CS528

Rolling Horizon and Workload Prediction

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Outline

- Power Aware Scheduling in Cloud
- **Rolling Horizon**
- Work load Prediction

Energy Minimization Problem

- Given N tasks with (e_i,d_i), $a_i=0$
- Given M machines with Power model of Machines

$$P(t) = P_{min} + \alpha.u(t)^3$$

Execute all the tasks without missing deadlines and goal is to minimize energy.

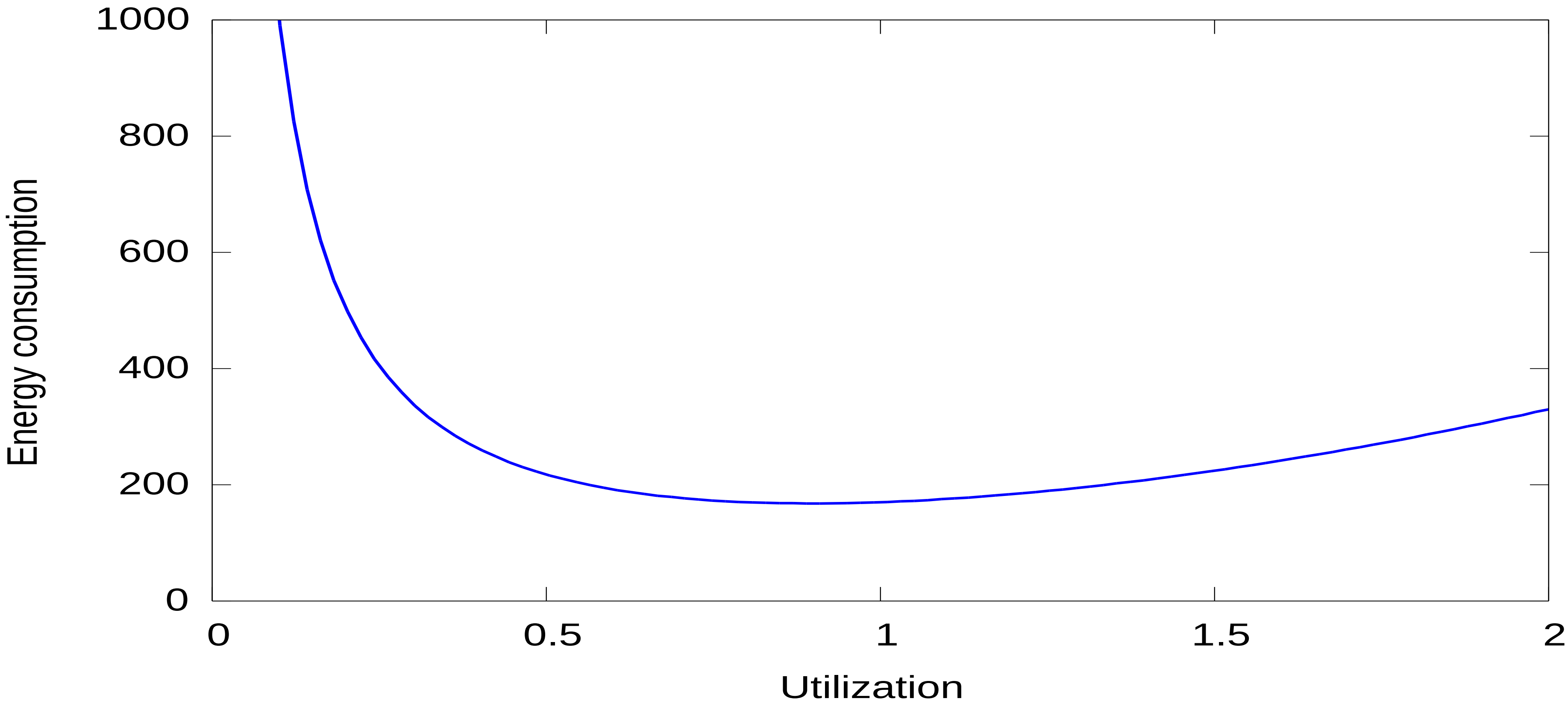
Energy Model of Server/Host

- Processor is the major contributor
- Considered both static and dynamic EC

$$E = \int_{t_1}^{t_2} P(t)dt$$

$$P(t) = P_{min} + \alpha.u(t)^3$$

Energy Model of Server/Host



- When a task runs with utilization u,

$$E = (P_{min} + \alpha.u^3).e/u = (P_{min}/u + \alpha.u^2).e$$

Critical Utilization

Minimum utilization

- Utilization required by a task to finish at deadline

$$u_{i\_min} = e_i / d_i$$

Least feasible VM

- Closest VM type which can support u_{i_min}

Critical utilization

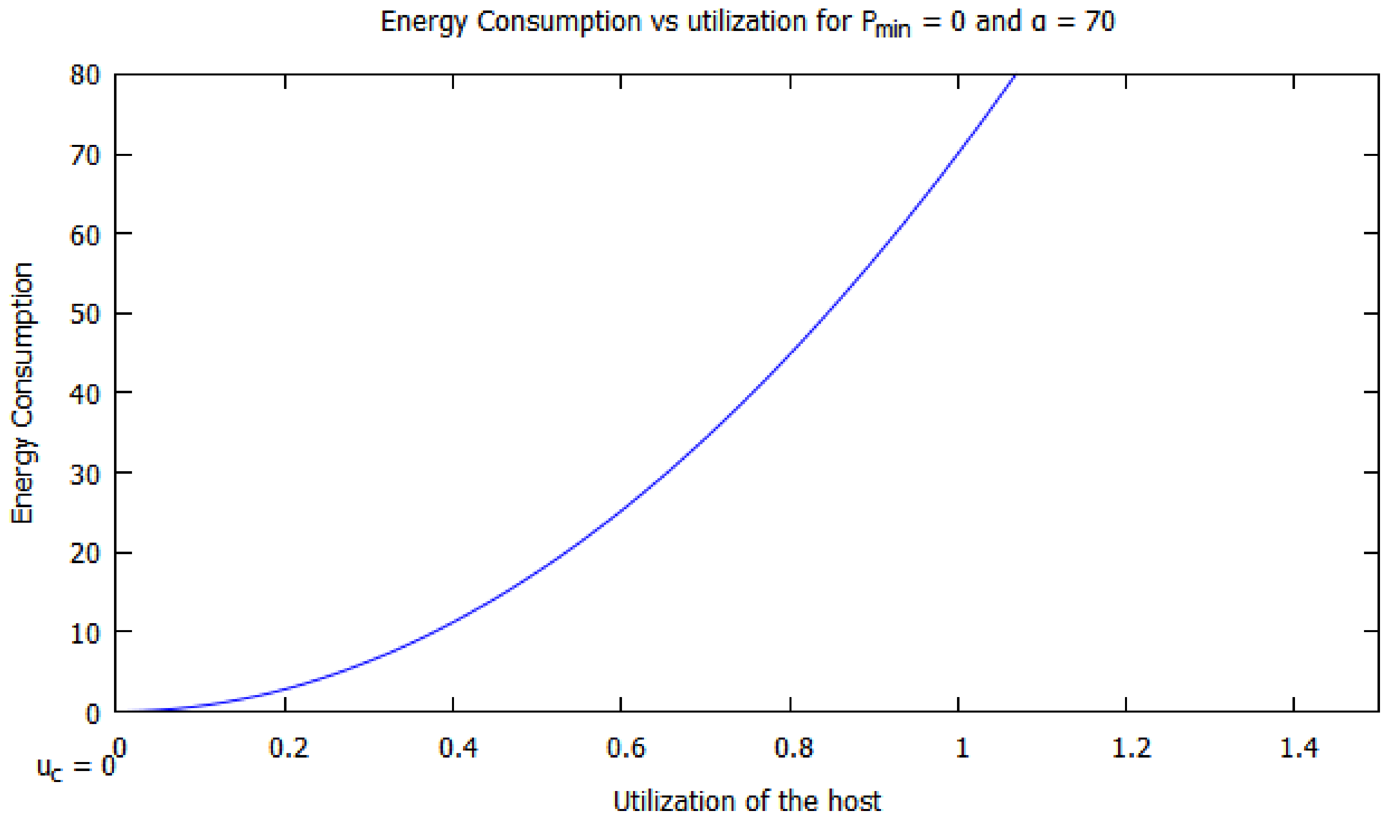
- Utilization of a host when energy consumption is minimum

$$u_c = \sqrt[3]{P_{min}/2\alpha}$$

Classify of host based on U_c

- Case 1 : Negligible static power (i.e. $P_{min} = 0$)
  => u_c=0
- Case 2 : Very high static power
  => u_c>1
- Case 3 : General case
  => 0<u_c<=1

Scheduling for Case I : P_{min}=0

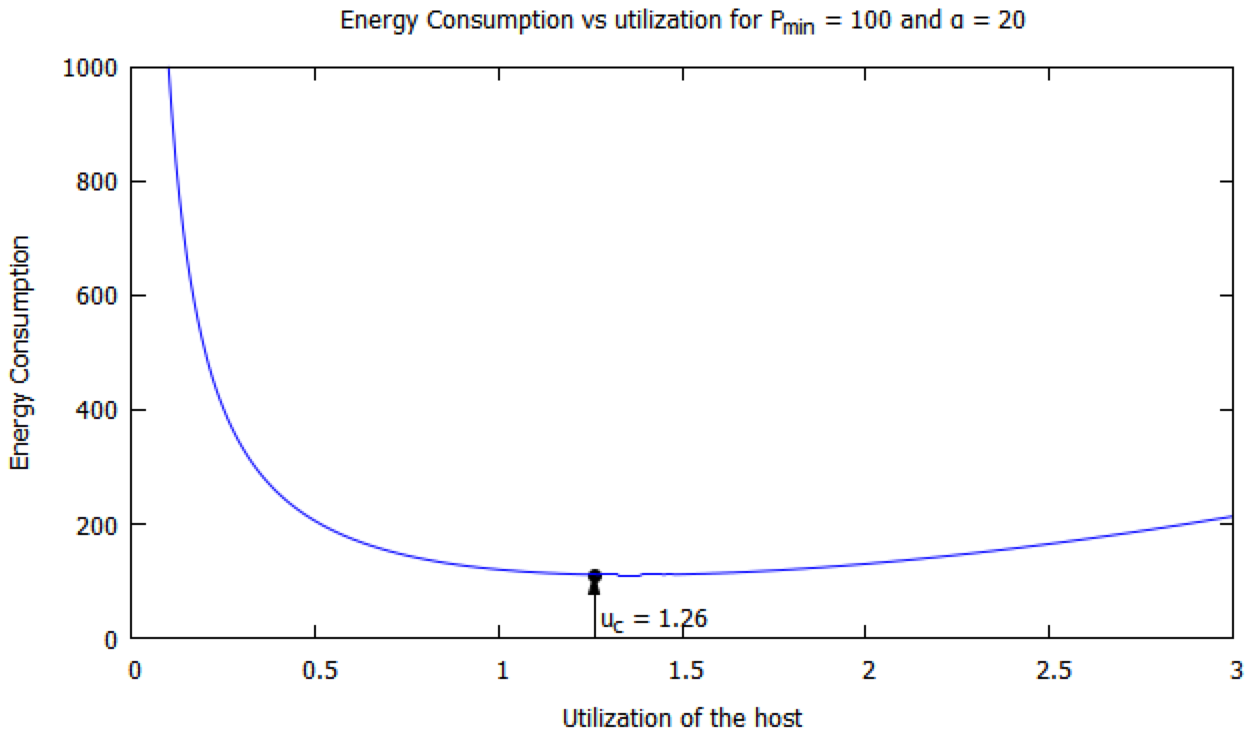


- For every task, choose the least feasible VM type
- Allocate the VM to a new host

$E = \alpha . u_t^2 . e$

$u_1^2 + u_2^2 < (u_1 + u_2)^2$

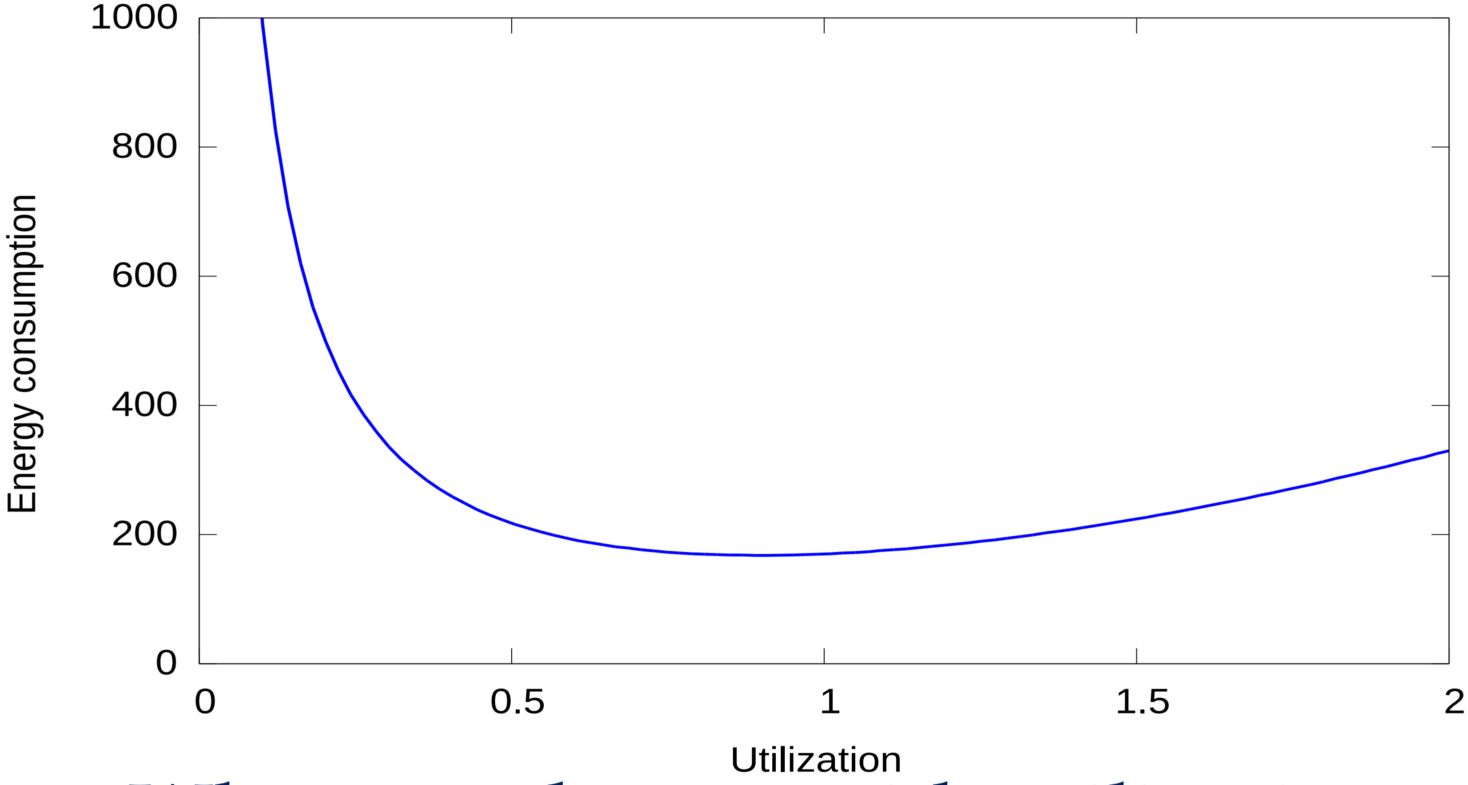
Scheduling for Case II : $U_c>1$



- Maximum utilization of a running host is 1
- Closest feasible utilization value is 1
- Solved using general case with utilization 1

Energy Model of Server/Host

- Power consu. of a host, $P = P_{min} + \alpha u^3$



$P_{min} = 100$

$\alpha = 70$

- When a task runs with utilization u,

$$E = (P_{min} + \alpha u^3).l / u = (P_{min}/u + \alpha u^2).l$$

Energy Model of Server/Host

Least feasible VM type

- A VM with utilization $\lceil u_{i\_min} \rceil$
- $u_{i\_min} = l_i / d_i$ (uti. to finish a task just at deadline)

Critical utilization

- utilization of a host when energy consumption is minimum

$$u_c = \sqrt[3]{P_{min}/2\alpha}$$

Target of the scheduler is to keep the host utilization at u_c

Reference

Zhu et. al, "Energy-Aware Rolling-Horizon Scheduling for Real-Time Tasks in Virtualized Cloud Data Centers", IEEE HPCC 2013

Basic of Energy Aware RTS in Cloud

- Developing EA cloud data centers
  - not only can reduce power electricity cost
  - but also can improve system reliability.
- Real time task : task completion before deadline, QoS (weak term -reliable)
- Energy Saving using
  - Resource scaling up and scaling down strategies
- Rolling Horizon

Scheduling Model

- Given a virtualized data center that is characterized by an infinite set of physical computing hosts

$$H = \{h_1, h_2, \cdots\}$$

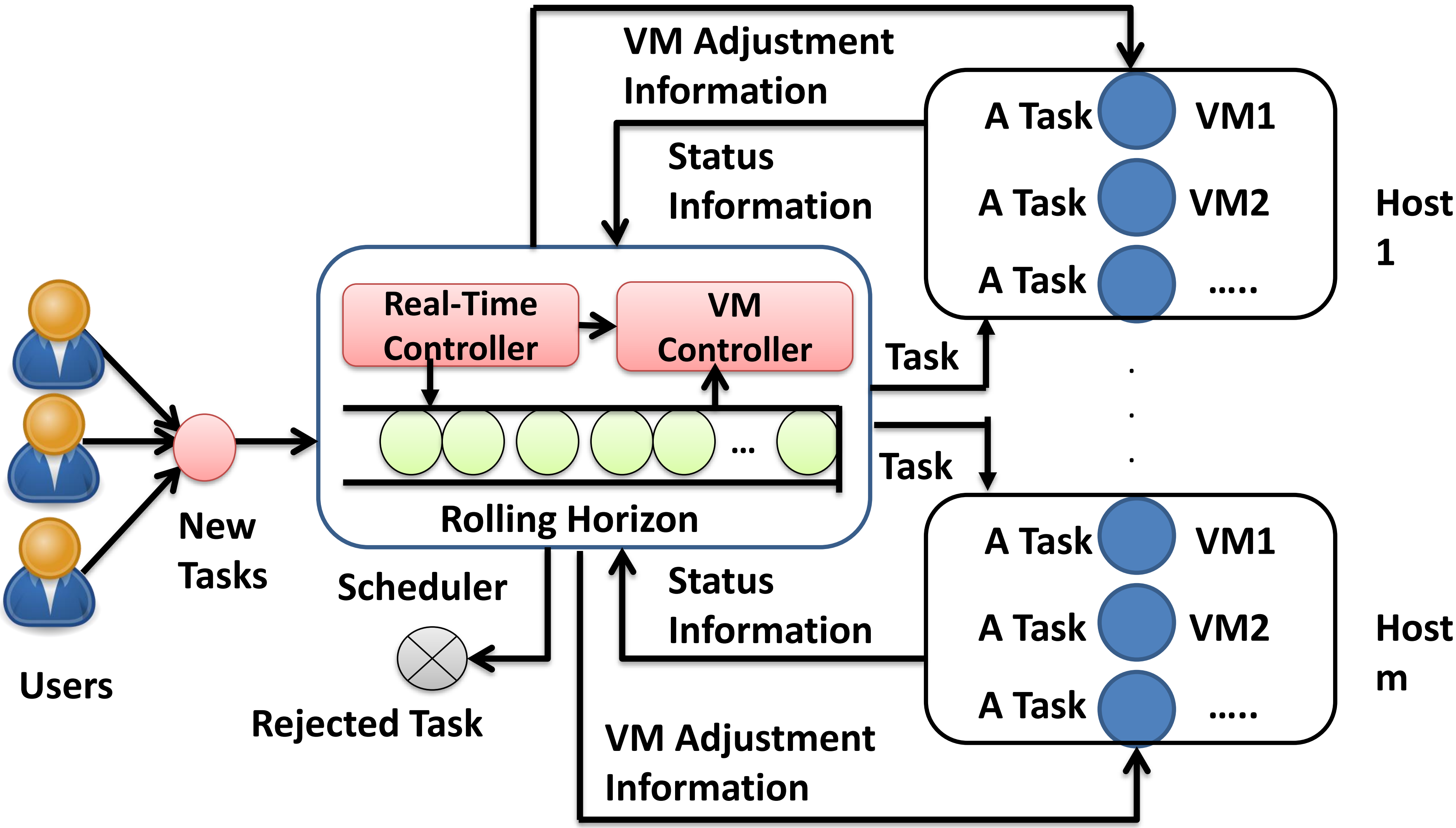
- Hardware infrastructure H
  - for creating virtualized resources
  - to satisfy users' requirements.
- Active host set H_a with $H_a \subseteq H$.
- Host $\mathbf{h_k}$ is characterized by $\mathbf{h_k(c_k, r_k, n_k)}$
  - Compute power in MIPS, ram size, net bandwidth

Scheduling Model

- Host h_k is have set V_k of virtual machine

  $V_k = \{ v_{1k}, v_{2k}, .., v_{|Vk|k}\}$
- For a VM v_{jk} is characterized by $c(v_{jk}), r(v_{jk}), n(v_{jk})$
  - Fraction of Compute power in MIPS, ram size, net bandwidth allocated to v_{jk}
- Multiple VMs can be dynamically
  - Started and stopped on a single host
  - Based on the system workload.
- At the same time, some VMs are able
  - To migrate across hosts in order to consolidate resources
  - And further reduce energy consumption.

Scheduling Architecture



Working of RH Scheduler

- Scheduler consists of
  - Rolling-horizon, Real-time Controller, VM Controller.
- Scheduler work
  - Takes tasks from users and
  - Allocates them to different VMs.
- Rolling-horizon holds
  - Both new tasks and waiting tasks to be executed.
- A scheduling process is triggered
  - By new tasks, and all the tasks of RH to rescheduled

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Scheduling ()@New Task Arrives

- **Step 1**. Scheduler checks System status information such as
  - running tasks' remaining execution time, active hosts, VMs' deployments,
  - Tasks in waiting pool including their deadlines,
  - Currently allocated VMs, start time, etc.
- **Step 2**. Sort the tasks in rolling-horizon
  - by their deadlines to facilitate scheduling operation.

Scheduling ()@New Task Arrives

- **Step 3**. Real-time controller determines
  - Whether a task in RH can be finished before its deadline.
- The VM controller adds VMs
  - to finish the task within timing constraint
  - if current VMs cannot finish it successfully.
  - If no schedule can be found to satisfy the task's timing requirement although enough VMs has been added by testing
- The task will be rejected. Or the task will be retained in the rolling-horizon.

Scheduling ()@New Task Arrives

- **Step 4**. Update the scheduling decision for the tasks in rolling-horizon,
  - Their execution order, start time,
  - Allocated VMs and new active hosts.
- **Step 5**. When a task in the rolling-horizon is ready to execute
  - dispatch the task to assigned VM.

Scheduling ()@New Task Arrives

- Additionally, when
  - tasks arrive slowly, tasks have loose deadlines or their count is less, making system workload light
- VM controller considers both
  - the status of active hosts and task information, and
- VM Controller then decides
  - Whether some VMs should be stopped or migrated to consolidate resources
  - So as to save energy

Task Model

- A set $T = \{t_1, t_2, \cdots\}$ of independent tasks that arrive dynamically.
- A task t_i submitted by a user have

  $t_i = \{a_i, l_i, d_i, f_i\}$ Where a_i, l_i, d_i and f_i are
  - Arrival time, task length/size, deadline, and finish time of task t_i.
- Let rt_{jk} be the ready time of VM v_{jk} at host h_k.
- st_{ijk} be the start time of task t_i on VM v_{jk}.
- Execution time of task t_i on VM v_{jk}.

$$et_{ijk} = \frac{l_i}{c\,(v_{jk})}.$$

c(v): compute capacity MIPS of VM

Task Model

- Finish time of task t_i on v_{jk}, $ft_{ijk} = st_{ijk} + et_{ijk}$.
- Boolean x_{ijk} reflect mapping of tasks
  - to VMs at different hosts in a virtualized Cloud data center,

x_{ijk} = 1 if task t_i is allocated to VM v_{jk} at host h_k

=0, otherwise.

- Task's timing constraint can be guaranteed

$$x_{ijk} = \begin{cases} 0 & ft_{ijk} > \mathbf{d}_i \\ 0 \text{ or } 1, & ft_{ijk} \le \mathbf{d}_i \end{cases}$$

Energy Consumption Model (ECM)

- EC by hosts in a data center
  - is mainly determined by CPU, memory, disk storage and network interfaces,
  - in which CPU consumes major part of energy
- CPU EC: static part (E_s) + dynamic part (E_d)
  - E_d is dominant > 80%, E_s follows similar trend to E_d
- EC of running task t_i on VM v_{jk} : $\mathbf{ec_{ijk}=ecr_{jk} \cdot et_{ijk}}$
  - Term $\mathbf{ecr_{jk}}$: EC rate of the VM $\mathbf{v_{jk}}$

ECM of Tasks on VMs

- Total EC by executing all the tasks is

$$\mathbf{ec}^{\mathbf{exec}} = \sum_{k=1}^{|Ha|} \sum_{j=1}^{|Vk|} \sum_{i=1}^{T} x_{ijk} . ec_{ijk}$$

$$= \sum_{k=1}^{|Ha|} \sum_{j=1}^{|Vk|} \sum_{i=1}^{T} x_{ijk} . ecr_{jk} * et_{ijk}$$

  - H_a=active hosts, V_k=VM of host *k*, **T**=task set
- EC is incurred when VMs are sitting idle
  - All the VMs of a host is idle
  - Some of VM of a host Idle
- EC considering the execution time and idle time

$$\mathbf{ecei} = \mathbf{ec}^{\mathbf{exec}} + \mathbf{ec}^{\mathbf{allIdle}} + \mathbf{ec}^{\mathbf{partIdle}}$$

ECM of host with idle VMs

- EC when all the VMs of a host is idle
  - Host can be set to a lower EC rate by DVFS
  - ECR of VM v_{jk} by ecr^{idle}_{jk}
  - Idle time when all the VMs in a host h_k are idle is it_k

$$ec^{allIdle} = \sum_{k=1}^{|Ha|} \sum_{j=1}^{|Vk|} ecr^{idle}{}_{jk} .\, it_k$$

- EC when some of VM of a host Idle

$$ec^{partIdle} = \sum_{k=1}^{|Ha|} \sum_{j=1}^{|Vk|} ecr_{jk} .\; t_j^{partIdle}$$

with $t_j^{partIdle} = \max(f_i) - it_k - \sum_{i=1}^{T} x_{ijk} * et_{ijk}$

Final ECM of host

- Although some VMs are placed on a host
  - maybe some resource is still unused
  - However, the resource also consume energy.
- Suppose there are s periods in each which the count of VMs in host h_k is different from another.
- Let t_p to denote the time in the period p, $V_{k(p)}$ vm count in pth period on host k
- EC due to unused resources of hosts
  - $ec^{unused} = \sum_{k=1}^{|Ha|} \sum_{p=1}^{s} \left(ecr(h_k) - \sum_{j=1}^{V_k(p)} ecr_{jk} \right) . tp$
- So total EC of Cloud system

$$\boxed{ec = ecei + ec^{unused} = ec^{exec} + ec^{allIdle} + ec^{partIdle} + ec^{unused}}$$

Scheduling Goals and Trade-offs

- Less running hosts ==>
  - less consumed energy
  - may greatly affect **guarantee ratio** of real-time **tasks**
- Energy Conservation and TGR are two conflicting objectives
- Good scheduling strategy makes a good trade-off by dynamically
  - Starting hosts, Closing hosts
  - Creating VMs, canceling VMs
  - Migrating VMs
  - **according to the system workload.**

Energy **A**ware **R**olling **H**orizon Scheduling

- Traditional scheduling: once a task is scheduled
  - it is dispatched immediately to the local queue of a VM or a host
- In EARH: puts all the waiting tasks RH queue
  - Their schedules are allowed to be adjusted for the schedulability of the new task
  - possibly less energy consumption.
- Essential advantage of RH optimization
  - task migration required by rescheduling does not yield any overhead
  - as all the tasks are waiting in the rolling-horizon.

EARH Approach

- Attempt to append new task to the end of former allocated tasks on a VM.
- Start time st_{ijk} of task t_i on VM v_{jk}

  $\boldsymbol{st_{ijk}} = \mathbf{max}\{\boldsymbol{rt_{jk}}, \boldsymbol{a_i}\}$, rt_{jk} is ready time of v_{jk}
- Ready time get updated once task $\mathbf{t_p}$ added to $\mathbf{v_{jk}}$

  $\boldsymbol{rt_{jk} = st_{pjk} + et_{pjk}}$.
- When a task cannot be successfully allocated in any current VM
  - scaleUpResource() is done to create a new VM
  - With the goal of finishing the task within its deadline.

Scale up resources: in three steps

- Step1: Create a new VM
  - in a current active host without any VM migration
- Step2: If Step 1 fails
  - Migrate some VMs among current active hosts
  - To yield enough resource on a host and
  - then create a new VM on it
- Step3: if Step 2 fails
  - start a host and then create a new VM on it.

Scale up resources: in three steps

- *Some terms*
  - $st(h_k)$: start-up time of host h_k
  - $ct(v_{jk})$: creation time of VM v_{jk}
  - $mt(v_{jk})$: migration time of VM v_{jk}, $=r\ (v_{\text{jk}})/n(v_{\text{jk}})$, RAM and Network
- Using different steps products different start times for a task,

$$st_{ijk} = \begin{cases} a_i + ct(v_{jk}), & \text{if setp1,} \\ a_i + ct(v_{jk}) + \sum_{p=1}^{|p|} mt(v_{pk}), & \text{if setp2,} \\ a_i + st(h_k) + ct(v_{jk}), & \text{if setp3.} \end{cases}$$

Scheduling EARH

for each task t_i in set Q **do**

$findTag \leftarrow$ FALSE; $findVM \leftarrow$ NULL;

for each VM v_{jk} in the system **do**

Calculate the start time st_{ijk} and execution time et_{ijk}

If $st_{ijk} + et_{ijk} \leq d_i$ **then** $findTag \leftarrow$TRUE; Compute ec_{ijk}

if $findTag$ == FALSE **scaleUpResource()**;

if $findTag$ == TRUE **then**

Select v_{sk} with min energy consumption to execute t_i

$findVM \leftarrow v_{sk}$

else Reject task t_i

Update scheduling decision of t_i and remove it from Q