Dependency and Priority Based Multi-Queue IoT Task Scheduling in Heterogeneous Systems

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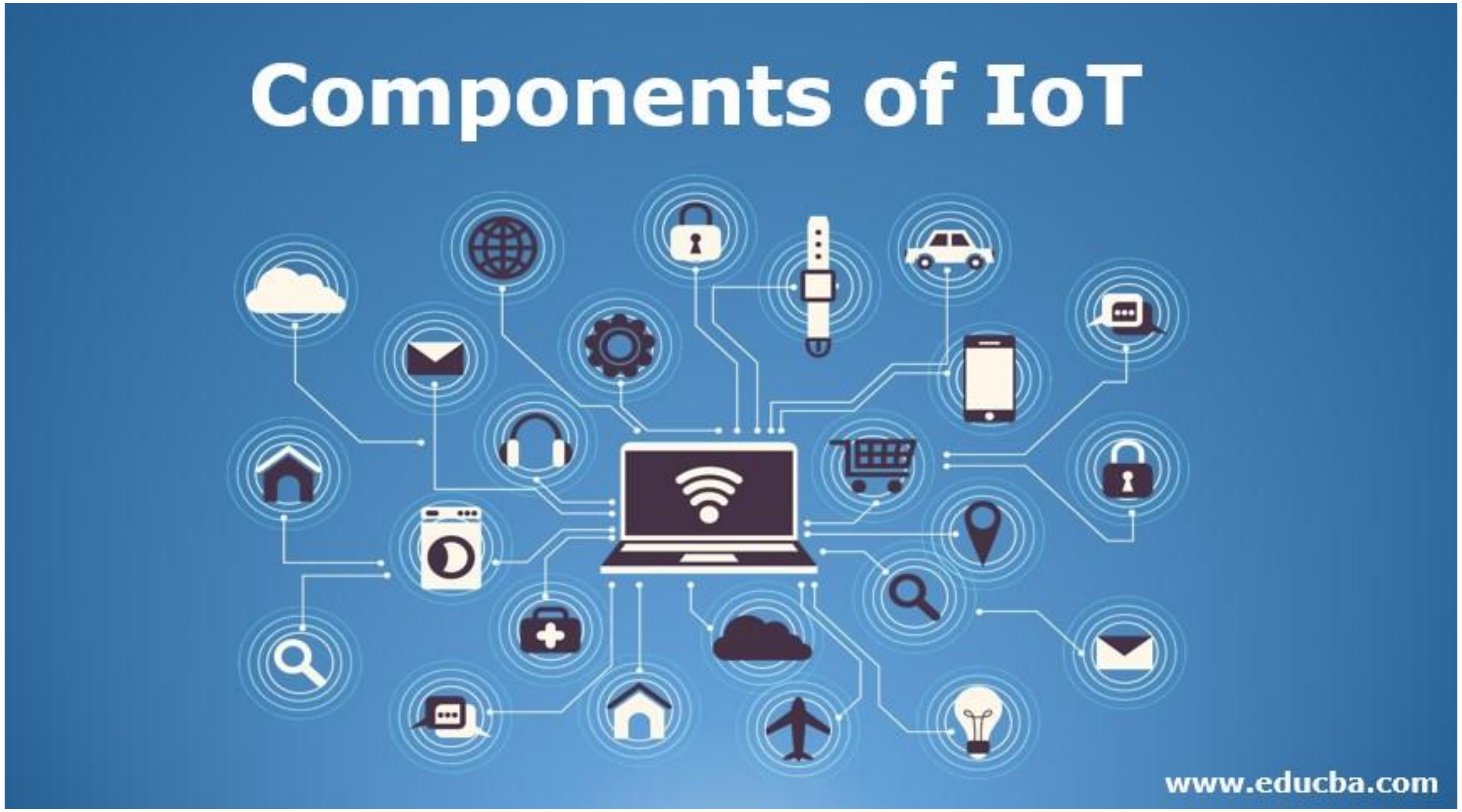
OUTLINE

PRELIMINARIES

INTERNET OF THINGS



A network of physical objects embedded with sensors, software, and other technologies to collect and exchange data over the internet.

TASK

A unit of work that–

- Needs to be completed within a specified timeframe
- Using a finite set of resources
- Involves complex management and processing of large datasets

TASK SCHEDULING

Process of allocating computational tasks to appropriate resources with a goal to –

- Optimize performance
- Minimize response time
- Reduce cost and energy

LIMITATIONS OF IoT DEVICES

- Low computing resources
- Low energy resources
- Limited storage capacity
- Low data rate
- Stringent chip area

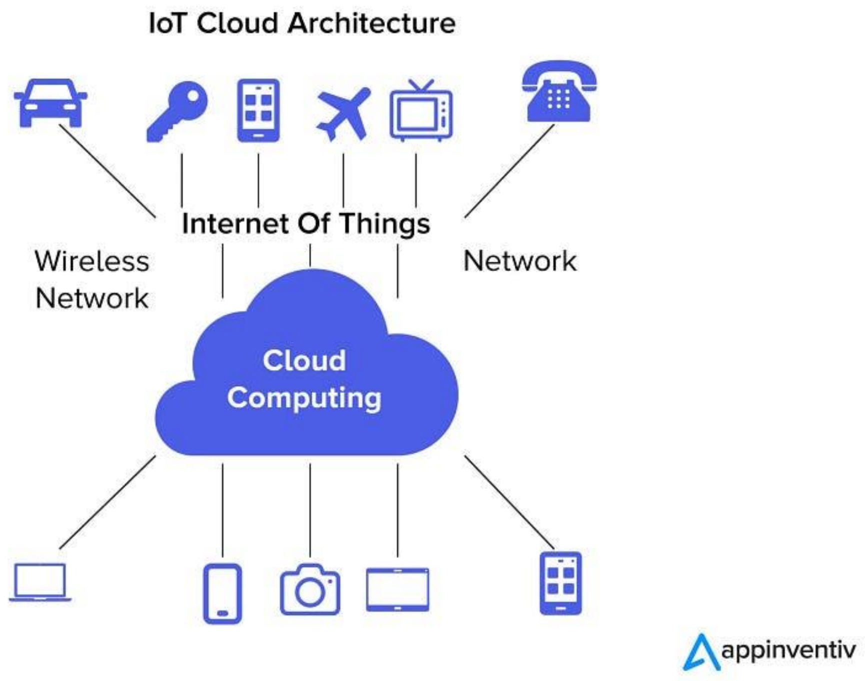
CLOUD COMPUTING

Advantage:

- Can process and analyze the enormous amounts of data produced by IoT devices.

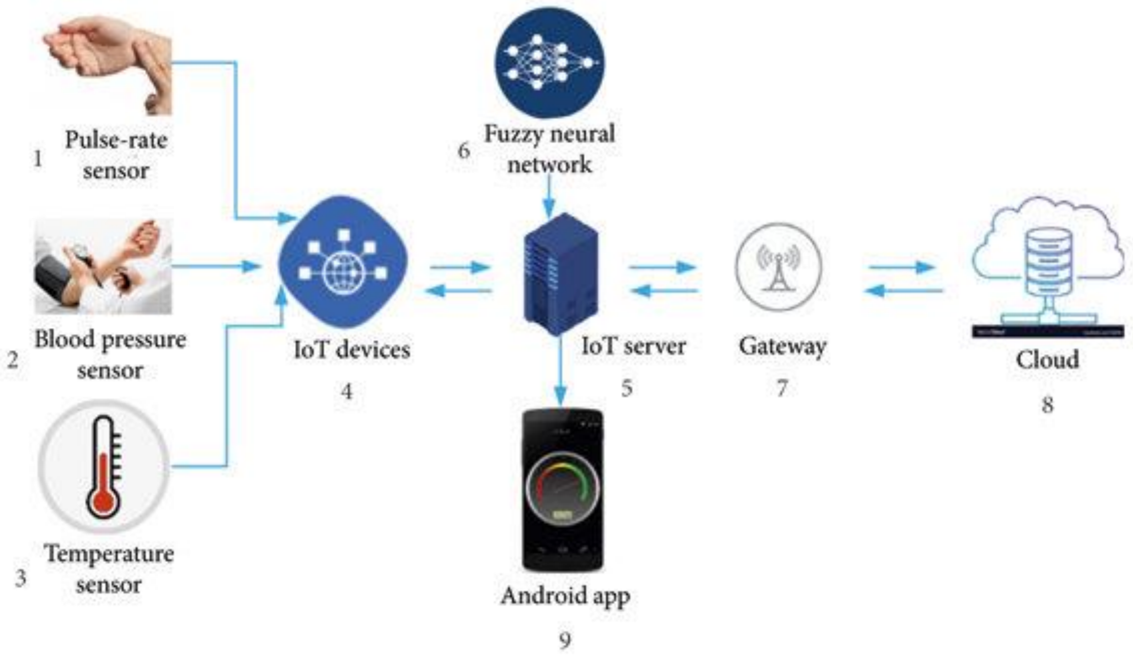
Disadvantage:

- High latency
- Low scalability
- Centralized distribution



DELAY SENSITIVE IoT APPLICATIONS

- Designed to operate within specific time constraints
- Any delays or variations in timing affects their performance or functionality

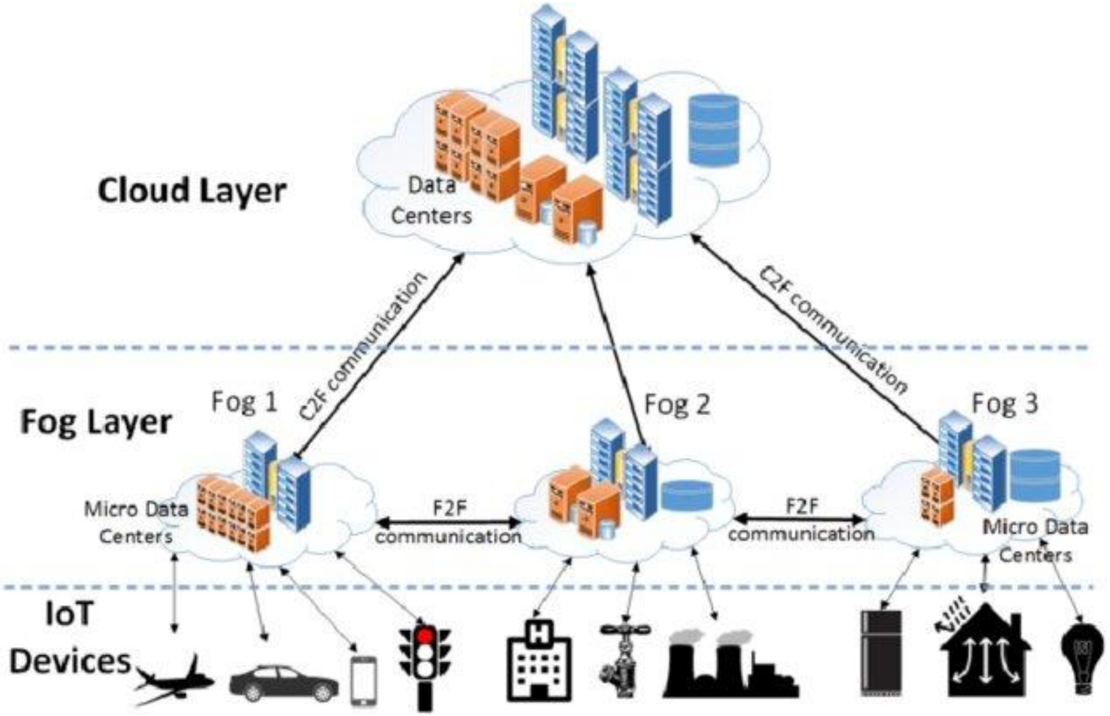


Example: IoT in Healthcare

FOG COMPUTING

Fog Layer:

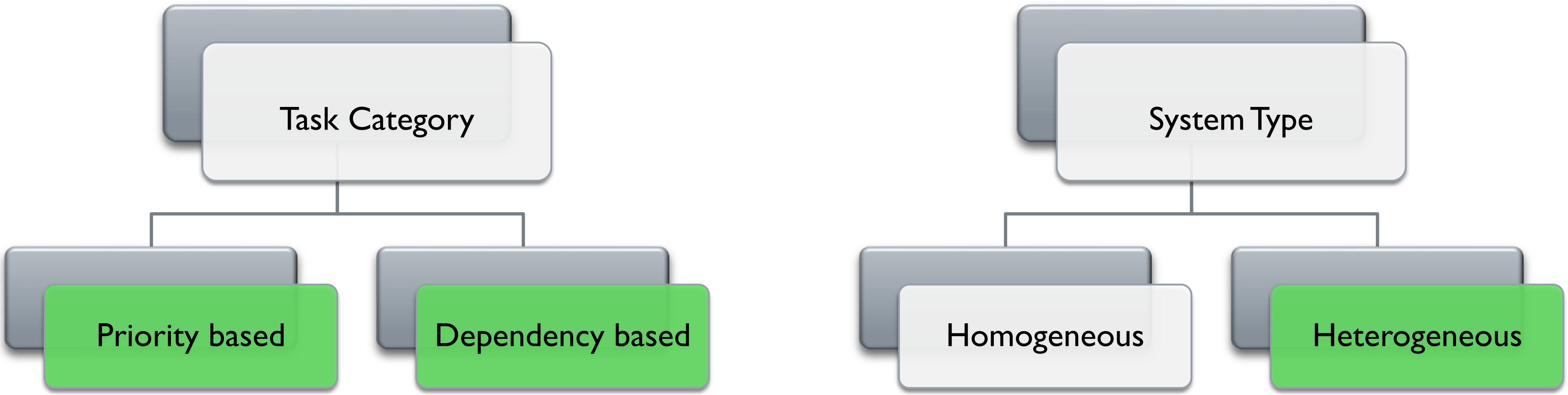
- An decentralized intermediate layer between the IoT devices and the cloud.
- Reduces communication delays compared to cloud-only architecture.
- Enables the implementation of many latency-sensitive IoT services.
- Lower storage and processing capabilities than the cloud



IoT TASK WORK CATEGORIES

- Task processing location / Architecture
  - Cloud
  - Fog-cloud
- Fog Architecture
  - Resource Allocation
  - Scheduling Algorithm

IoT TASK WORK CATEGORIES



IoT TASK WORK CATEGORIES

DOMAIN FOR OUR WORK

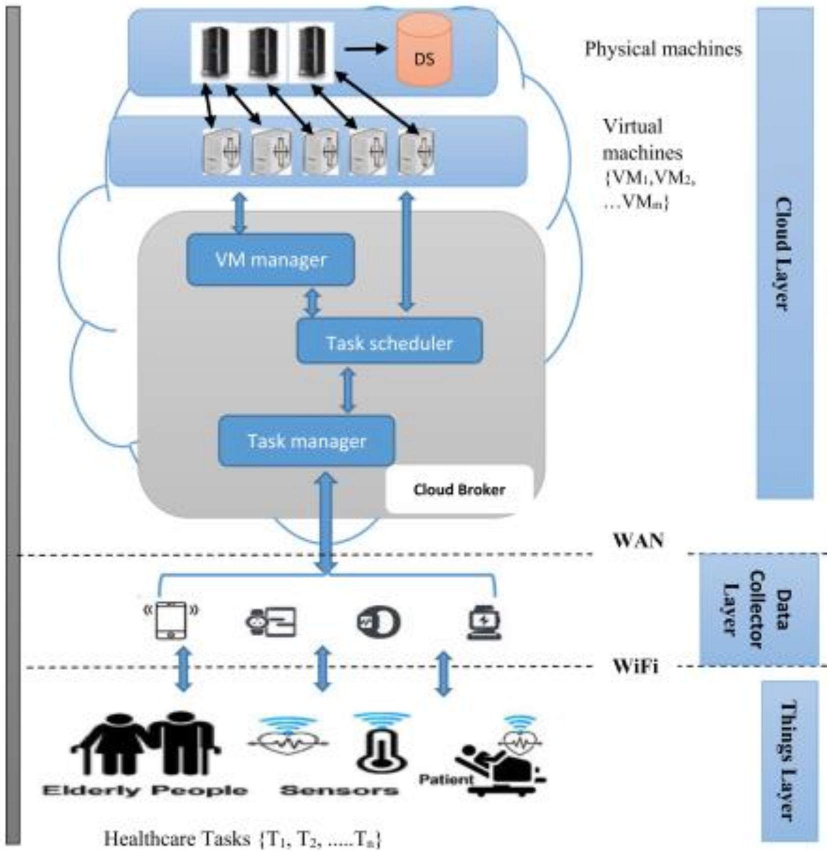
- Dynamic Batch Scheduling
- Priority and Dependency Based Task
- Heterogeneous System
- Fog Computing

LITERATURE REVIEW

PRIORITIZED SCHEDULING TECHNIQUE FOR HEALTHCARE TASKS IN CLOUD COMPUTING [1]

Key Contributions:

- Prioritized Sorted Task-Based Allocation Technique
- Scheduling occurs in **cloud layer**
- Tasks are first assigned into **multi-queue** depending on their priority value
- Task with higher priority and higher length is allocated to higher capacity VM **(heterogeneous)**



Cloud (Three layer) Architecture

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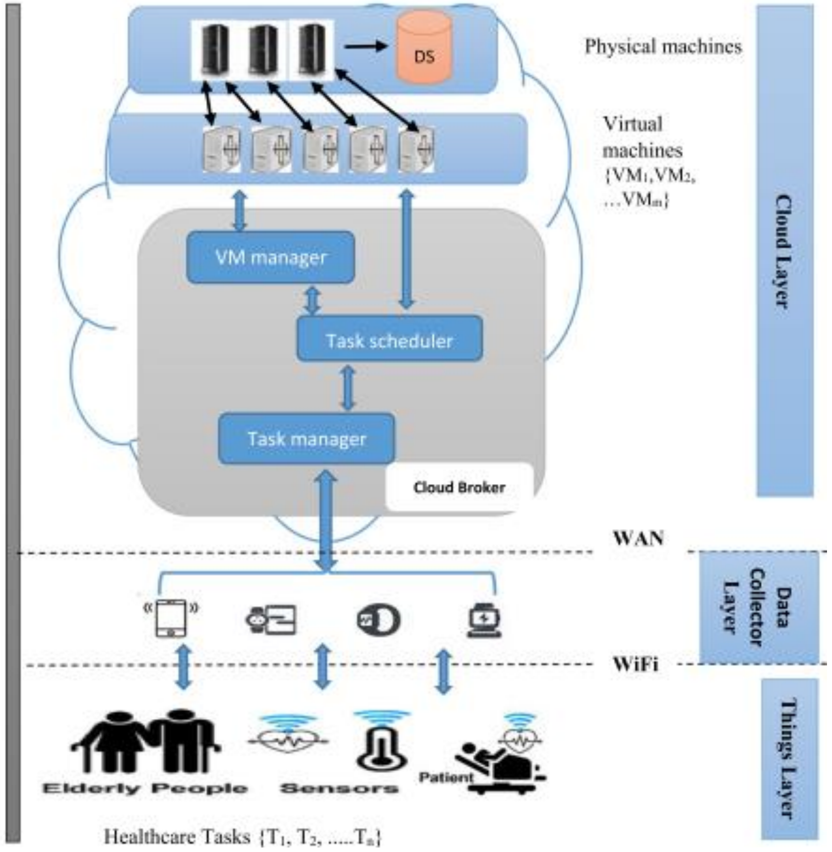
Limitations:

- Did not consider **Fog**
- Did not consider **Task dependency**

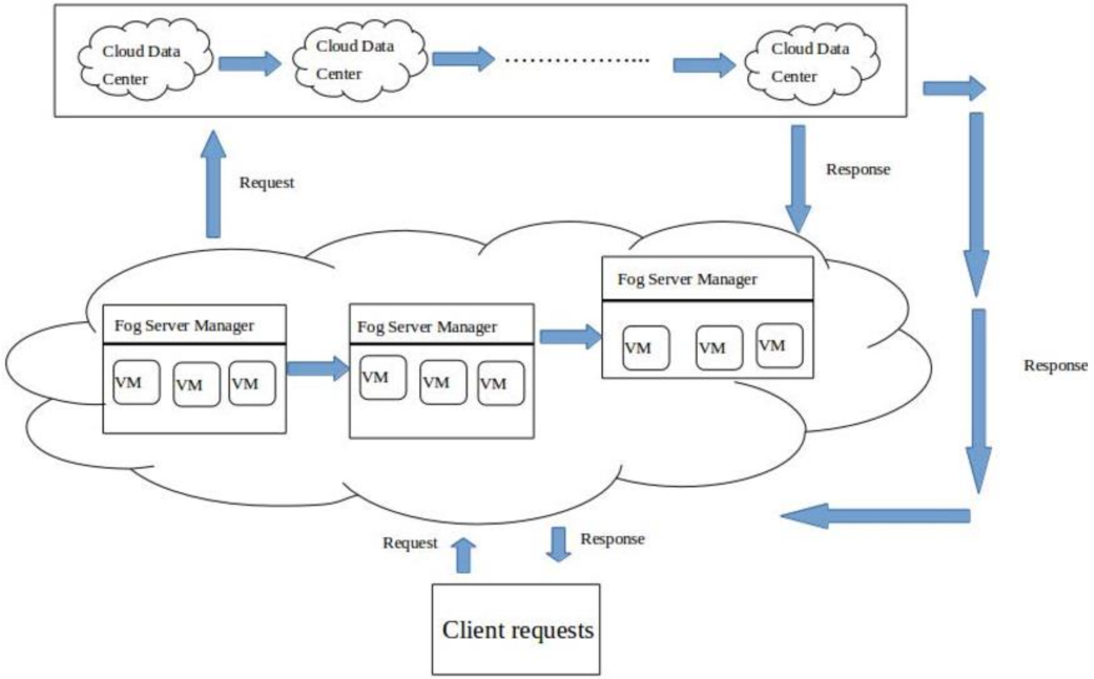


Cloud (Three layer) Architecture

PRIORITIZED TASK SCHEDULING IN FOG COMPUTING [2]

Key Contributions:

- Priority based **multi-queue** task scheduling algorithm
- Scheduling occurs in **fog layer**
- Assigns task to nearest fog node
- Task is sent to the cloud if the fog layer does not have sufficient resource



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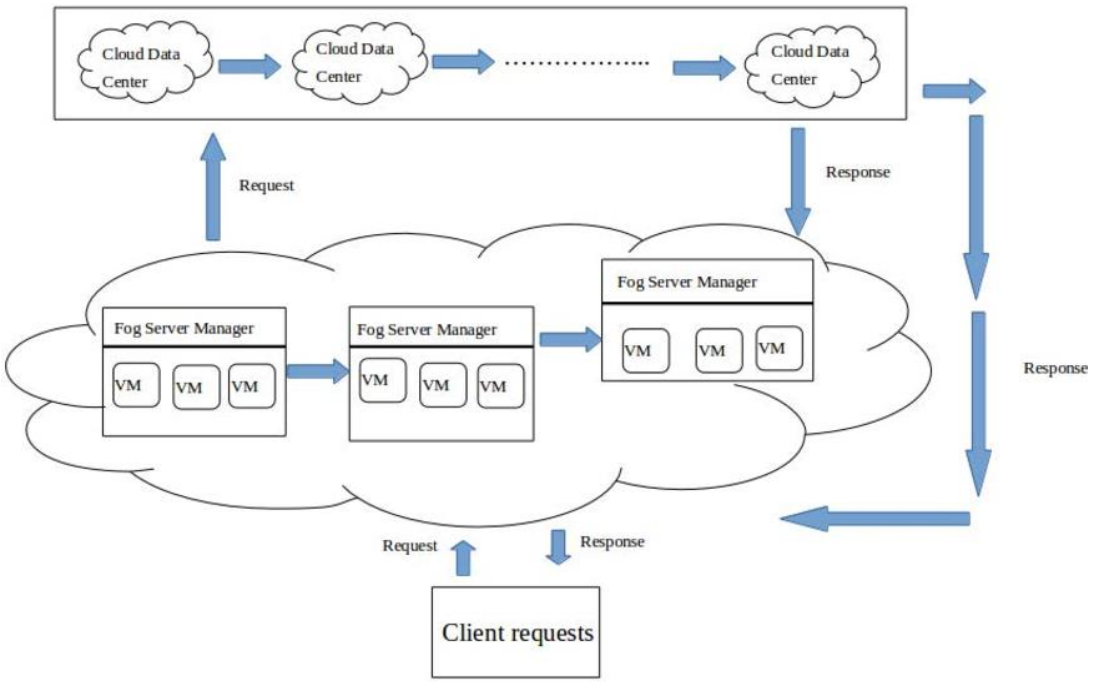
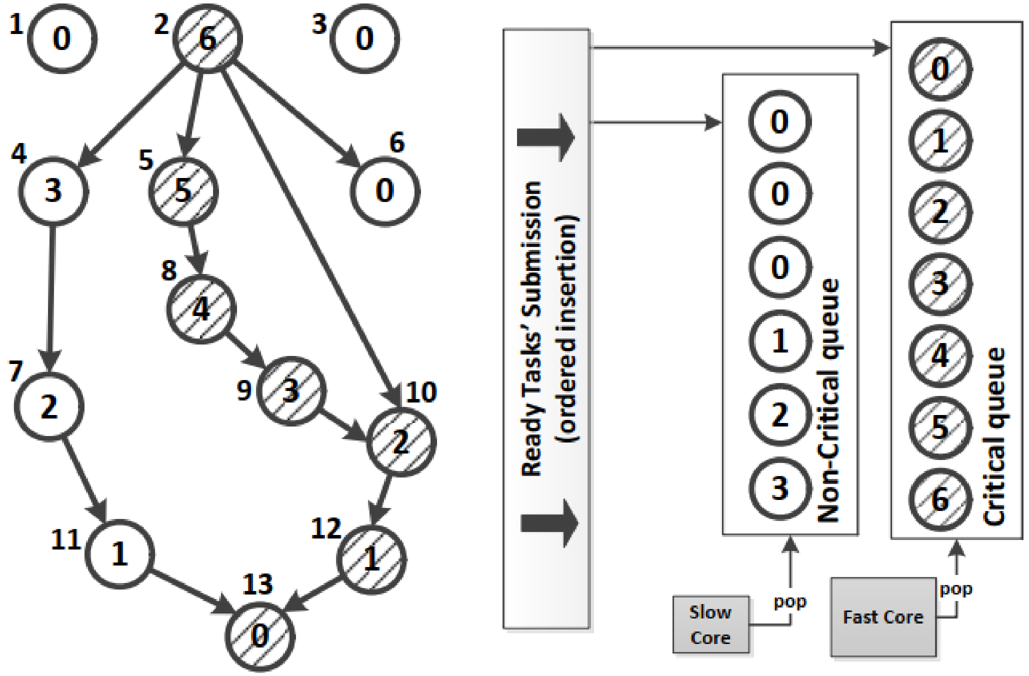


Fog-Cloud (Three layer) Architecture

CRITICALITY-AWARE DYNAMIC TASK SCHEDULING FOR HETEROGENEOUS ARCHITECTURES [3]

Key Contributions:

- Criticality-aware **dynamic** task scheduler (CATS)
- **Heterogeneous multi-core** (slow and fast) platform
- Tasks are considered critical if they are part of the longest path in the in-flight dynamic state of the dependency graph.



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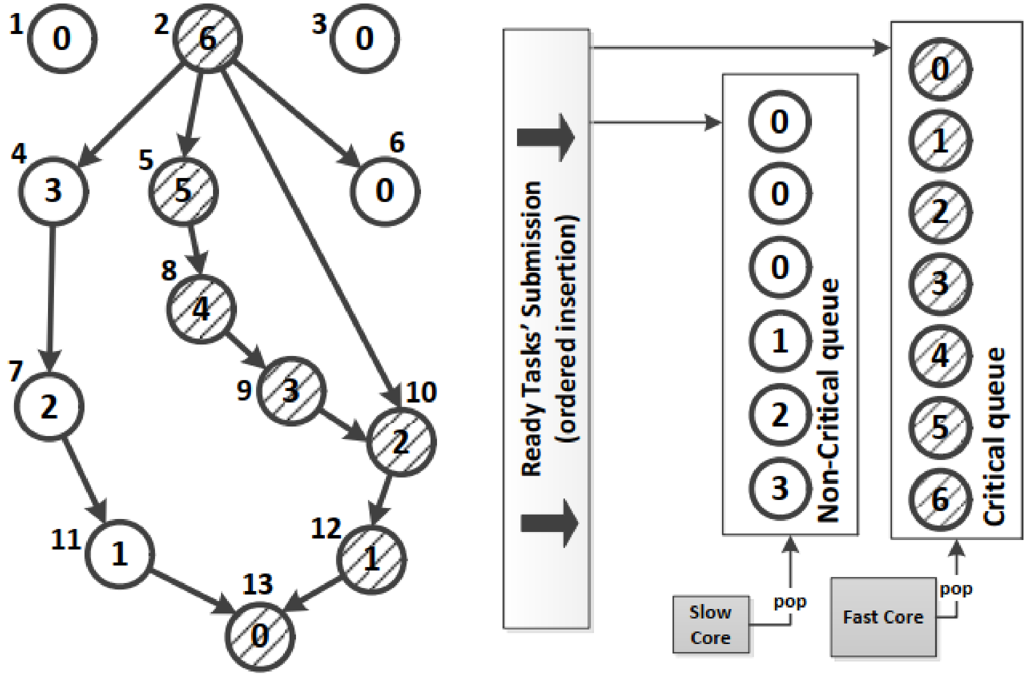
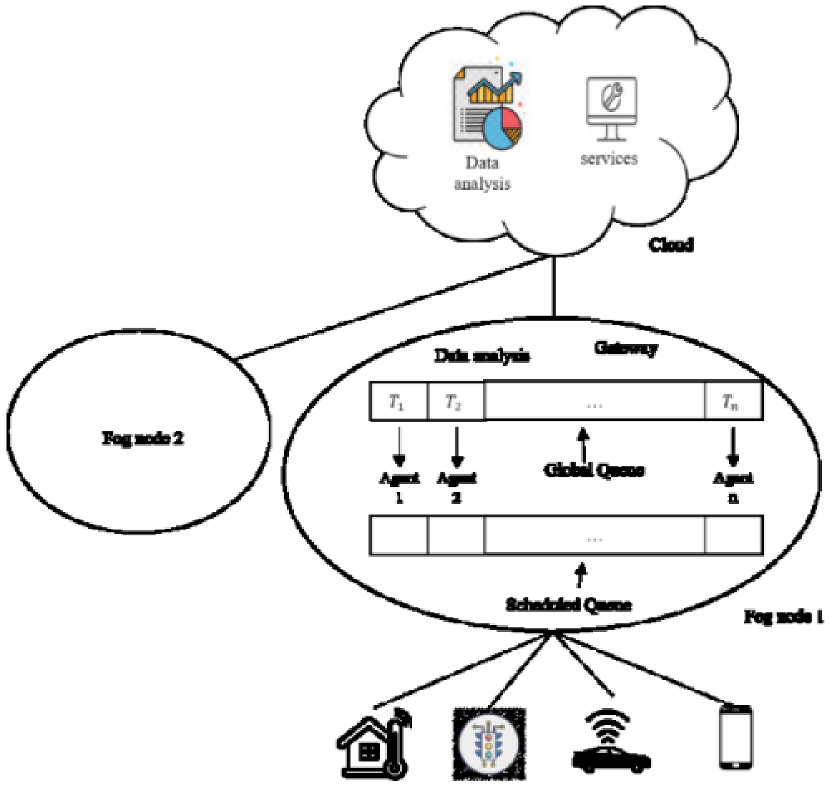
Limitations:

- Only one dependency chain is given priority



A MULTI-AGENT BASED MODEL FOR TASK SCHEDULING IN CLOUD-FOG COMPUTING PLATFORM [4]



Key Contributions:

- Multi-agent based **non-preemptive** task scheduler
- Scheduling occurs in **fog layer**
- **Single-queue** implementation
- Tasks are sorted according to their importance values (waiting time, status and priority values of dependent tasks) and also the number of resources required to be performed

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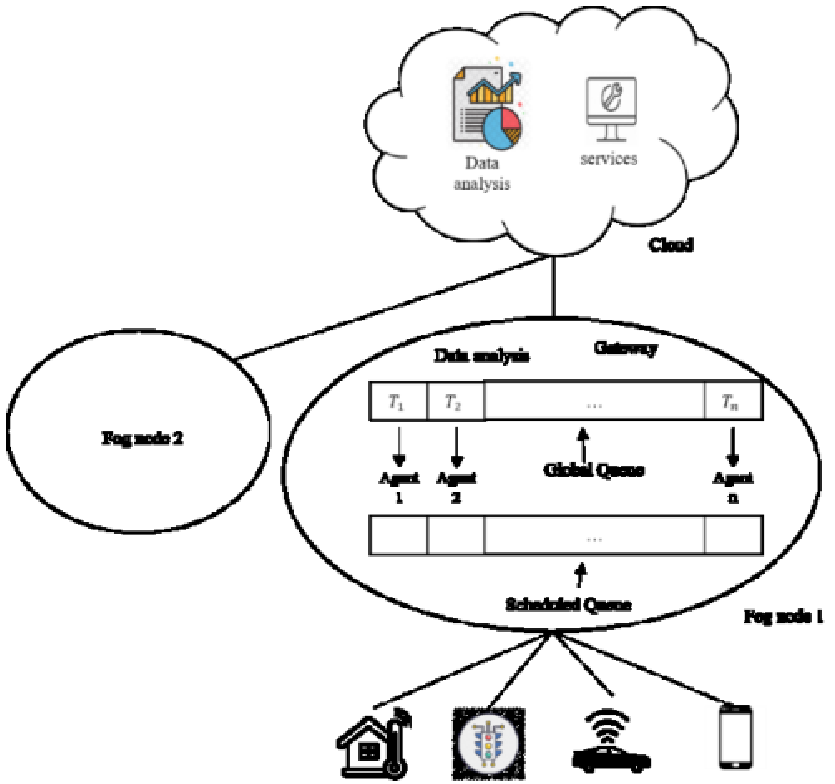
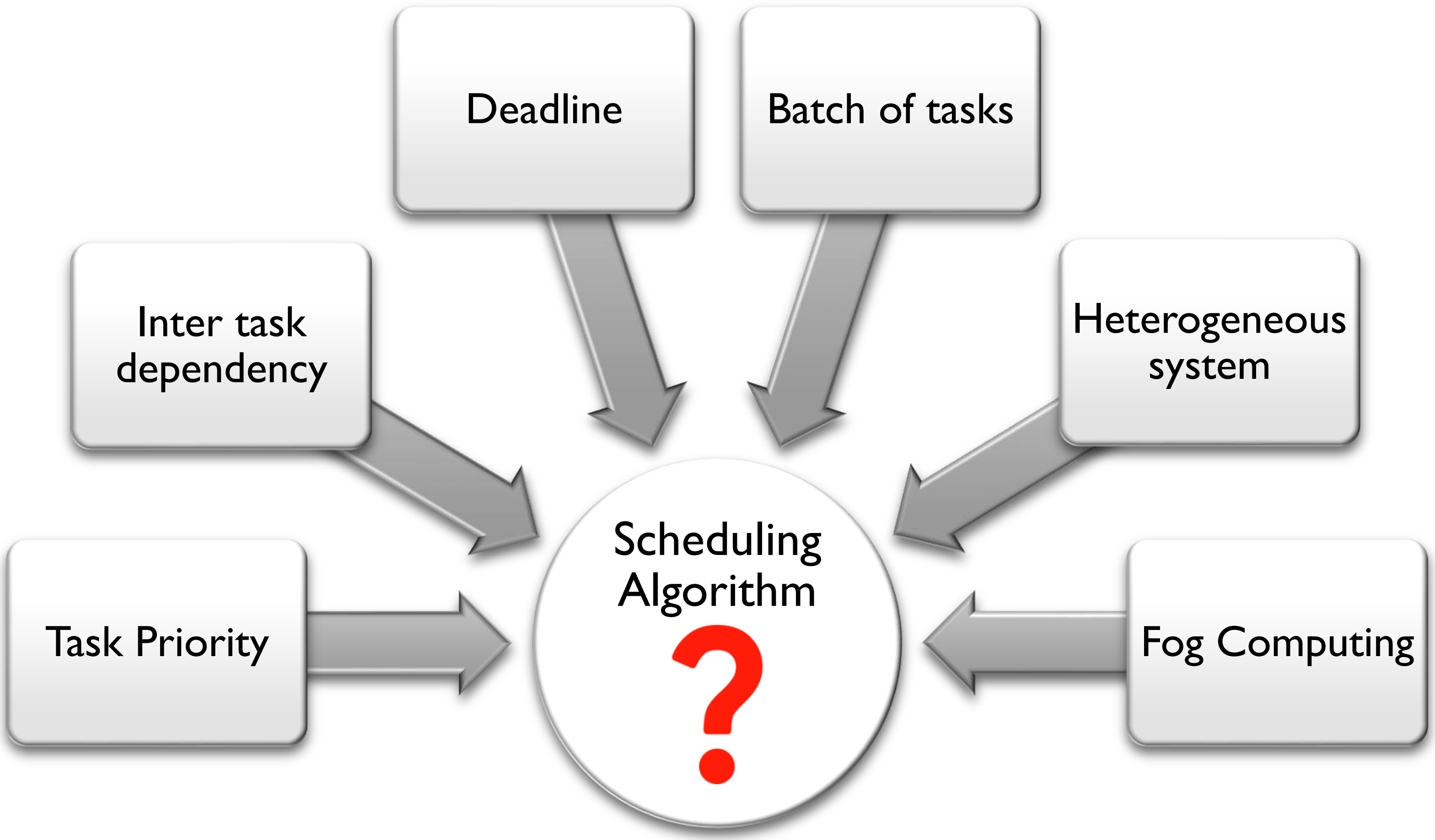


Limitations:

- Did not consider **Multi-queue**
- **Single VM System**

MOTIVATION

MOTIVATION


Deadline
Batch of tasks
Inter task dependency
Heterogeneous system
Task Priority
Scheduling Algorithm
?
Fog Computing

PROBLEM DEFINITION

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Design and Implementation of an **IoT Task Scheduling Algorithm** that -

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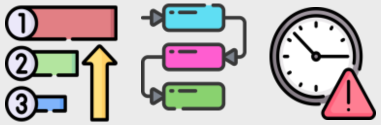
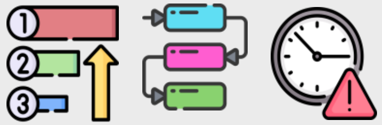


Considers **Task Priority, Inter-Dependency and Deadline**

PROBLEM DEFINITION

Design and Implementation of an **IoT Task Scheduling Algorithm** that -



Considers **Task Priority, Inter-Dependency and Deadline**

Considers **Batch of Tasks for Dynamic Resource Assignment**

PROBLEM DEFINITION

Design and Implementation of an **IoT Task Scheduling Algorithm** that -

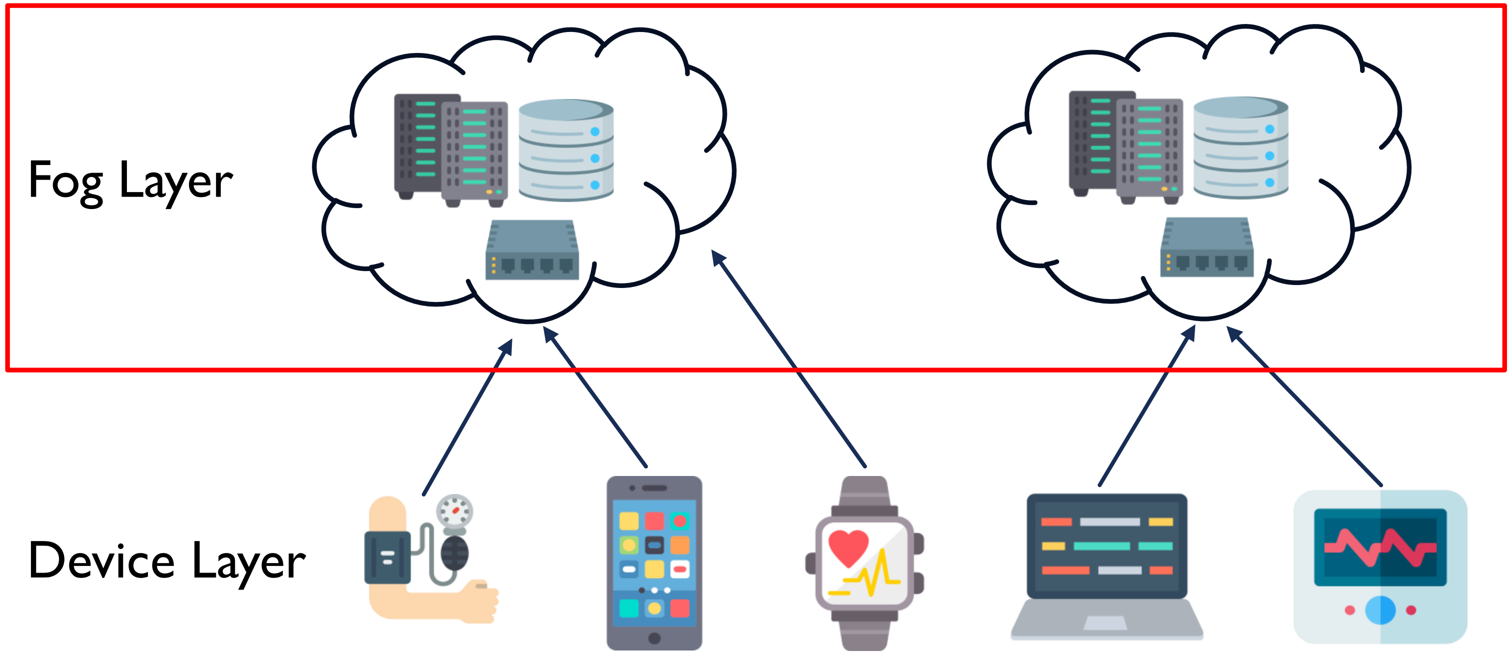
- Considers **Task Priority, Inter-Dependency and Deadline**
- Considers **Batch of Tasks for Dynamic Resource Assignment**
- Introduces a **Numerical Scoring Mechanism** incorporating task priority and dependency

OUR CONTRIBUTION

- Designing and Implementing a **Dynamic Batch Scheduling Algorithm** for **Delay-Sensitive** IoT Tasks with Varying **Priorities and Inter-task Dependencies**
- Introducing a **Numerical Scoring Mechanism** for Every Task Incorporating Task Priority and Dependencies
- Utilizing **Multi Queues** in **Heterogeneous Fog Computing System**

METHODOLOGY

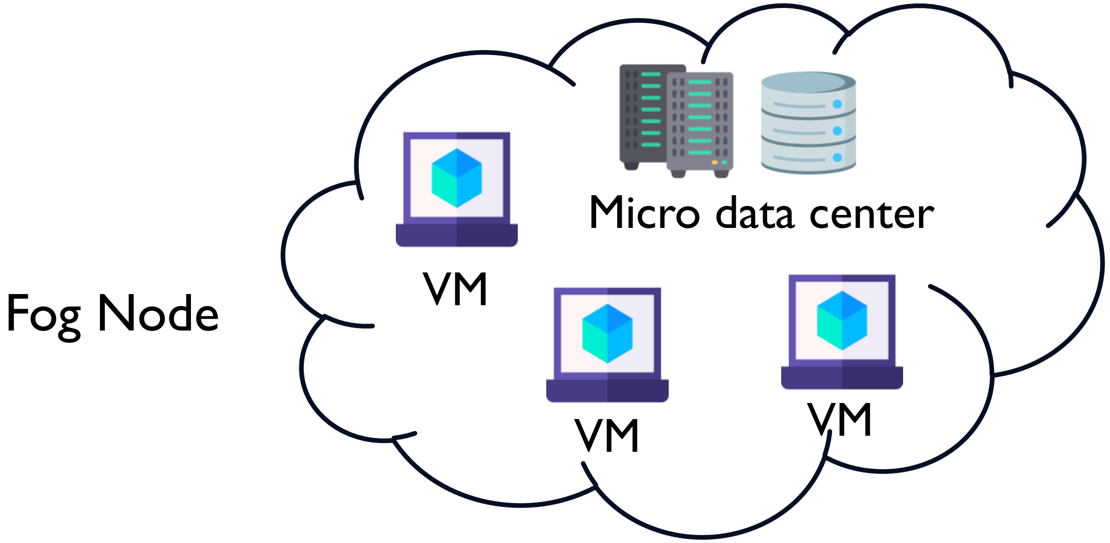
SYSTEM ARCHITECTURE



FOG LAYER

- Consists of several Fog Nodes.
- Task from IoT devices are sent to nearest Fog node.

FOG NODE



Each fog node is composed of –

- a micro data center
- Several heterogeneous VMs

TASK GENERATION

We have generated a **Synthetic Taskset** for our purpose that has the following properties –

- Task ID
- Priority Level (High=1, Medium=2, Low=3)
- MI (Million Instructions referred from Benchmark GoCJ_Dataset)
- Deadline (Process Time+Delay Time)
- Predecessor Task List

TASK GENERATION

We have generated a **Synthetic Taskset** for our purpose that has the following **hyperparameters** –

- Number of Total Tasks in a Batch
- Dependent Task Ratio
- Task Priority Level Ratio $[w_H + w_M + w_L = 1]$
- Number of Predecessor for a Task (min, max)

ALGORITHM OVERVIEW

A fog node receives a batch of tasks

↓

Task priority is updated if needed

↓

Priority-Dependency score is calculated for every task

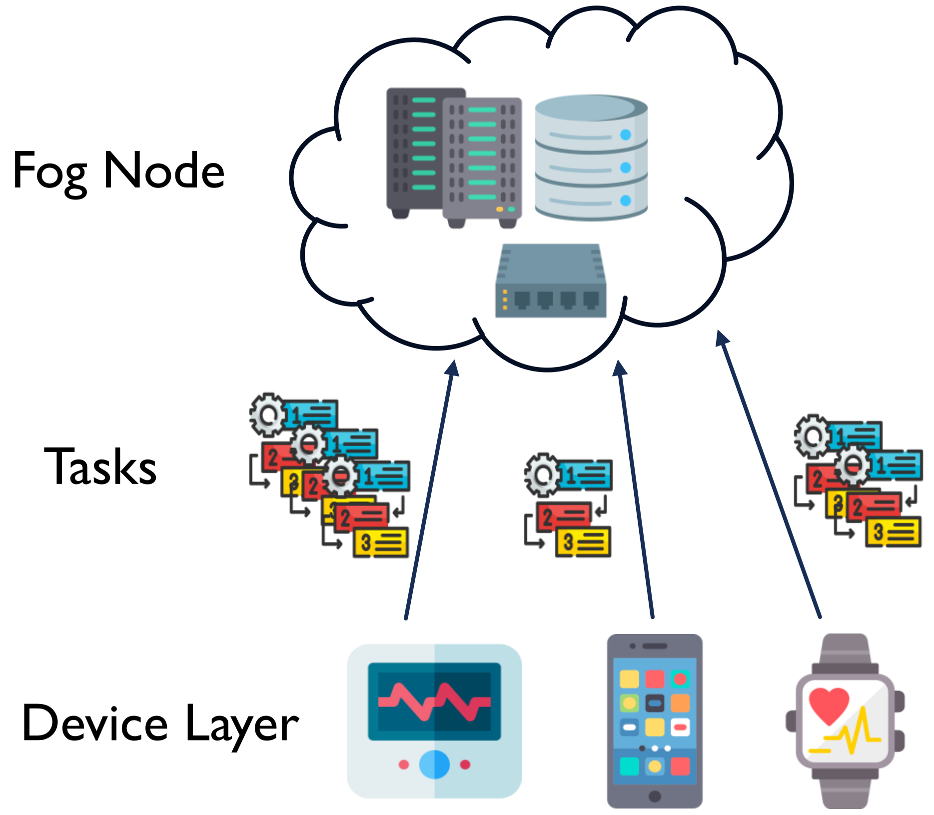
↓

Tasks are inserted into respective high, mid and low priority level queues (waiting and ready)

↓

Task is selected from ready queue based on deadline and PD_score and sent to the respective VM for execution

BATCH OF TASK ARRIVAL



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TASK PRIORITY UPDATE

Task Priority

- Original Priority
- Imposed Priority

Why Imposed Priority?

Prevent lower priority parent from causing higher priority child to miss deadline

A fog node receives a batch of tasks

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UPDATE TASK PRIORITY

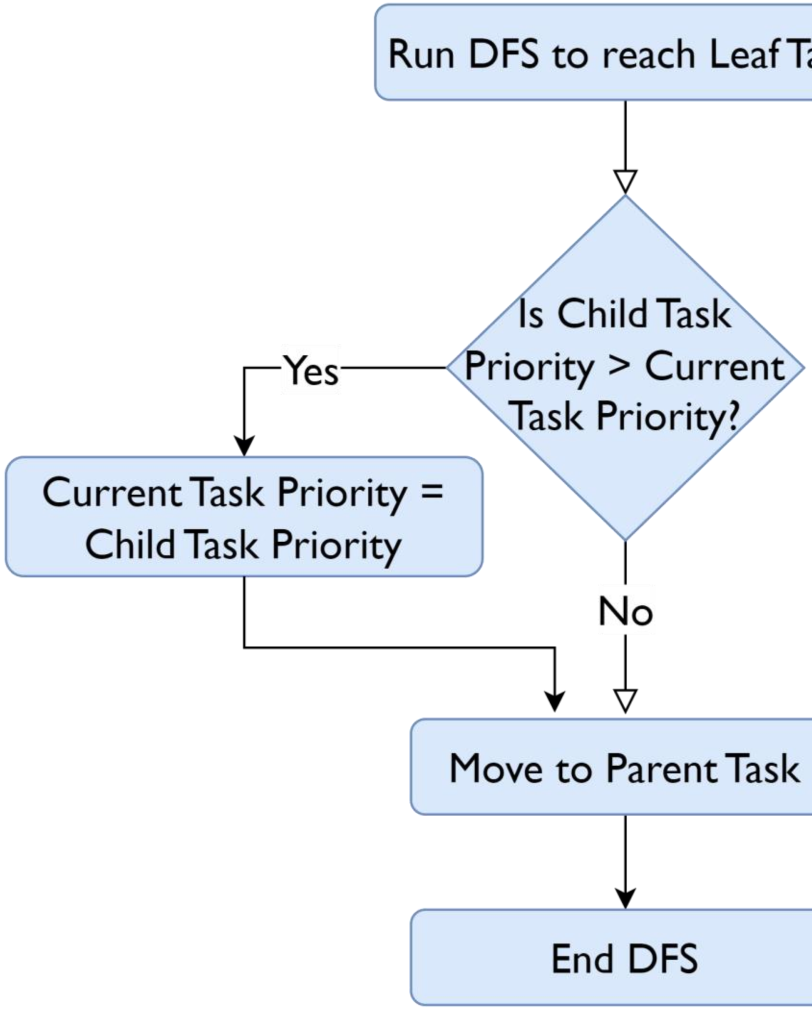

Fig: Task Priority Update Flowchart

UPDATE TASK PRIORITY

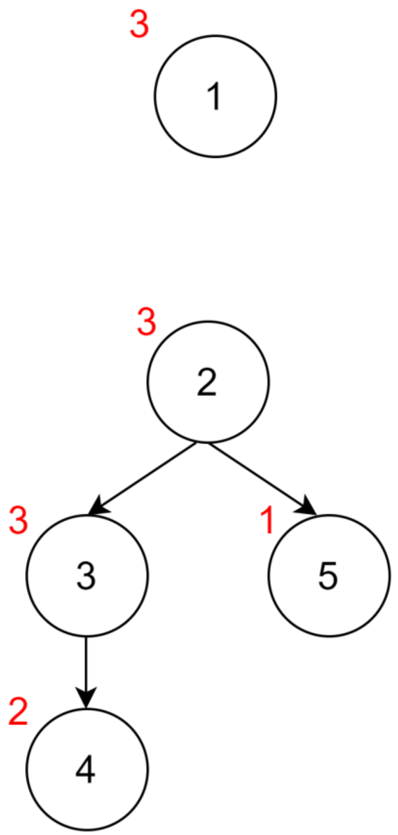

Fig: DAG Example

Task ID	Original Priority
1	3
2	3
3	3
4	2
5	1

UPDATE TASK PRIORITY

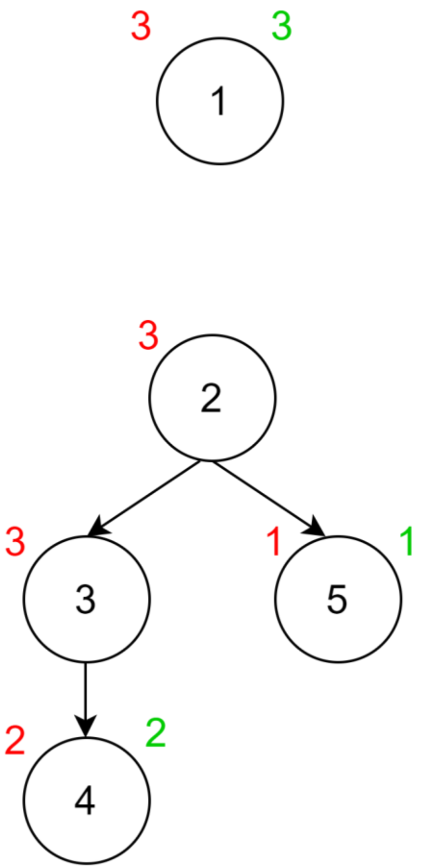

Fig: DAG Example

Task ID	Original Priority	Imposed Priority
1	3	3
2	3	
3	3	
4	2	2
5	1	1

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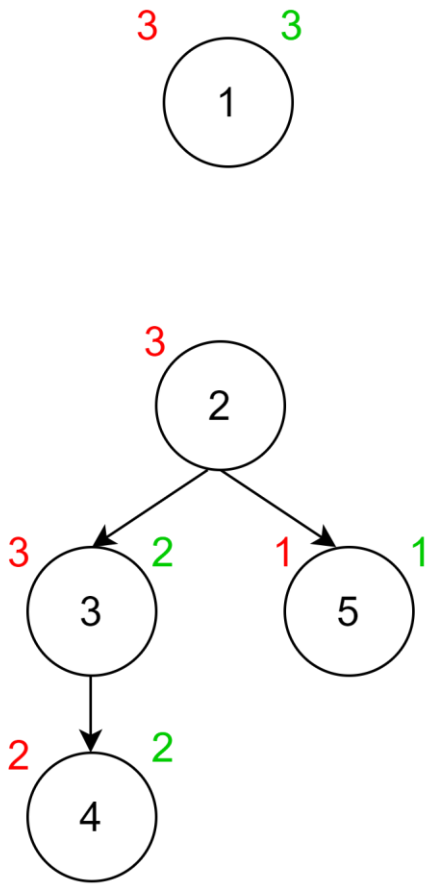

Fig: DAG Example

Task ID	Original Priority	Imposed Priority
1	3	3
2	3	1
3	3	2
4	2	2
5	1	1

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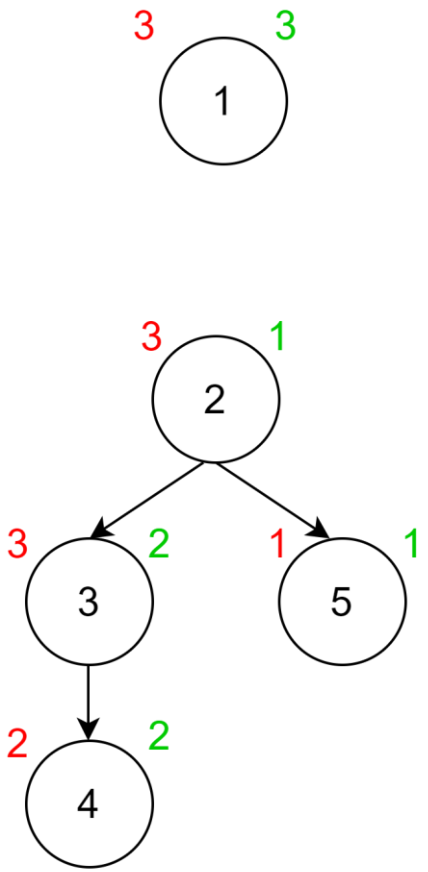

Fig: DAG Example

Task ID	Original Priority	Imposed Priority
1	3	3
2	3	1
3	3	2
4	2	2
5	1	1

PRIORITY-DEPENDENCY SCORE (PD_SCORE) CALCULATE

Set PD_Score = 0

PD_Score += ChildTask.PD_Score() + (4-ChildTask.Priority())

Current Task PD_Score = PD_Score

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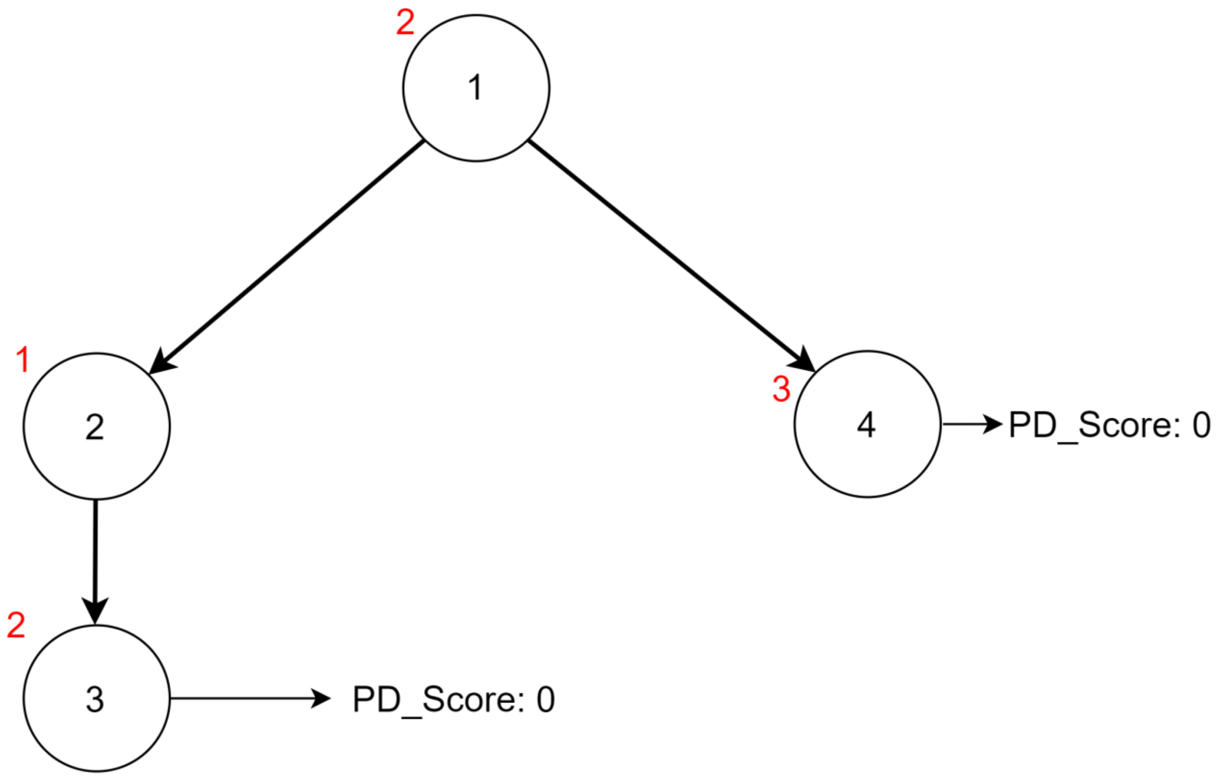

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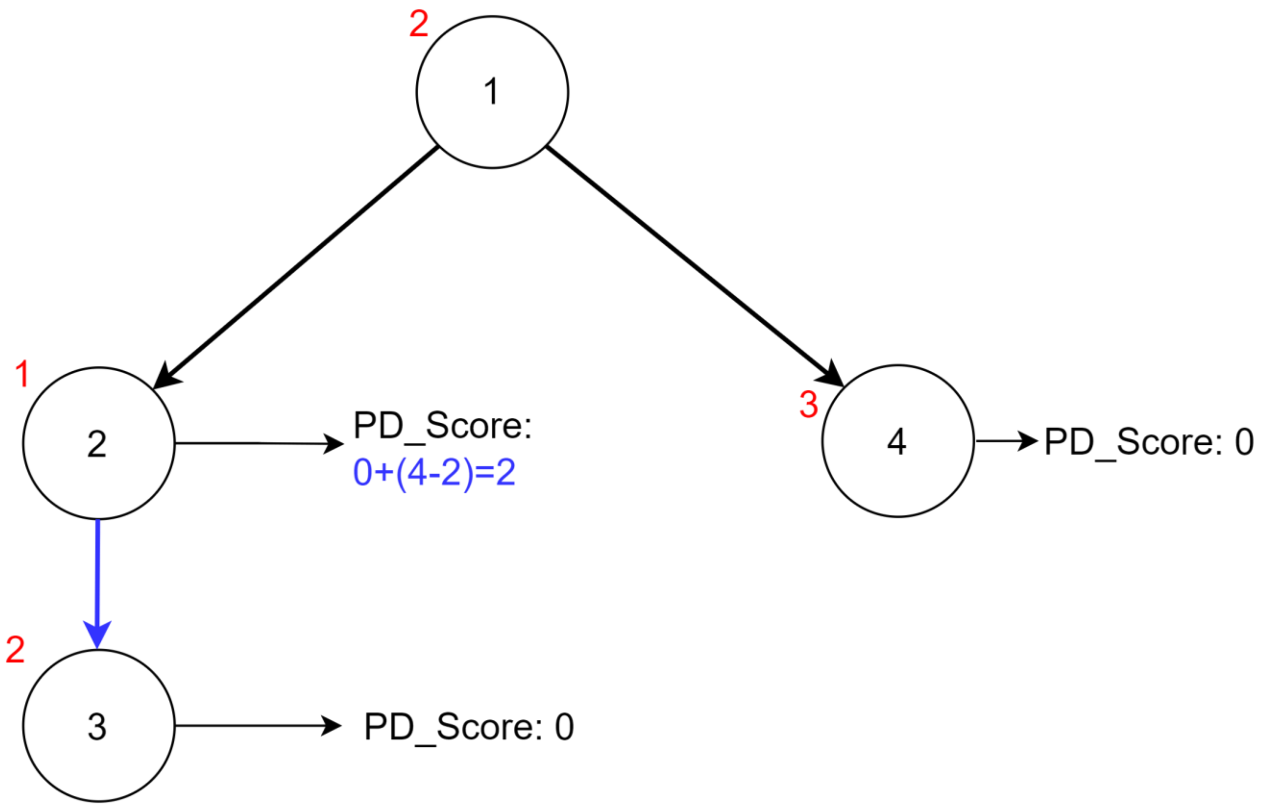

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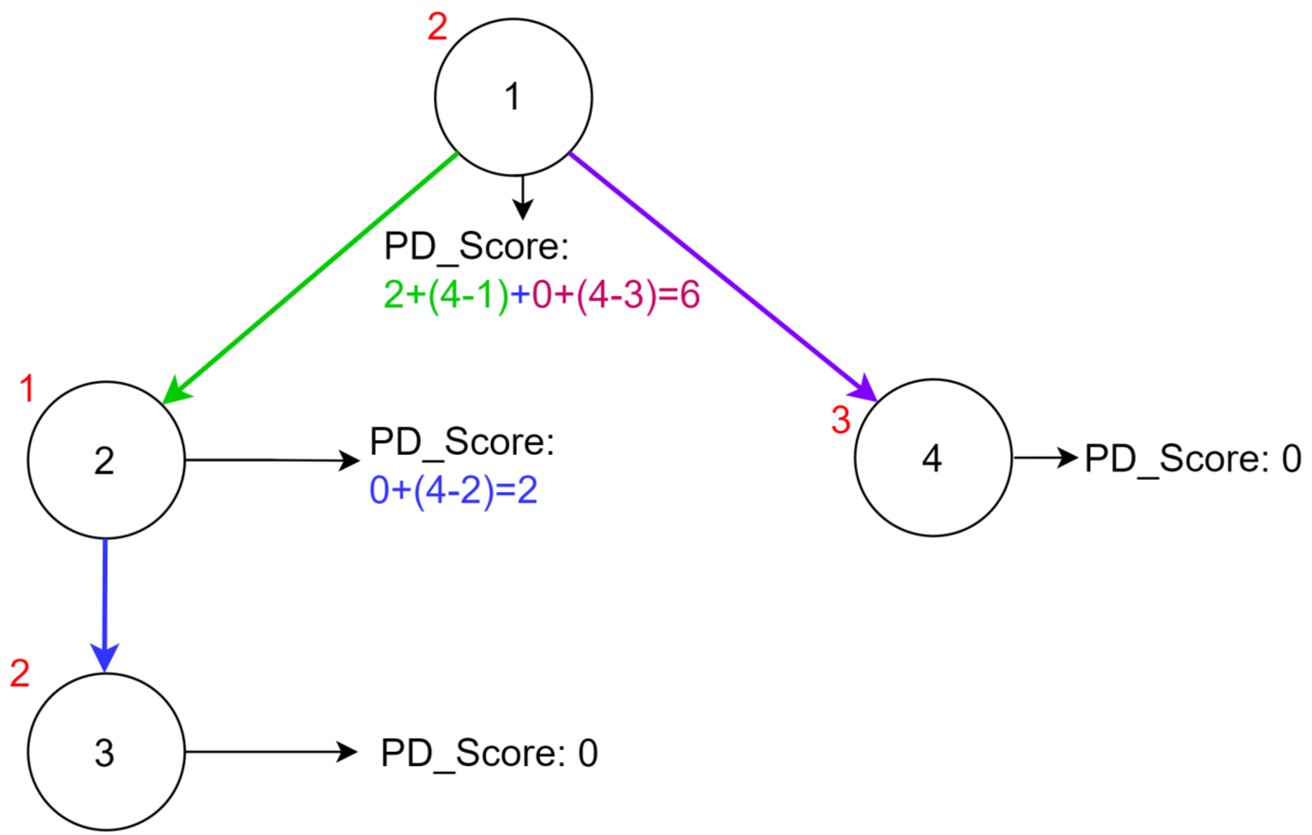
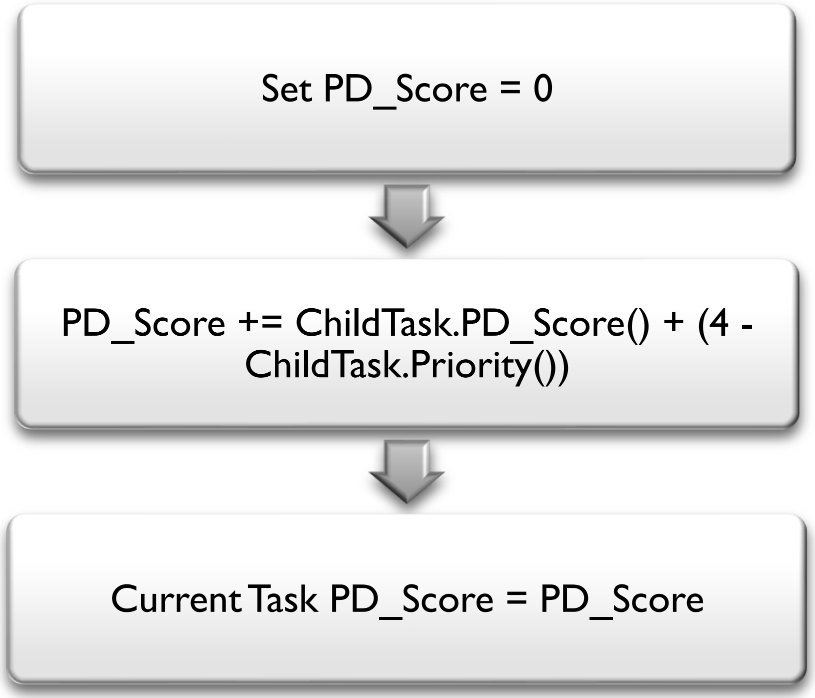
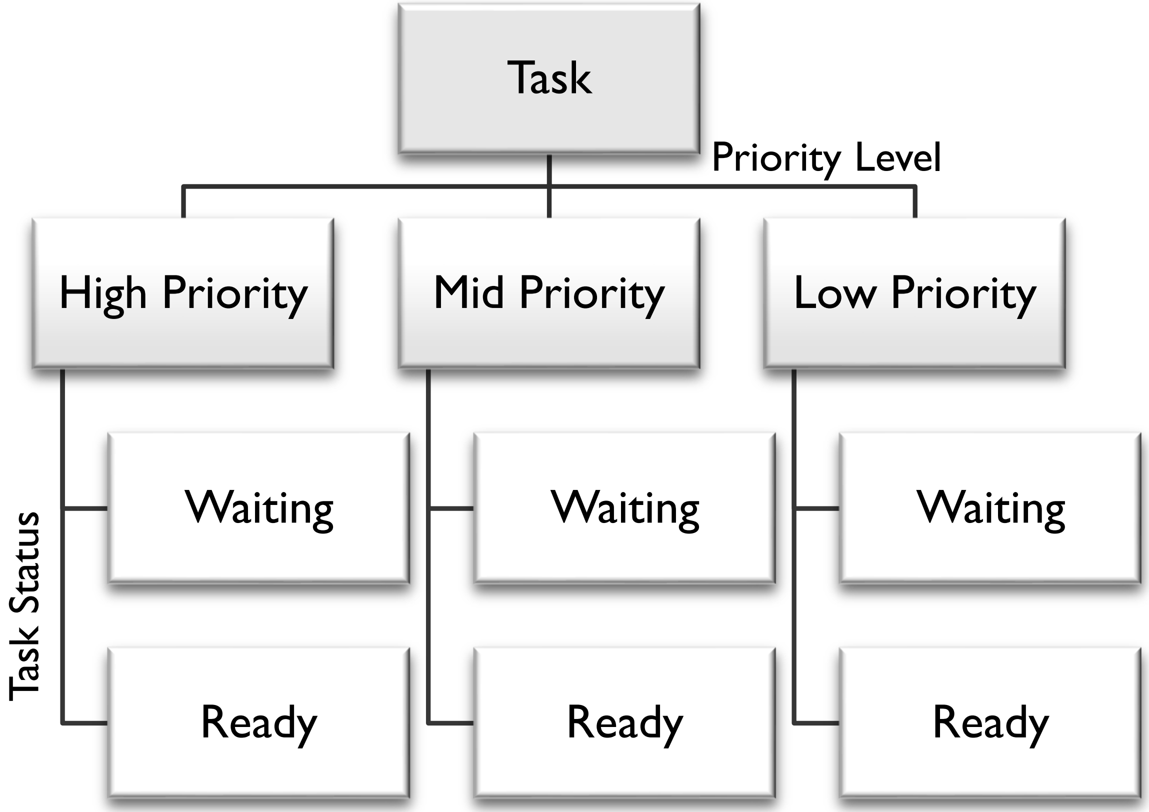
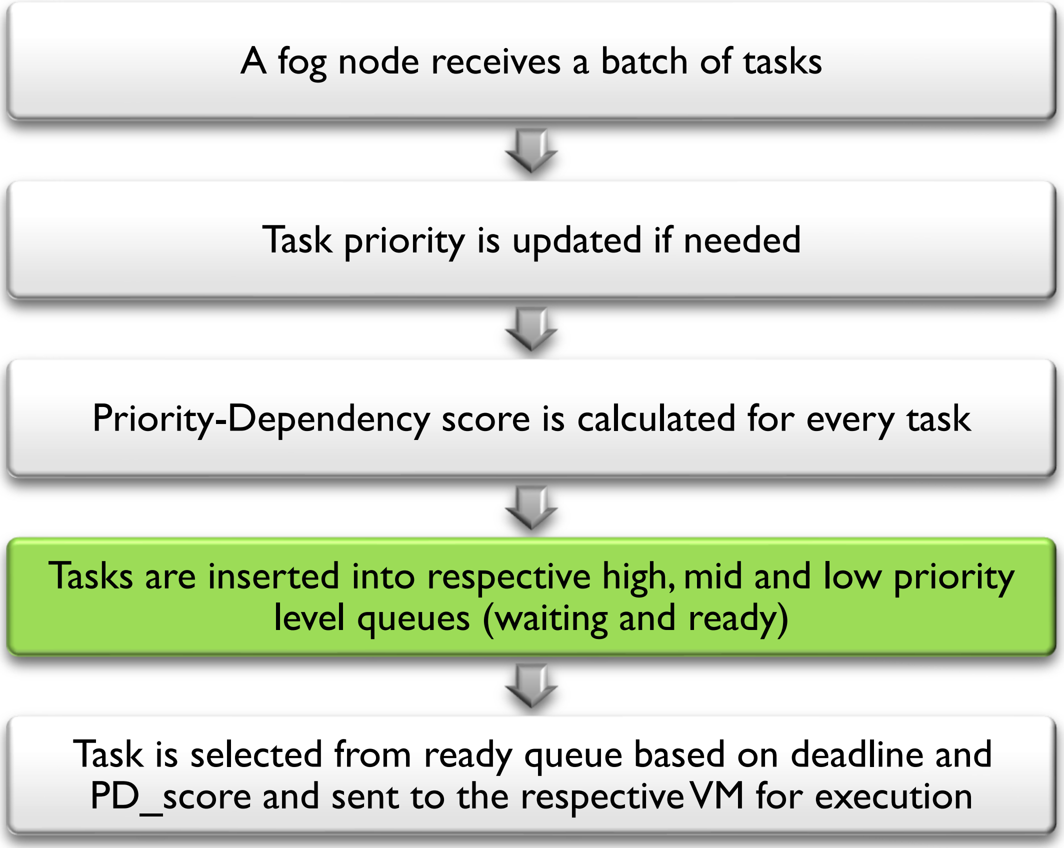


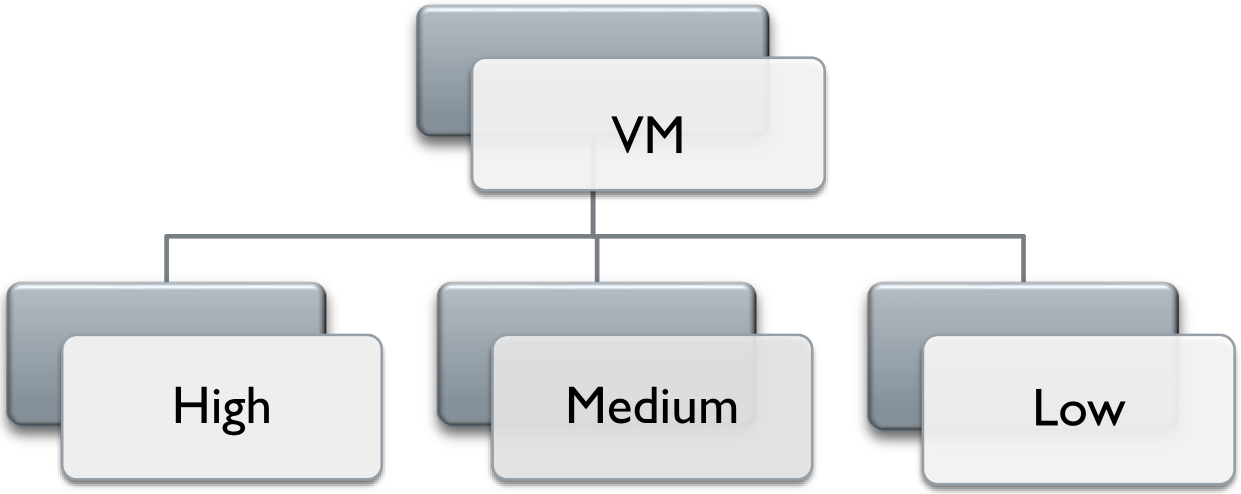


TASKS CATEGORIES





VM CATEGORIES



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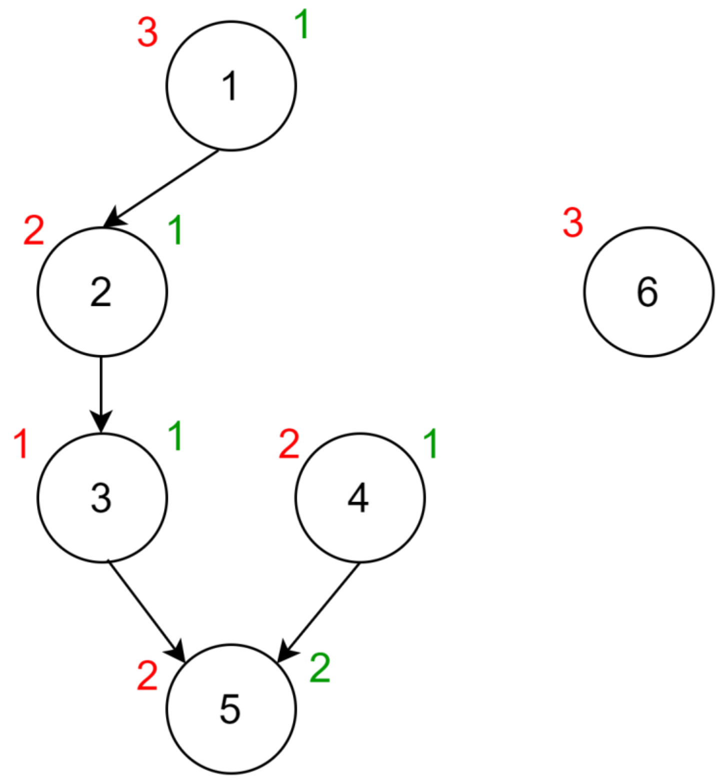
SAMPLE TASKSET

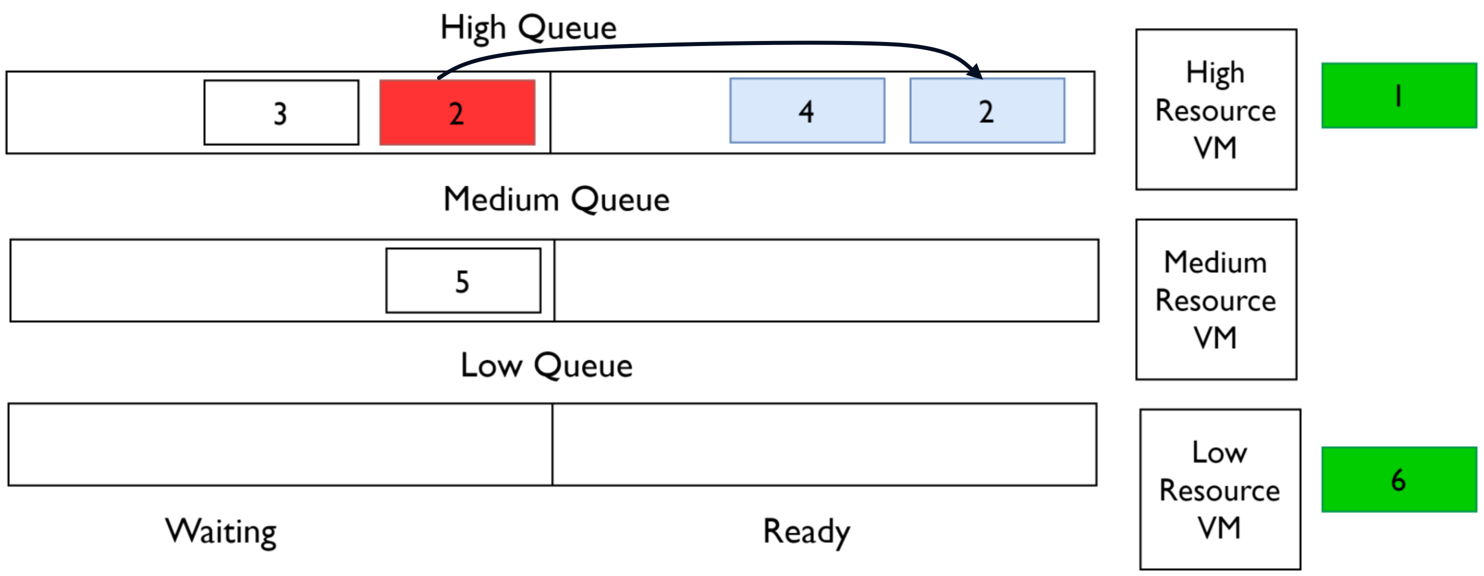
Task ID	Priority Level	Length (MI)	Deadline	Predecessor List	Imposed Priority	PD_Score
1	3	8000	10		1	7
2	2	10000	12	1	1	5
3	1	24000	26	2	1	2
4	1	9000	12		1	2
5	2	12000	30	3, 4	2	0
6	3	10000	40		3	0



TASK EXECUTION

Task ID	Deadline	Predecessor List	Imposed Priority	PD_Score
1	10		1	7
2	12	1	1	5
3	26	2	1	2
4	12		1	2
5	30	3, 4	2	0
6	40		3	0

TASK EXECUTION



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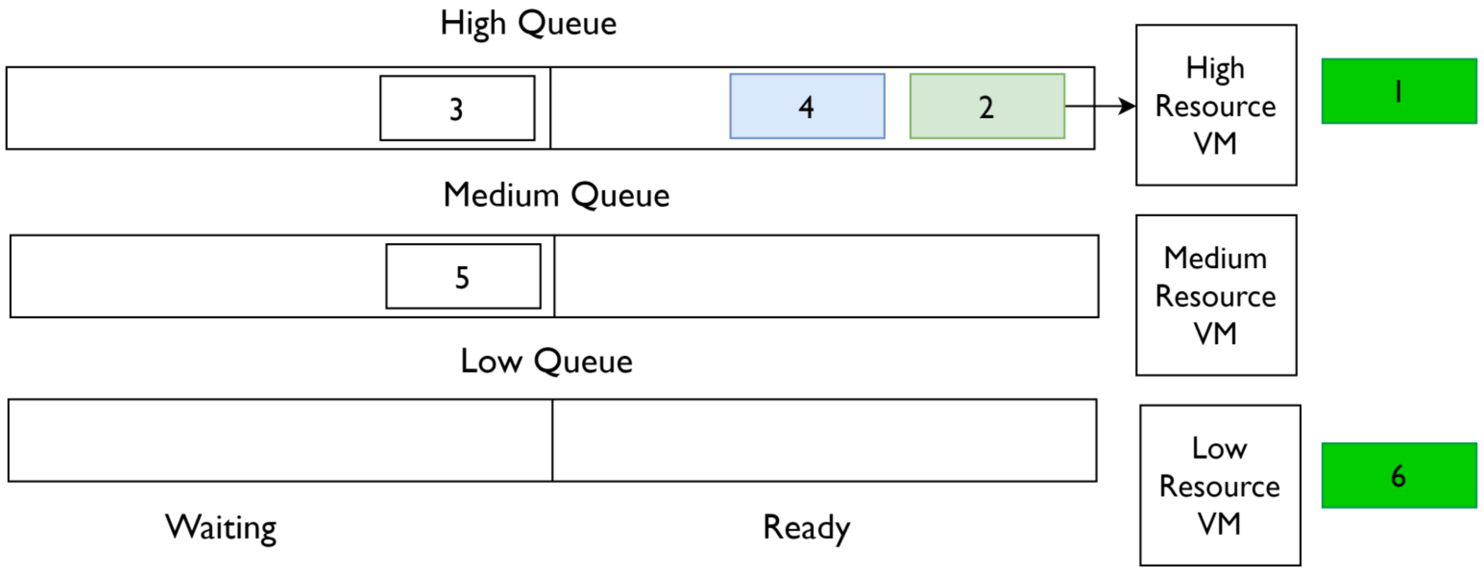

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EXPERIMENTS AND RESULTS

EXPERIMENTAL SETUP

Evaluation Metrices

- $Task\ Completion\ Rate = \dfrac{Tasks\ Completed\ on\ Time}{Total\ Number\ of\ Tasks}$
- $Response\ Time = \dfrac{Start\ Time\ - Arrival\ Time}{Total\ Number\ of\ Tasks}$
- $Makespan = Max(End\ Time) - Min(Start\ Time)$
- $Throughput = \dfrac{Time\ of\ Tasks\ Completed\ on\ Time}{Total\ Time\ to\ Complete\ all\ Tasks}$

Hyper-parameters

- *Total Number of Tasks*
- *Dependent Task Ratio*
- *Number of Max Parent of a Task*
- *Task Priority Level Ratio*

ALGORITHMS

- Proposed: Scoring with Heterogeneous Multi VMs
- Prioritized Task Scheduling without scoring (Choudhari [2])
- Scoring with Homogeneous Multi VMs
- Scoring with Single VM

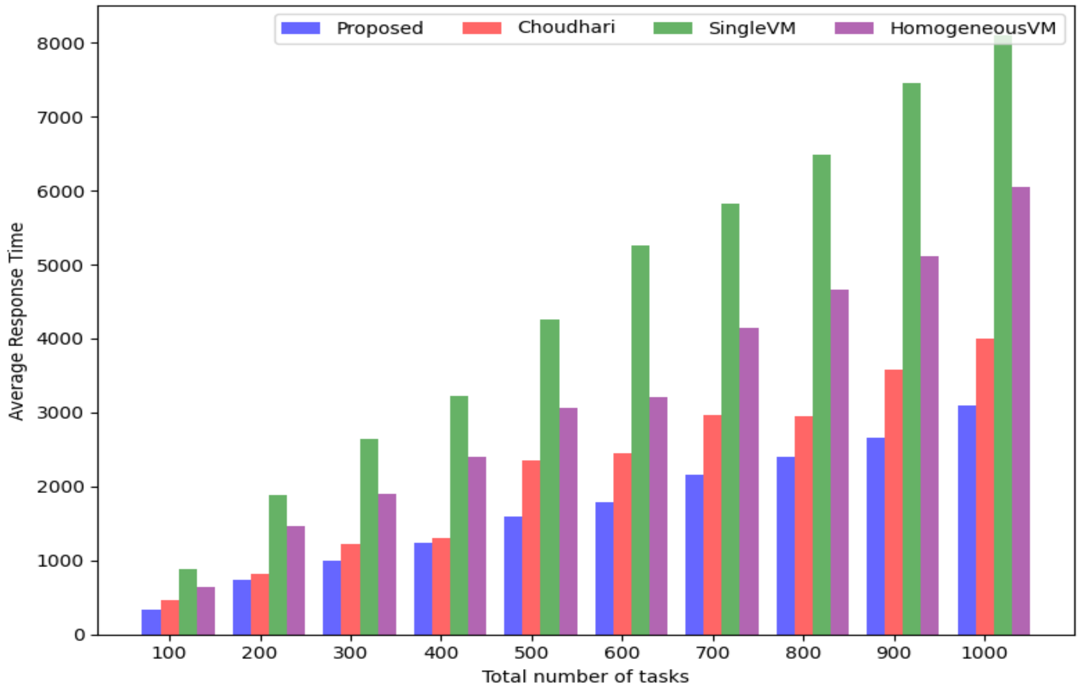
EXPERIMENT - I

Hyperparameters:

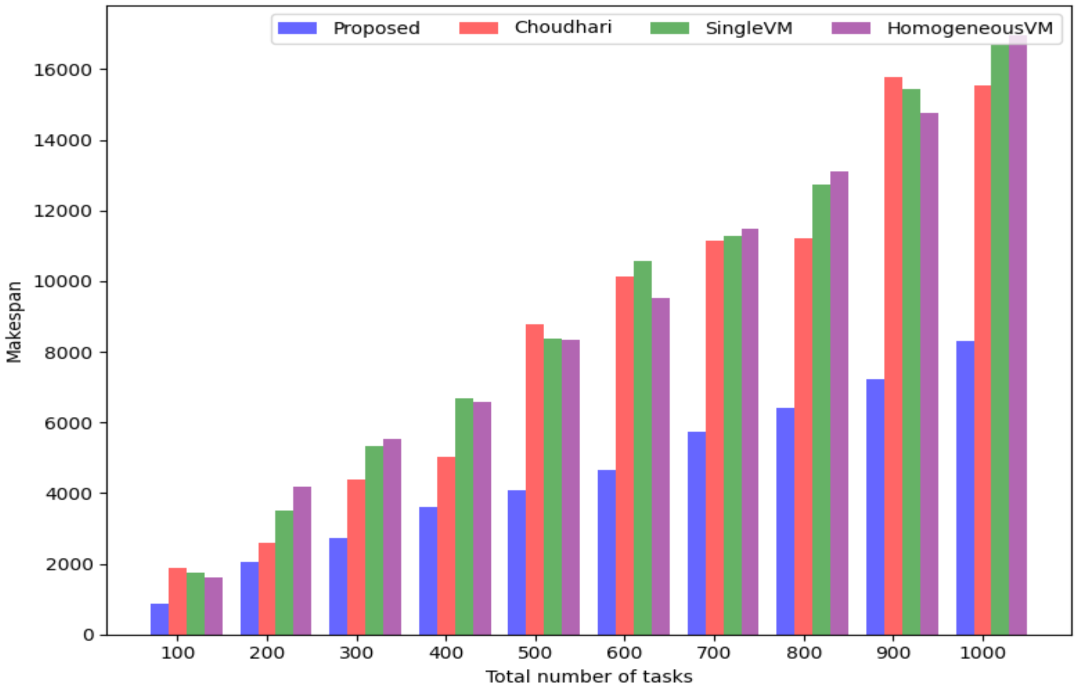
- Fixed
  - Dependent Task Ratio = 50%
  - Priority Level Ratio $[w_H = 0.4, w_M = 0.35, w_L = 0.25]$
  - Number of Predecessor for a Task $(min = 1, max = 3)$
- Variable:
  - Number of Tasks : $100 - 1000$

EXP-I: VARYING TOTAL NUMBER OF TASKS

Parameters: Dependent Task Ratio = 50% Task Priority Ratio = [0.4, 0.35, 0.25] Num_predecessors = {1, 3}



Average Response Time vs Total Number of Tasks



Makespan vs Total Number of Tasks

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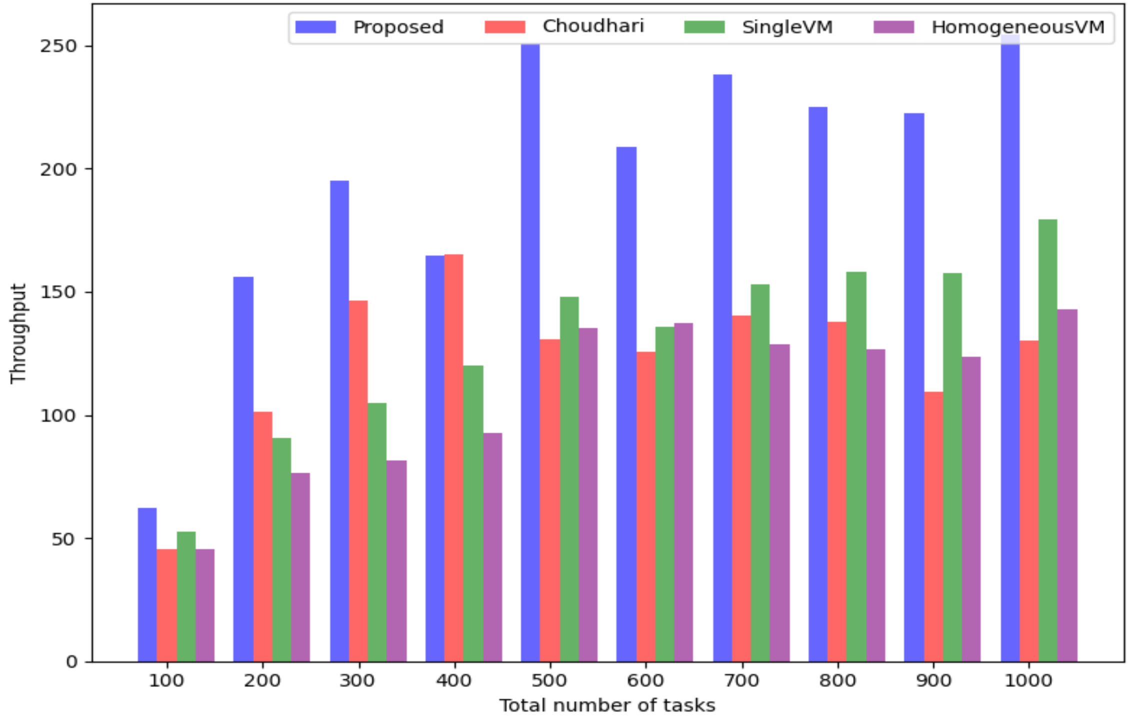
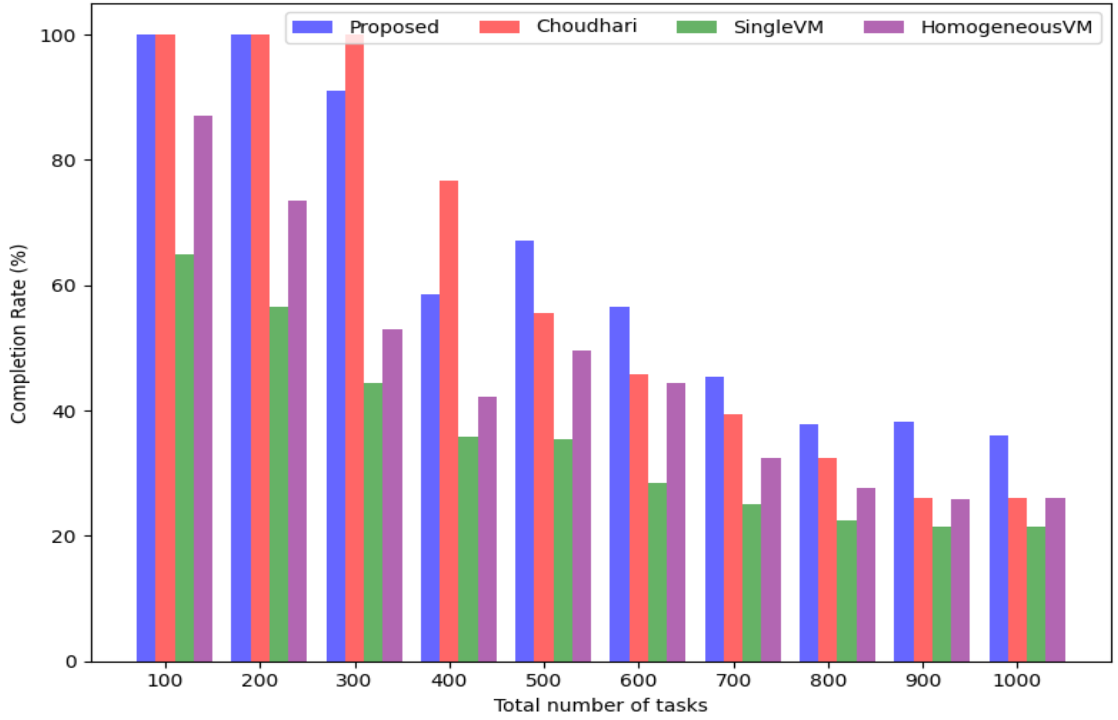


Throughput vs Total Number of Tasks



Task Completion Rate vs Total Number of Tasks

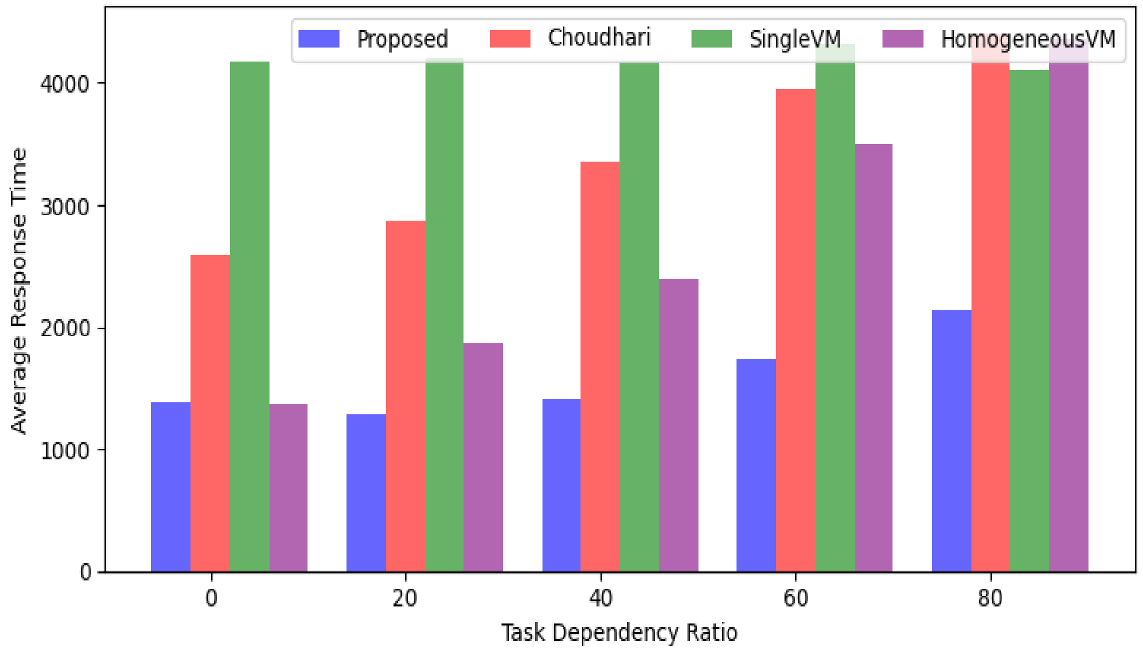
EXPERIMENT - II

Hyperparameters:

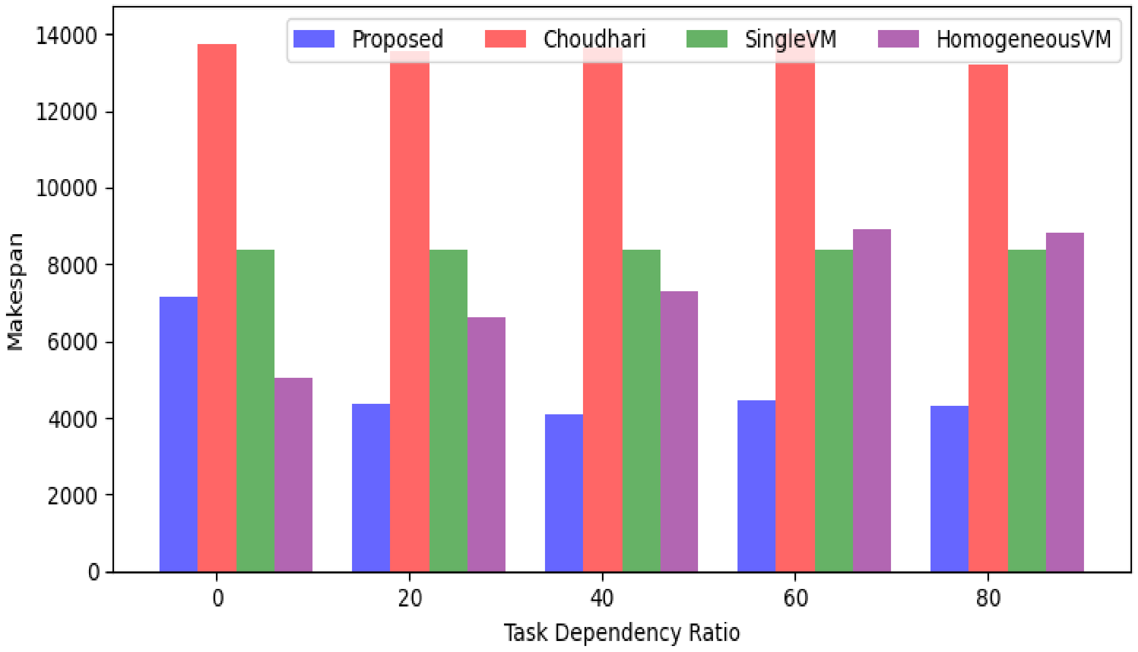
- Fixed
  - Number of Tasks = 500
  - Priority Level Ratio $[w_H = 0.4, w_M = 0.35, w_L = 0.25]$
  - Number of Predecessor for a Task $(min = 1, max = 3)$
- Variable:
  - Dependent Task Ratio: 0% - 80%

EXP-II: VARYING DEPENDENT TASK RATIO

Parameters: Number of Tasks = 500 Task Priority Ratio = [0.4, 0.35, 0.25] Num_predecessors = {1, 3}



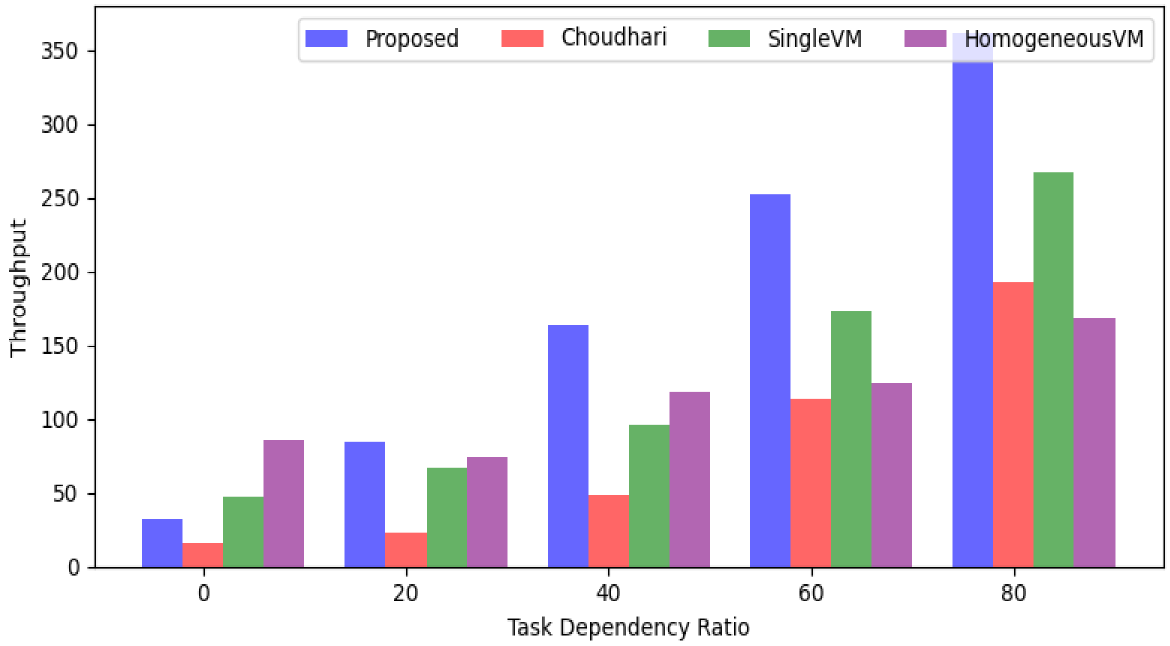
Average Response Time vs Dependent Task Ratio



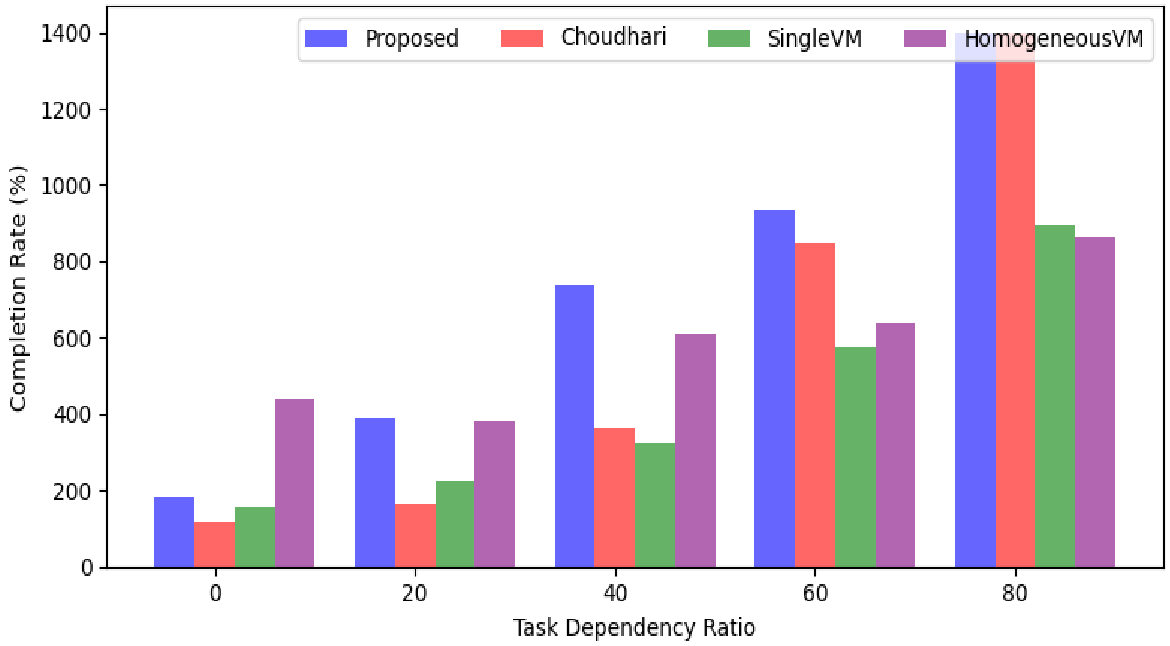
Makespan vs Dependent Task Ratio

EXP-II: VARYING DEPENDENT TASK RATIO

Parameters: Number of Tasks = 500 Task Priority Ratio = [0.4, 0.35, 0.25] Num_predecessors = {1, 3}



Throughput vs Dependent Task Ratio



Task Completion Rate vs Dependent Task Ratio

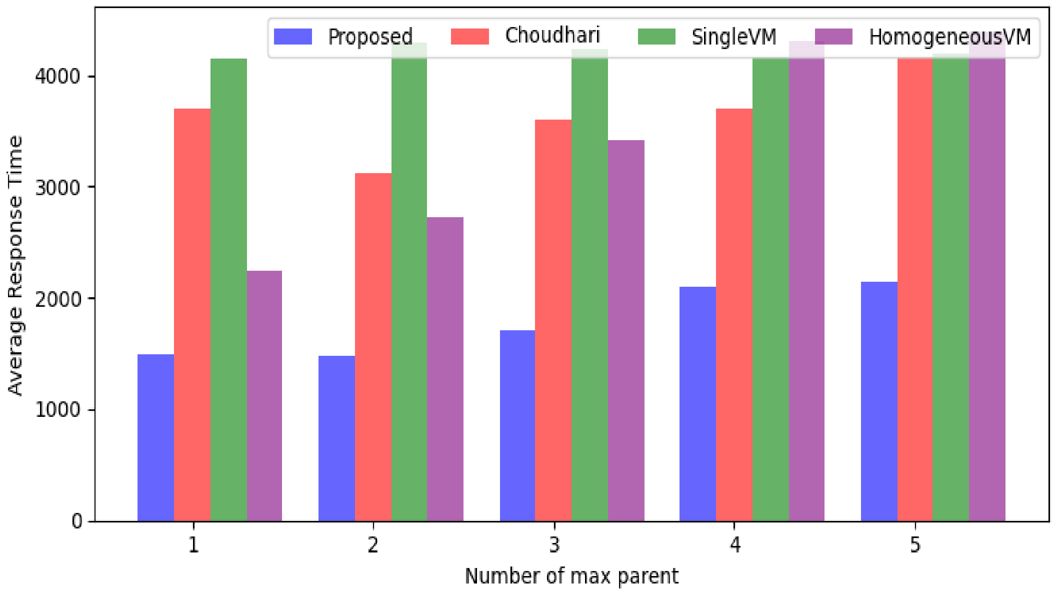
EXPERIMENT - III

Hyperparameters:

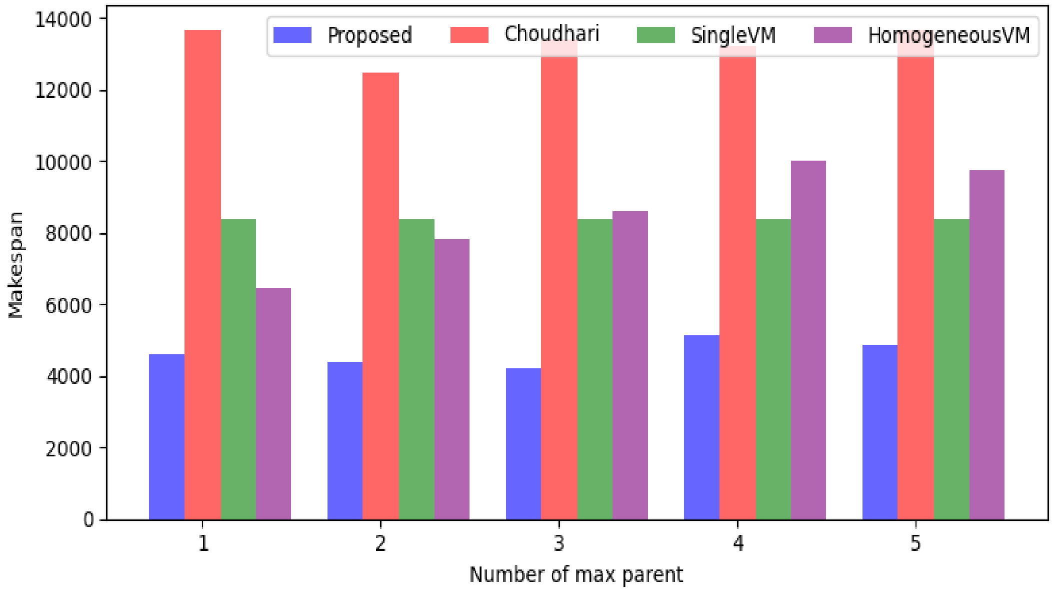
- ❑ Fixed
  - Number of Tasks = 500
  - Dependent Task Ratio = 60%
  - Priority Level Ratio $[w_H = 0.4, w_M = 0.35, w_L = 0.25]$
- ❑ Variable:
  - Number of Predecessor for a Task $(min = 1, max = 1 - 5)$

EXP-III: VARYING MAX NUMBER OF PREDECESSOR OF A TASK

Parameters: Number of Tasks = 500 Dependent Task Ratio = 60% Task Priority Ratio = [0.4, 0.35, 0.25]



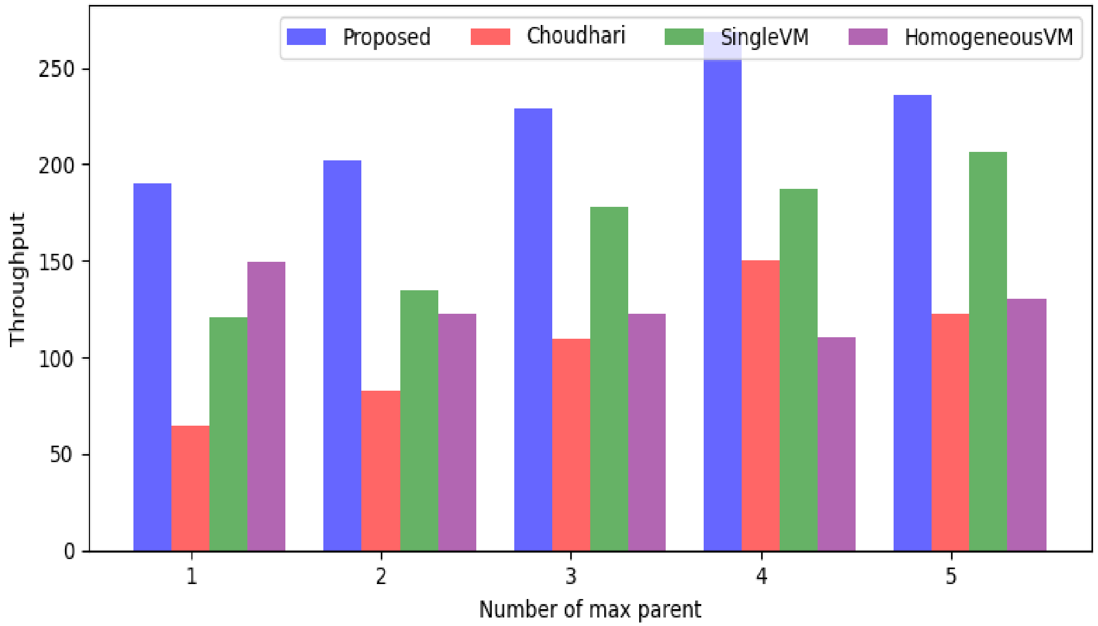
Average Response Time vs Number of Max Predecessor



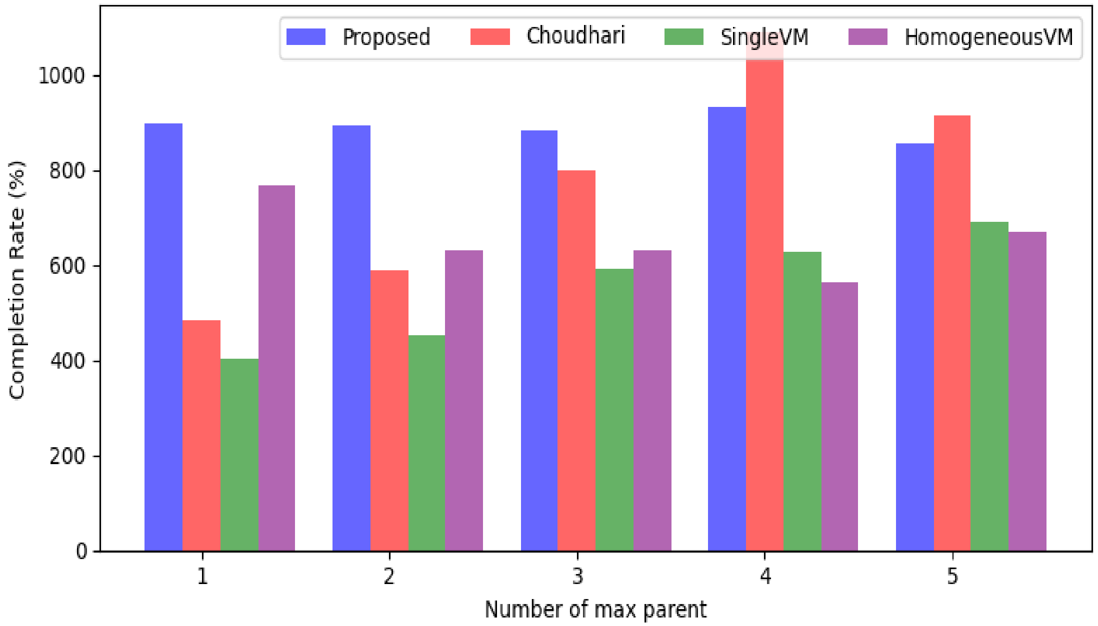
Makespan vs Number of Max Predecessor

EXP-III: VARYING MAX NUMBER OF PREDECESSOR OF A TASK

Parameters: Number of Tasks = 500 Dependent Task Ratio = 60% Task Priority Ratio = [0.4, 0.35, 0.25]



Throughput vs Number of Max Predecessor



Task Completion Rate vs Number of Max Predecessor

EXPERIMENT - 4

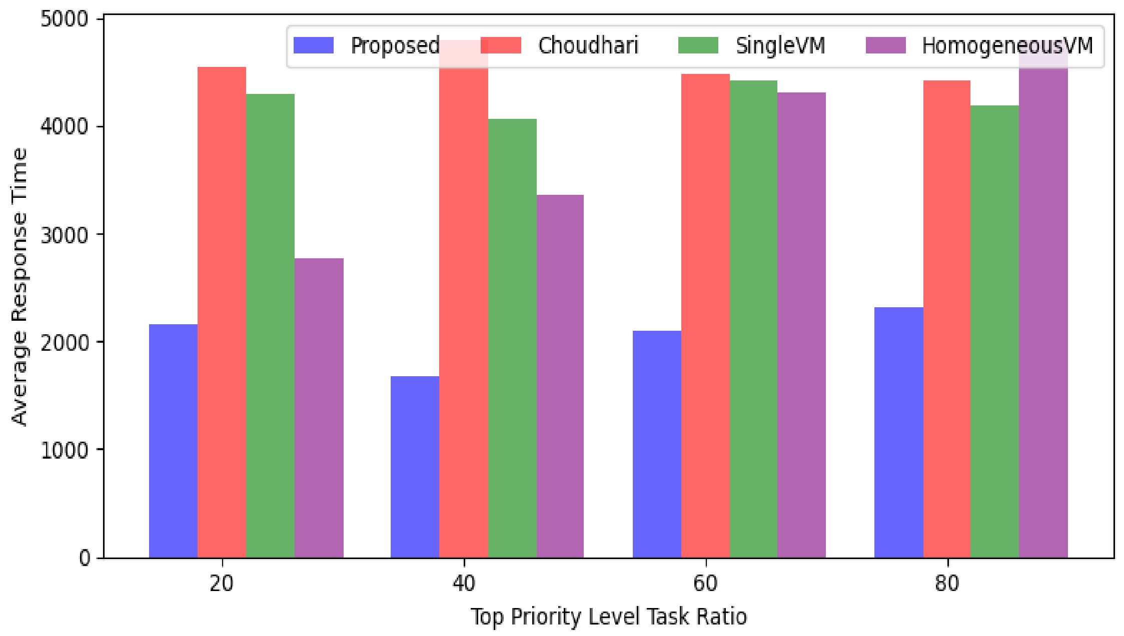
Hyperparameters:

- ❑ Fixed
  - Number of Tasks = 500
  - Dependent Task Ratio = 60%
  - Number of Predecessor for a Task $(min = 1, max = 3)$
- ❑ Variable:
  - Priority Level Ratio

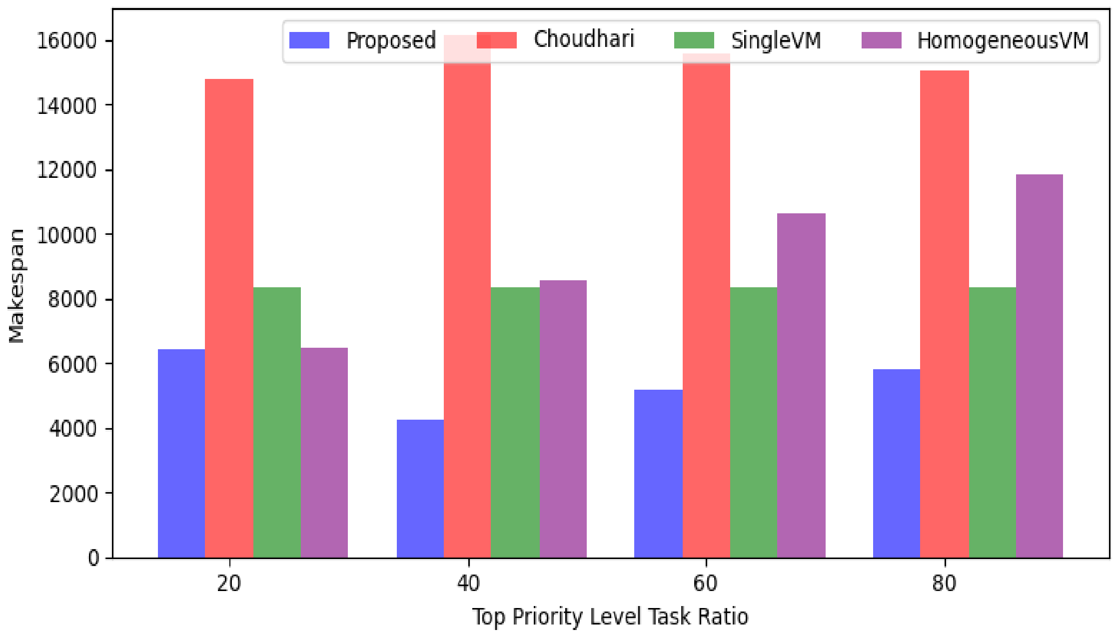
$$[w_H = 0.2 - 0.8, w_M = 0.8 - 0.2, w_L = 1 - w_H - w_M]$$

EXP-IV: VARYING TASK PRIORITY RATIO

Parameters: Number of Tasks = 500 Dependent Task Ratio = 60% Num_predecessors = {1, 3}



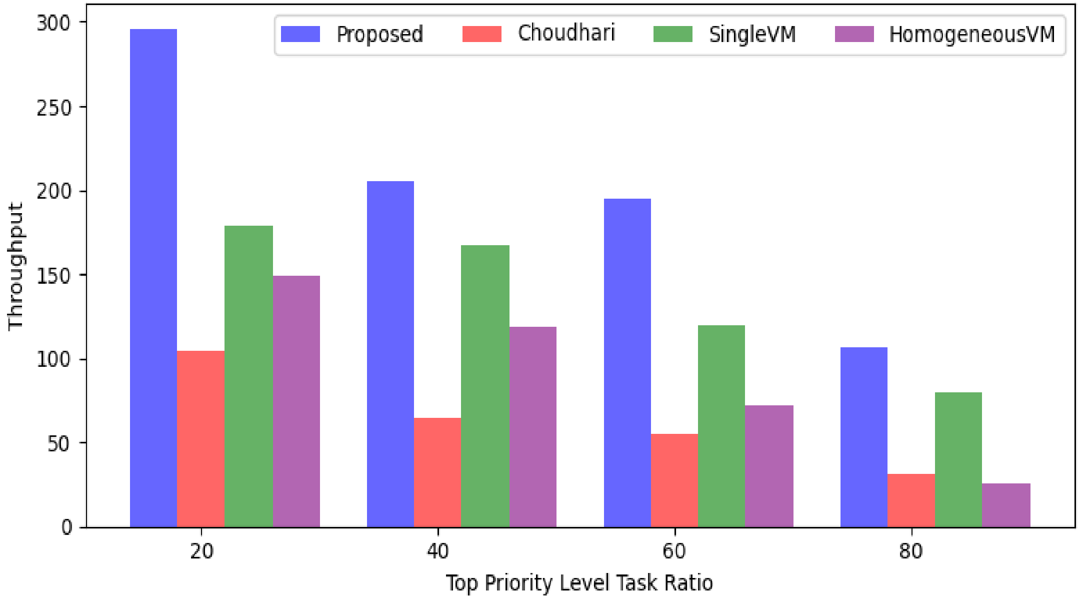
Average Response Time vs Task Priority Ratio



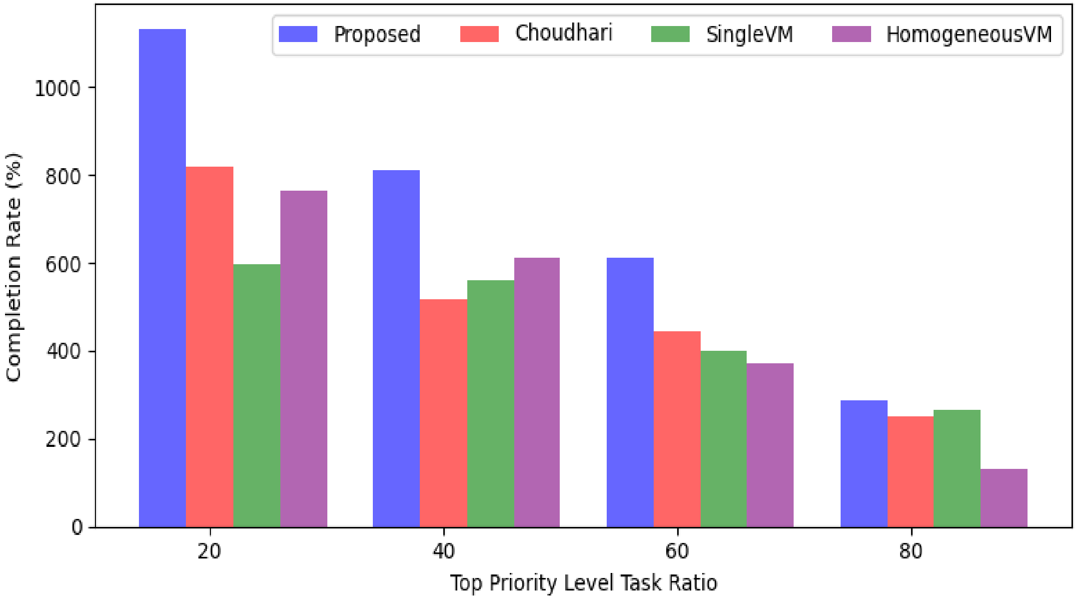
Makespan vs Task Priority Ratio

EXP-IV: VARYING TASK PRIORITY RATIO

Parameters: Number of Tasks = 500 Dependent Task Ratio = 60% Num_predecessors = {1, 3}



Throughput vs Task Priority Ratio



Task Completion Rate vs Task Priority Ratio

EXPERIMENT SUMMARY

Metric / Hyper Parameters	Response Time	Makespan	Throughput	Task Completion Rate
Number of tasks (100-1000)	Proposed	Proposed	Proposed	(100-200) Proposed & Choudhari (300-400) Choudhari (500-1000) Proposed
Dependent task ratio (0%-80%)	0% Homogeneous, (20-80)% Proposed	0% Homogeneous, (20-80)% Proposed	0% Homogeneous, (20-80)% Proposed	0% Homogeneous, (20-80)% Proposed
max parent of a task (1-5)	Proposed	Proposed	Proposed	(1-3) Proposed (4-5) Choudhari
High priority tasks ratio (20%-80%)	Proposed	Proposed	Proposed	Proposed

FUTURE WORKS

- Fog Resource Management
- Task Preemption
- Fault Tolerance

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