEE CLOUD 2018 [11]: Proposed a scalable dynamic programming algorithm called DROPLET, to partition operations in IoT applications across shared edge and cloud resources, while minimizing completion time of the end-to-end operations.

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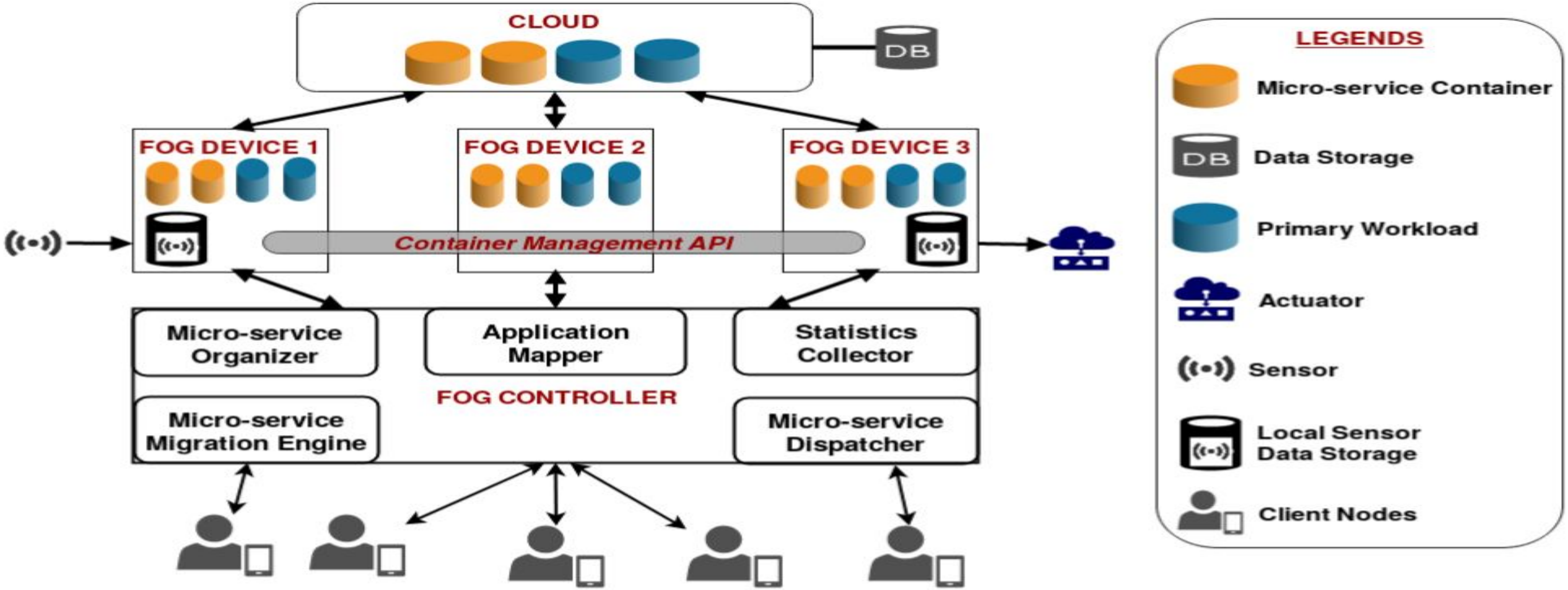
System Architecture with PTC framework



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System Architecture: Components

- Client Node: It generates a fog service request.
- Fog Controller Device: It manages the computation offloading in the fog devices.
- Fog Device: Fog devices are responsible for the actual computation and storage related to the applications provided by the fog-cloud.
- Cloud: It manages the overloaded scenarios when it is not possible to cater to all the micro-service demands inside the fog.

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Micro-service Placement as an Optimization

- Objective Function with Constraints:

$$\underset{A}{\text{minimize}} \qquad T_{Resp}^{max}(A)$$

subject to:

$$\mathcal{R}(A) \geq \vec{Z}$$

- $T_{Resp}^{max}(A)$ is maximum response time taken by the applications.
- $\mathcal{R}(A)$ is the resource availability vector.

$\vec{Z}$ = $(z_{i,q,t} = 0 : i = (0, \ldots, n), q = (0, \ldots, f), t = (0, \ldots, l))$.

- n is the number of fog nodes.
- f is total number of resource types.
- l is the number of time slots.

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Solution: Micro-service Placement using BO

- Bayesian Optimization:
  - As the problem is NP-hard and difficult to implement due to high monitoring overhead, we propose a reinforcement learning framework which requires very little monitoring and can perform in the presence of noise. For this purpose, we design Bayesian Optimization (BO) based mechanism, PTC.
- We assume that the utility function $T_{Resp}^{max}(A)$ follows a normal distribution.
- Acquisition Function: It notifies BO to choose the configurations for subsequent experiments. It leads the framework towards optimum configuration.

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Solution: Micro-service Placement using BO (contd.)

- Acquisition Function:

$$\mu(a_u) = \mathbb{E}(T^{max}_{Resp}(a_u))$$
$$K(a_u, a_v) = \mathbb{E}\left(\left(T^{max}_{Resp}(a_u) - \mu(a_u)\right)\left(T^{max}_{Resp}(a_v) - \mu(a_v)\right)\right)$$

- Mean function.
- Covariance kernel function.

Where, a_u and a_v are the allocation matrices.

$$U_{min} = \min_{a \in \mathcal{D}_d}(T^{max}_{Resp}(a))$$
$$\pi = \frac{U_{min} - \mu(a_d)}{\sigma(a_{d-1}, a_d)}$$
$$\sigma(a_{d-1}, a_d) = \sqrt{K(a_{d-1}, a_d)}.$$

- U_{min} is the minimum value of the average response time observed till iteration d.
- $\sigma(a_{d-1}, a_d)$ is the standard deviation between the allocation matrices a_{d-1} and a_d.

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Solution: Micro-service Placement using BO (contd.)

- Acquisition Function:

$$EI(A|\mathcal{D}_d) = \begin{cases} 0 & \text{if:}\sigma(a_{d-1}, a_d) = 0 \\ ((U_{min} - \mu(a_d))\,\Phi(\pi)) + (\phi(\pi)\sigma(a_{d-1}, a_d)) \\ & \text{Otherwise} \end{cases}$$

- A is an allocation matrix. D_d is the set of prior observations after d iterations. Φ,φ as standard normal cumulative distribution function and standard normal density function respectively.

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Evaluation: Implementation Details

- Testbed Components:
  - Raspberry Pi 3 model b single-board computers as the fog devices
  - Docker for micro-service isolation
  - Institute private cloud
- Baselines:
  - Foglets [4]
  - Best-Fit [5], First-Fit [5]
  - Mobility-based [6]
- Simulator Used:
  - iFogSim [12]

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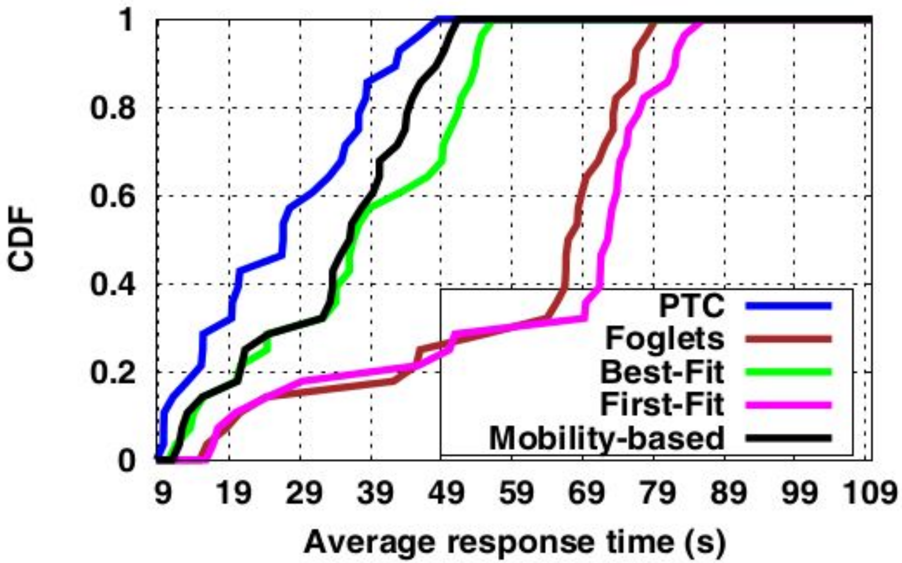
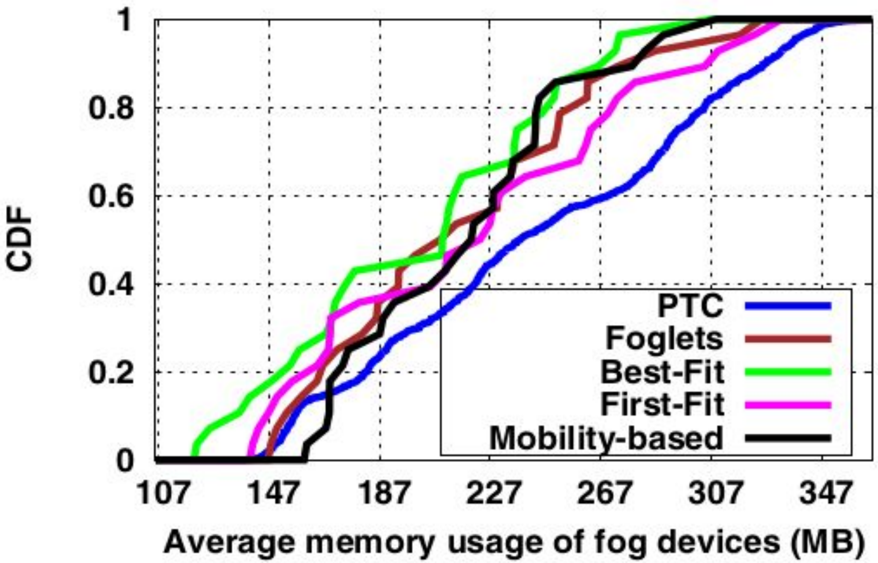
Evaluation in Testbed: Results





- PTC reduces the average response time by BO based reinforcement learning.
- PTC has more average memory usage of the fog devices than the baselines.

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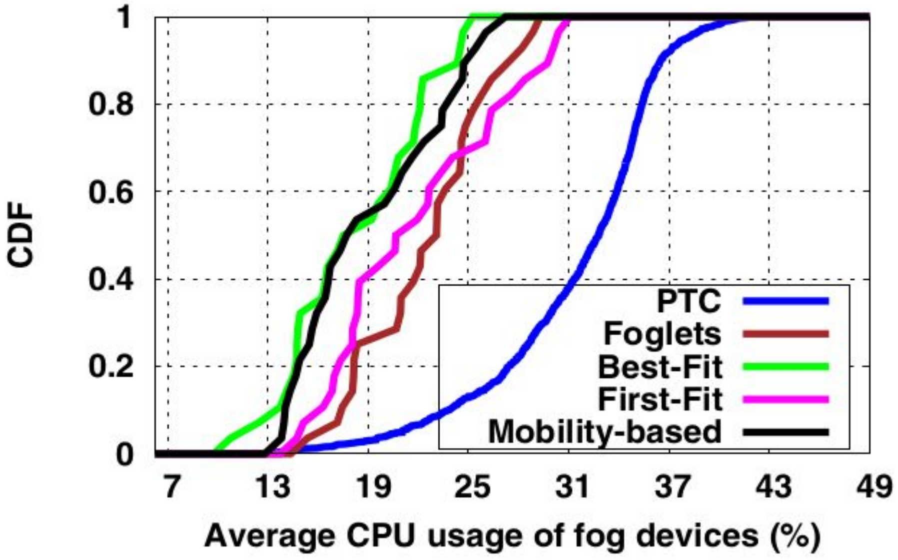
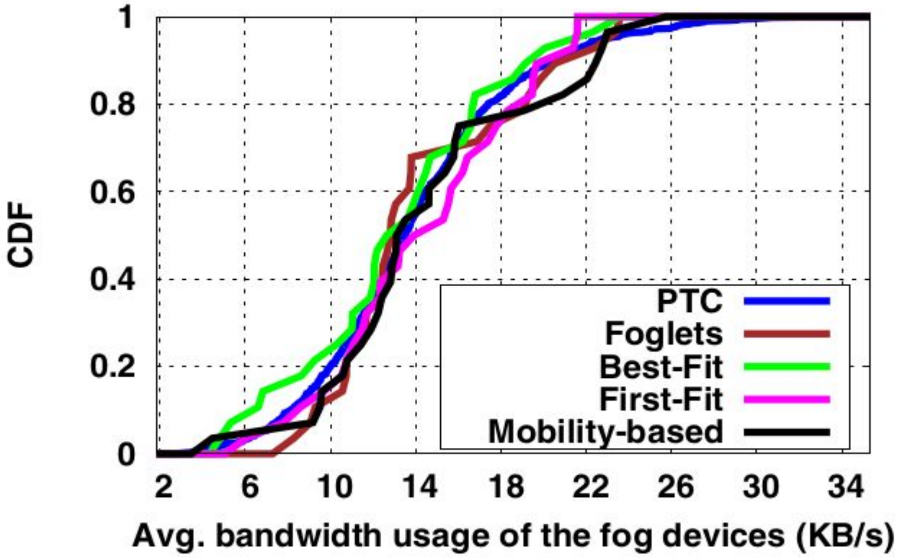
Evaluation in Testbed: Results (contd.)





- The average CPU usage of the fog devices is higher in PTC.
- The bandwidth usage of the fog is in the range of 3 KB/s -36 KB/s

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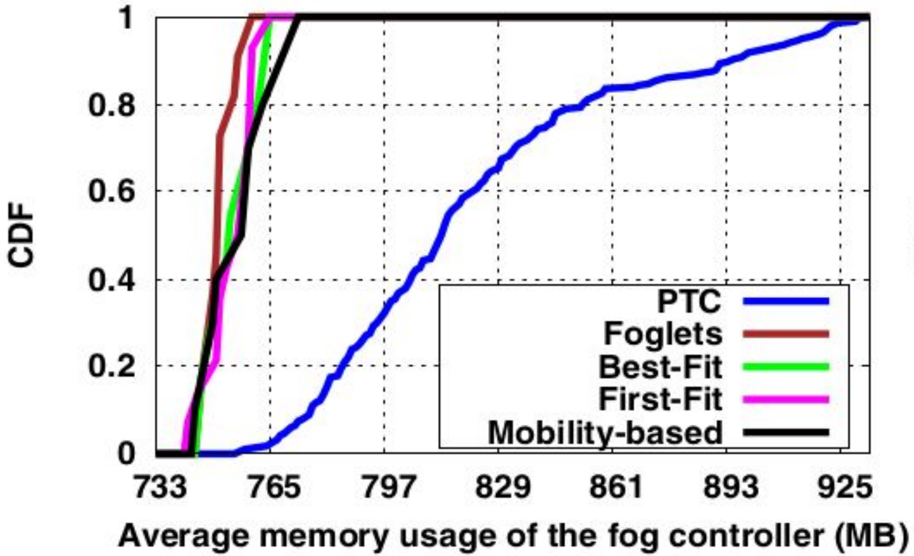
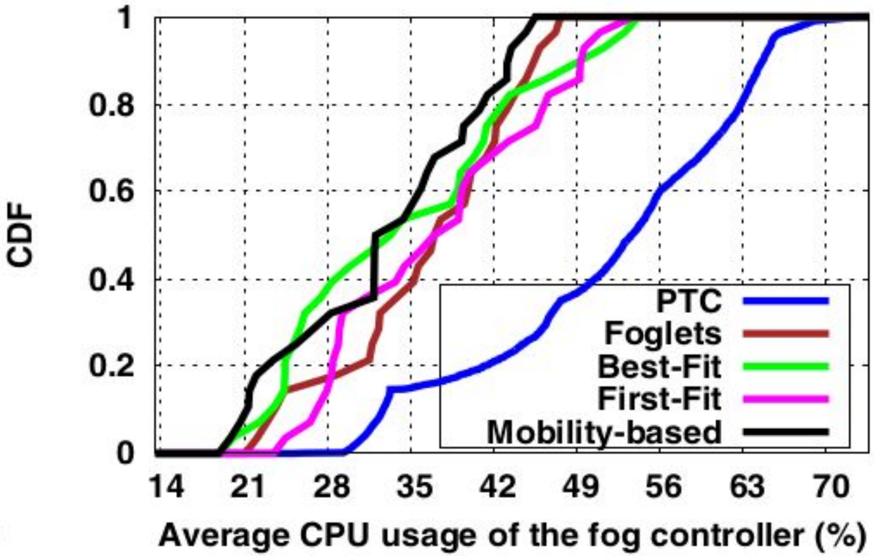
Evaluation in Testbed: Results (contd.)





- PTC has more average memory usage for the controller device due to the overhead of multiple iterations.
- The average CPU usage of the controller device is higher in PTC.

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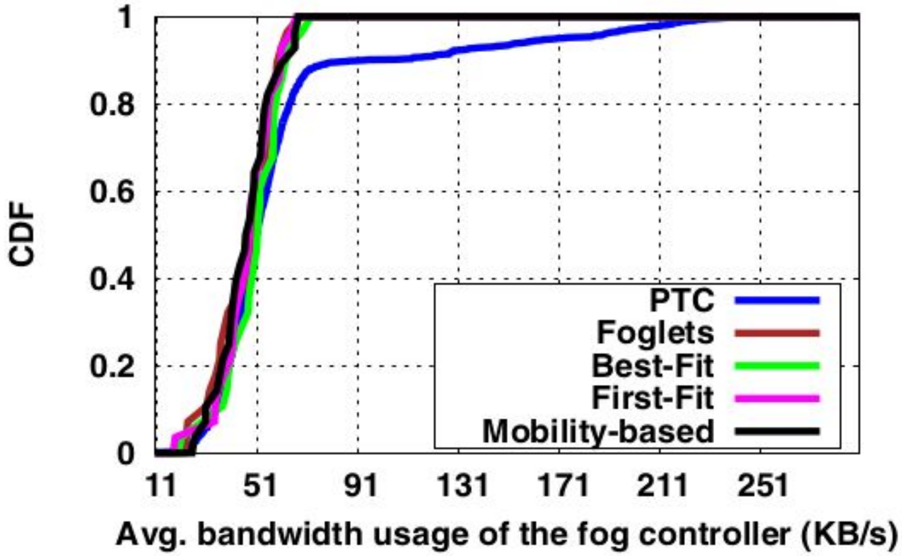
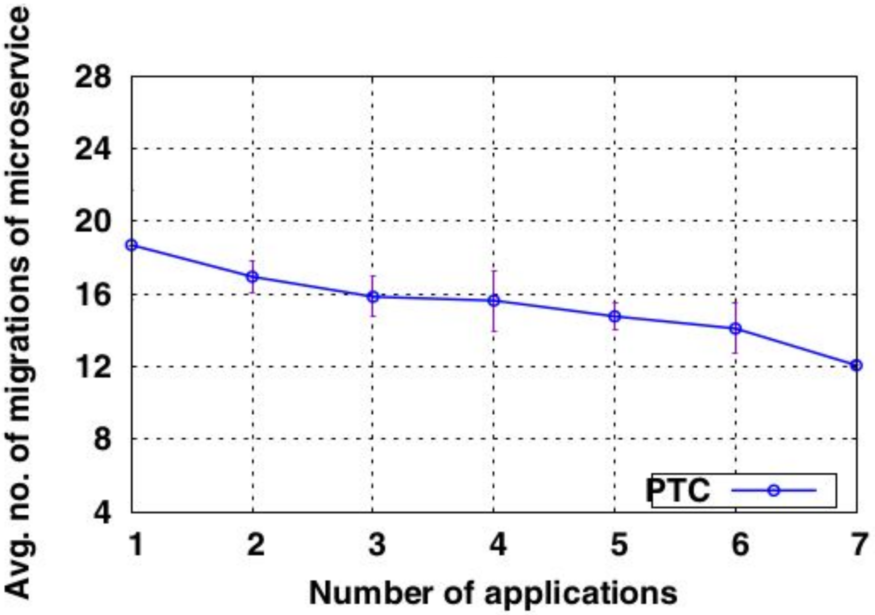
Evaluation in Testbed: Results (contd.)





- The bandwidth usage of the fog controller is in the range of 11 KB/s -291 KB/s
- Though the total number of migrations increases, the average number of migrations decreases with the increase in the number of applications.

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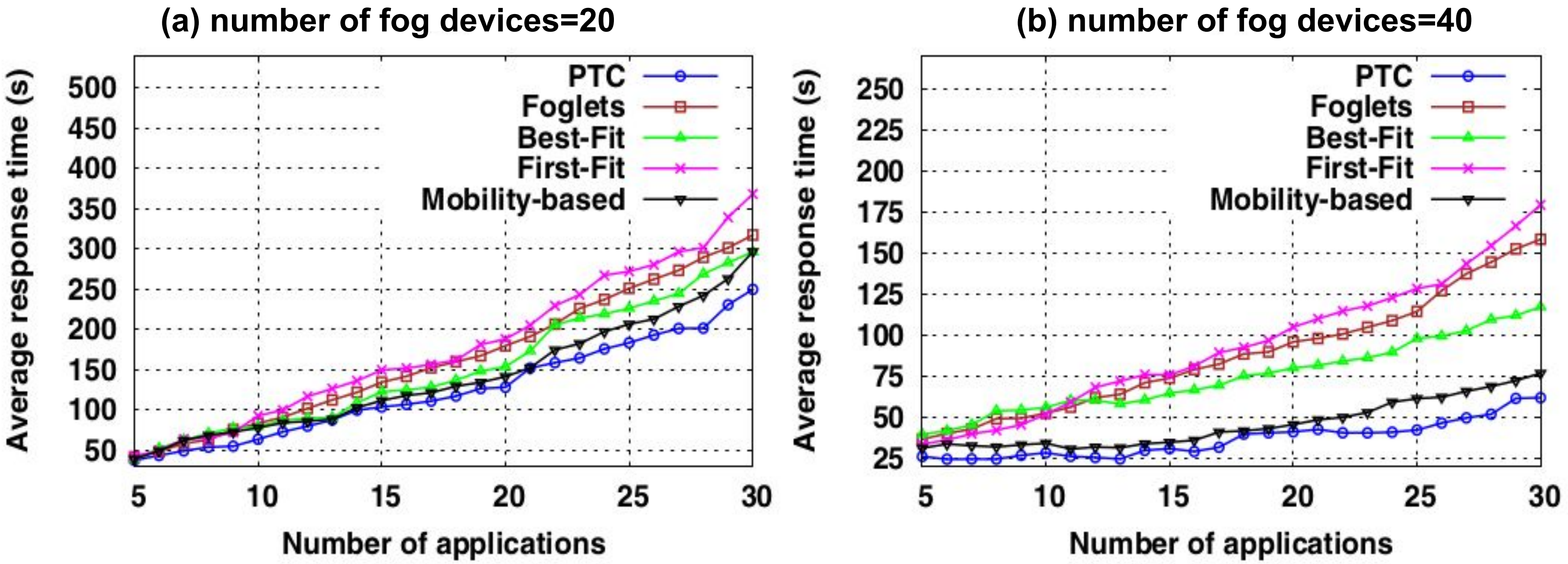
Evaluation in iFogSim Simulator: Results



- The average response time is reduced significantly in PTC, as the number of available fog devices increases.

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Conclusion

- Primary workload of the fog devices needs to be considered.
- The problem of containerized micro-service placement in IoT has been studied.
- We have formulated the micro-service placement problem as an optimization.
- BO-based iterative reinforcement learning mechanism is proposed.
- PTC is tested in an in-house testbed setup as well as in iFogSim simulator.
- It is observed that PTC can minimize the response time of the system.
- In the future, we plan to evaluate performance of PTC under different services.

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Thank You