An Advance Reservation-based Co-allocation Algorithm for Distributed Computers and Network Bandwidth on QoS-guaranteed Grids

Atsuko Takefusa, Hidemoto Nakada,

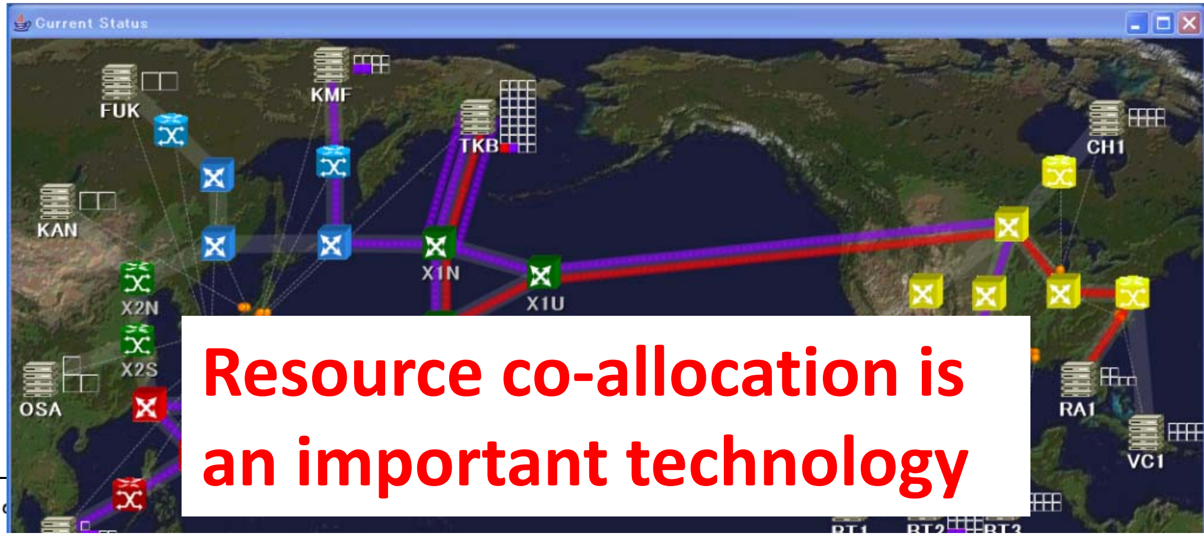
Tomohiro Kudoh, and Yoshio Tanaka

National Institute of Advanced Industrial Science and Technology (AIST)

Resource Co-allocation for QoS-guaranteed Grids

- QoS is a key issue on Grid/Cloud
  - Network (=Internet) is shared by abundant users
- Network resource management technologies have enabled the construction of QoS-guaranteed Grids
  - Dynamic resource co-allocation demonstrated

    G-lambda and EnLIGHTened Computing [GLIF06,SC06]
  - Each network is dedicated and dynamically provisioned
  - No connectivity w/o reservation



Resource co-allocation is an important technology

Preconditions of Our Co-allocation

- Commercial services
  - Some resources including network are provided by resource managers (RM) from commercial sectors
  - The resources will be charged
  - The RMs do not disclose all of resource information
- Advance reservation
  - Prediction-based scheduling systems, e.g. KOALA and QBETS, cannot guaranteed to activate co-allocated resources at the same time
    - The user has to pay for some commercial resources during the waiting time
- On-line reservation service
  - Try to complete resource co-allocation, quickly

Issues for Resource Co-allocation for QoS-guaranteed Grids (1/2)

- Co-allocation of both computing and network resources
  - There are constraints between computers and the network links
  - Cannot use list scheduling-based approaches and network routing algorithms based on Dijkstra's algorithm, straightforwardly
- Reflecting scheduling options
  - Users: (a) reservation time, (b) price, and (c) quality/availability
  - Administrators: (A) load balancing among RMs, (B) preference allocation, and (C) user priority

Issues for Resource Co-allocation for QoS-guaranteed Grids (2/2)

- Calculation time of resource co-allocation
  - Resource scheduling problems are known as NP-hard
  - Important to determine co-allocation plans with short calculation time, especially for on-line services

Our Contribution

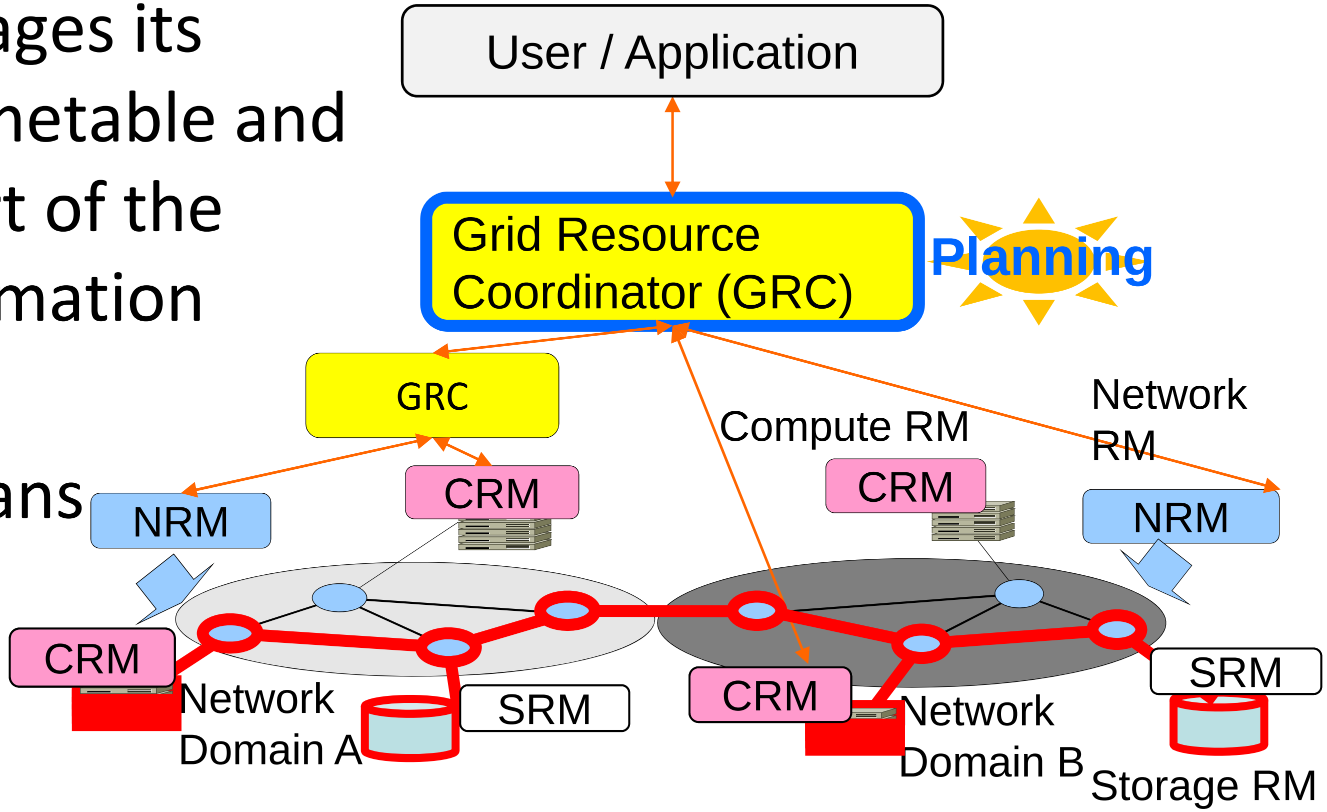
- Propose an on-line advance reservation-based co-allocation algorithm for distributed computers and network bandwidths
  - Model this resource co-allocation problem as an integer programming (IP) problem
  - Enable to apply the user and administrator options
- Evaluate the algorithm with extensive simulation, in terms of functionality and practicality
  - Can co-allocate both resources and can take the administrator options as a first step
  - Planning times using a general IP solver are acceptable for an on-line service

The Rest of the Talk

- Our on-line advance reservation-based co-allocation model
- An advance reservation-based co-allocation algorithm
  - Modeled as an IP problem
- Experiments on functional and practical issues
- Related work
- Conclusions and future work

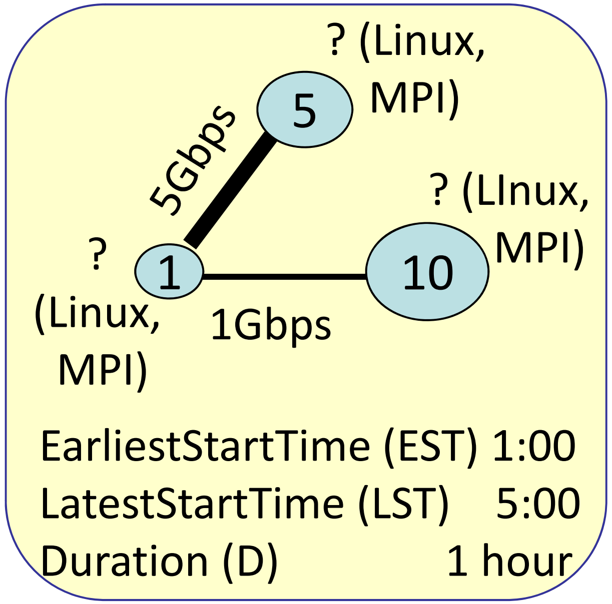
Our On-line Advance Reservation-based Co-allocation Model

- Consists of Global Resource Coordinators (GRCs) (= Grid scheduler) and resource managers (RMs)
- Each RM manages its reservation timetable and discloses a part of the resource information
- **GRC** creates reservation plans and allocates the resources

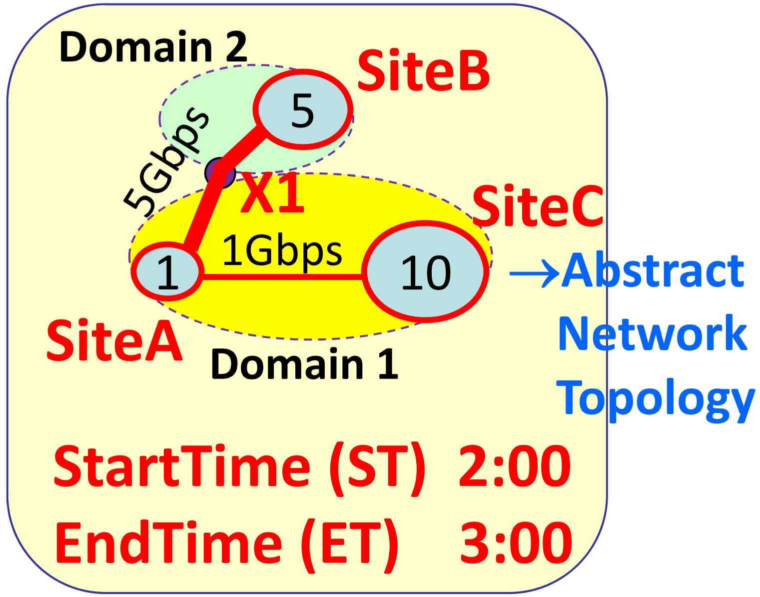


User Request and Reservation Plan

User Request



Reservation Plan



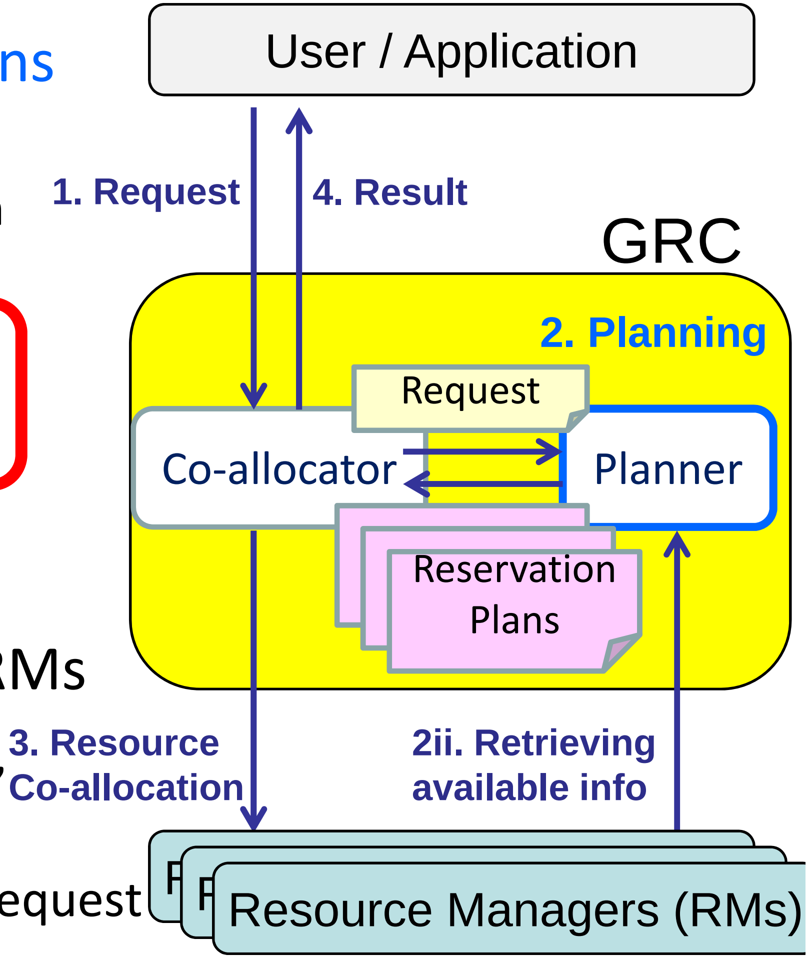
Resource Requirement Parameters

- Compute resources: # of CPUs/Cores, Attributes (e.g., OS)
- Network resources: Bandwidth, Latency, Attributes
- Time frames: Exact (ST and ET) or range (EST, LST, and D)

The Steps of Resource Co-allocation

1. GRC receives a co-allocation request from User
2. GRC Planner creates reservation plans
   - 2i. Selects N time frames from [EST, LST+D]
   - 2ii. Retrieves available resource information at the N time frames from RMs
   - 2iii. Determines N' (≤N) co-allocation plans using 2ii information
     → Modeled as an IP problem
   - 2iv. Sorts N' plans by suitable order
3. GRC tries to co-allocate the selected resources in coordination with the RMs
4. GRC returns the co-allocation result, whether it has succeeded or failed

If failed, the User will resubmit an updated request



Resource and Request Notations

Resources: $G=(V, E)$

- v_n ($\in V$) : Compute resource site or network domain exchange point
- $e_{o,p}$ ($\in E$) : Path from v_o to v_p

Resource parameters

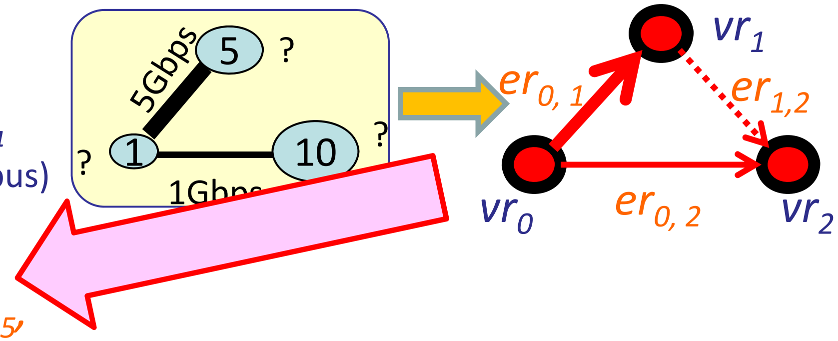
- wc_i ($i \in V$) : # of available CPUs
  wb_k ($k \in E$) : Available bandwidth
  ($e_{o,p}$ and $e_{p,o}$ share the same wb_k)
- vc_i ($i \in V$) : Value per unit of each CPU
  vb_k ($k \in E$) : Value per unit of bandwidth

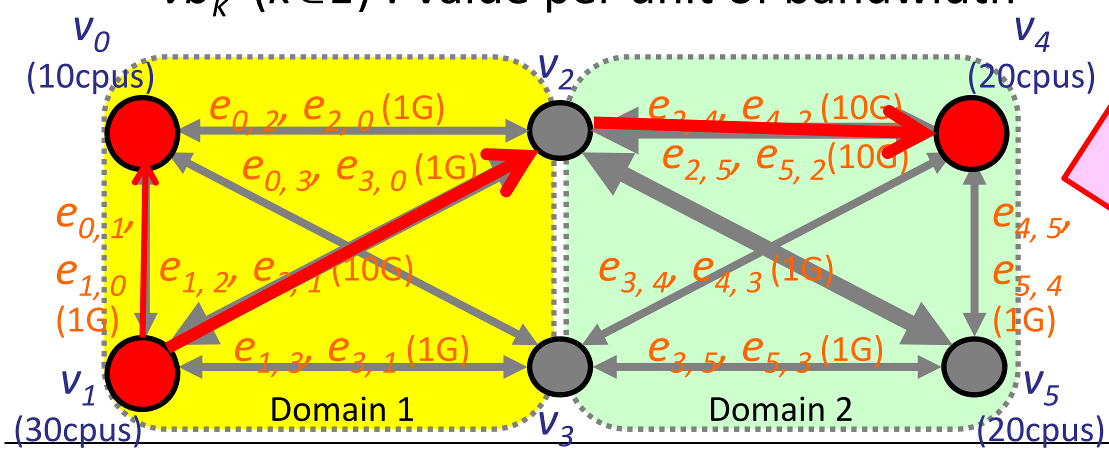
Request: $G_r=(V_r, E_r)$

- vr_m ($\in V_r$) : Requested compute site
- $er_{q,r}$ ($\in E_r$) : Requested network between vr_q and vr_r

Request parameters

- rc_j ($j \in V_r$) : Requested # of CPUs
- rb_l ($l \in E_r$) : Requested bandwidth

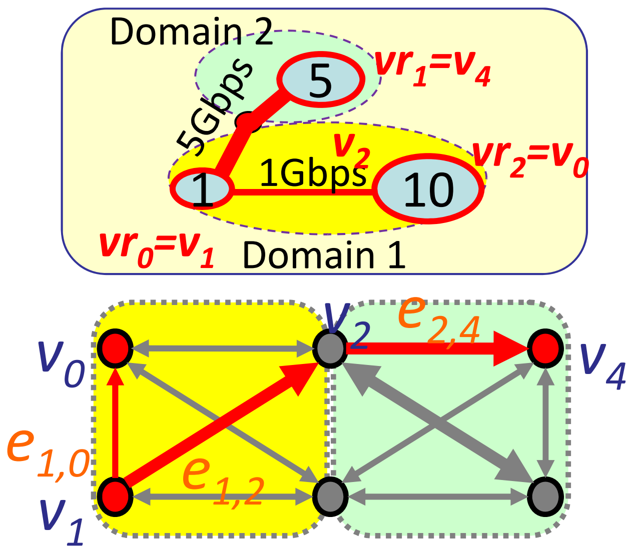




Modeling as a 0-1 IP Problem

X (Compute site plan) = $x_{i,j} \in \{0, 1\}$ $(i \in V, j \in V_r)$ (1)

Y (Network path plan) = $y_{k,l} \in \{0, 1\}$ $(k=(m, n) \in E,\ m, n \in V,\ l=(o, p) \in E_r,\ o, p \in V_r)$ (2)



Request

Resources

X =

	v_0	v_1	v_2	v_3	v_4	v_5
vr_0	0	1	0	0	0	0
vr_1	0	0	0	0	1	0
vr_2	1	0	0	0	0	0

Y =

	$e_{0,1}$	$e_{1,0}$	$e_{1,2}$	$e_{2,1}$	$e_{2,4}$	$e_{4,2}$	…
$er_{0,1}$	0	0	1	0	1	0	…
$er_{0,2}$	0	1	0	0	0	0	…
$er_{1,2}$	0	0	0	0	0	0	…

Objective function and Constraints

Minimize

$$\sum_{i \in v, j \in v_r} vc_i \cdot rc_j \cdot x_j + \sum_{k \in E, l \in E_r} ve_k \cdot rb_l \cdot y_{k,l} \quad (3)$$

Subject to

$$\forall j \in V_r, \sum_{i \in V} x_{i,j} = 1 \quad (4)$$

$$\forall i \in V, \sum_{j \in V_r} x_{i,j} \le 1 \quad (5)$$

$$\forall i \in V, \sum_{j \in V_r} rc_j \cdot x_{i,j} \le wc_i \quad (6)$$

$$\forall l \in E_r, \sum_{k \in E_r} y_{k,l} \begin{cases} \ge 1 \, (rb_l \ne 0) \\ = 0 \, (rb_l = 0) \end{cases} \quad (7)$$

$$\forall k \in E, \sum_{l \in E_r} rb_l \cdot y_{k,l} \le wb_k \quad (8)$$

$$\forall l = (o, p) \in E_r, \forall m \in V,$$
$$\sum_{n \in V, m \ne n} y_{(n,m),(o,p)} - \sum_{n \in V, m \ne n} y_{(m,n),(o,p)} = \begin{cases} x_{m,o} - x_{m,p} & (rb_l > 0) \\ 0 & (rb_l = 0) \end{cases} \quad (9)$$

(3) : Minimize the sum of resource values

(4),(5),(6) : Constraints on the compute site plan X

- (4) Select 1 site for each requested site
- (5) Each site is selected to 0/1 site
- (6) Each selected site can provide requested # of CPUs

(7),(8) : Constraints on the path plan Y

- (7) The sum of $y_{k,l}$ becomes more than 1, if requested
- (8) Each selected path can guarantee requested bandwidth

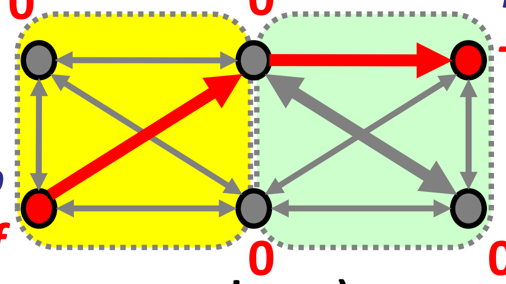
(9) : Constraint on both X and Y

Application of Mass Balance Constraints

$$\forall l = (o, p) \in E_r, \forall m \in V,$$

$$\sum_{n \in V, m \neq n} y_{(n,m),(o,p)} - \sum_{n \in V, m \neq n} y_{(m,n),(o,p)} = \begin{cases} x_{m,o} - x_{m,p} & (rb_l > 0) \\ 0 & (rb_l = 0) \end{cases} \quad (9)$$

Sum of outflow Sum of inflow 0 / *f* / -*f*



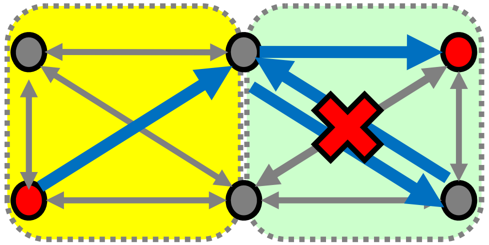
- Mass Balance Constraints (Kirchhoff's current law)
  - Except for source and sink, the sum of inflows equals to the sum of outflows
- Application of the constraints
  - Assume requested network $l = (o, p)$ ($\in E_r$) is "current" from o to p and the flow = 1
    $\rightarrow$ Right-hand side becomes 0 / 1 / -1
  - $x_{m,o}$=1 when m ($\in V$) is source, or $x_{m,p}$=1 when m is sink
    $\rightarrow$ Right-hand side could be represented as $x_{m,o} - x_{m,p}$

Additional Constraints

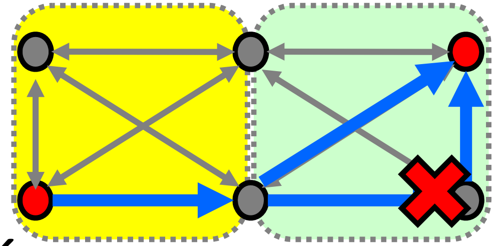
- Calculation times of 0-1 IP become exponentially long, due to NP-hard
- Propose additional constraints, which are expected to make calculation times shorter

Subject to

$$\forall l \in E_r, \forall m,n \in E (m \neq n), y_{(m,n),l} + y_{(n,m),l} \leq 1 \quad (10)$$



$$\forall l \in E_r, \sum_{k \in E} y_{k,l} \leq P_{\max} \quad (11)$$



Specifies P_{max}, the maximum of the number of paths for each network

→ Solutions might not be optimal

Reflecting co-allocation options

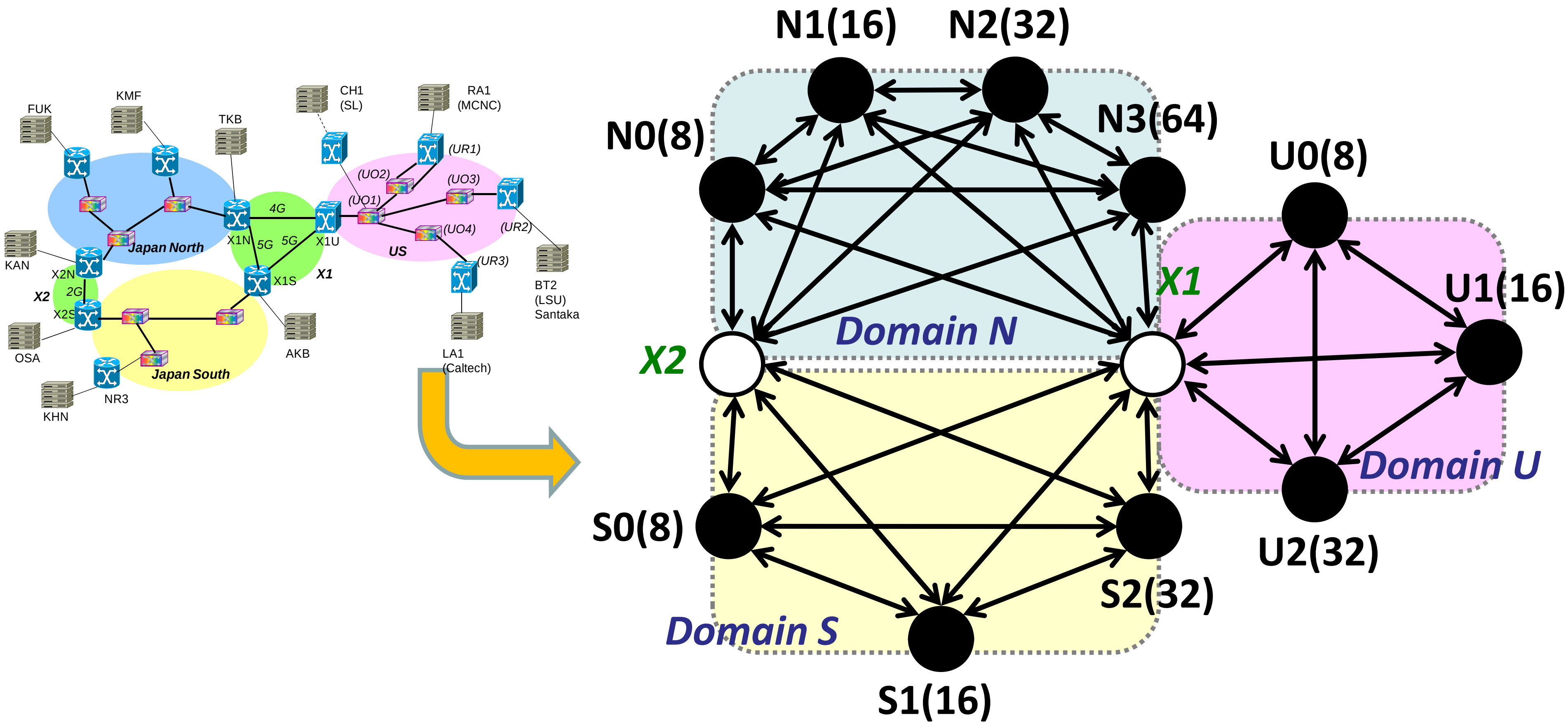
- User options
  - (a) Reservation time → Sort plans by times in stage 2iv
  - (b) Price → Sort plans by the total price
  - (c) Quality/Availability → Set vc_i and vb_k to their quality, modify the objective function, and then sort plans by the total value
- Administrator options
  - (A) Load balancing among RMs
  - (B) Preference allocation → Set vc_i and vb_k to weights of each resource
  - (C) User priority → Modify the retrieved available resource information

Experiments

- Evaluate the algorithm with extensive simulation
  - Assume an actual international testbed
- Experiments on functional issues
  - Can co-allocate both compute and network resources
  - Can take the administrator options as a first step
- Experiments on practical issues
  - Compare planning times using additional constraints and different IP solvers
  - Planning times are acceptable for an on-line service

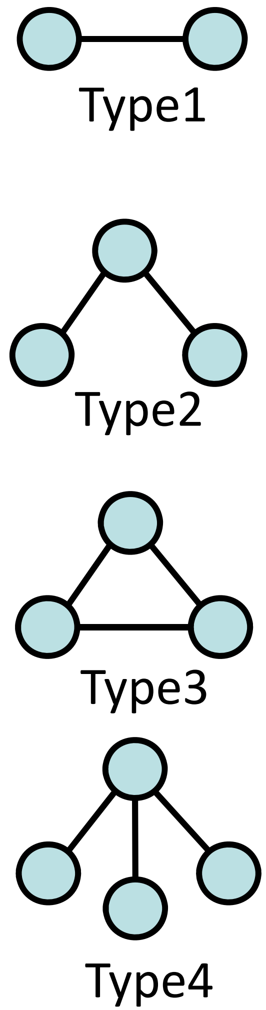
Experimental Environment

- Assume an actual testbed used in the G-lambda and EnLIGHTened Computing experiments
  - 3 network domains, 2 domain exchange points, and 10 sites



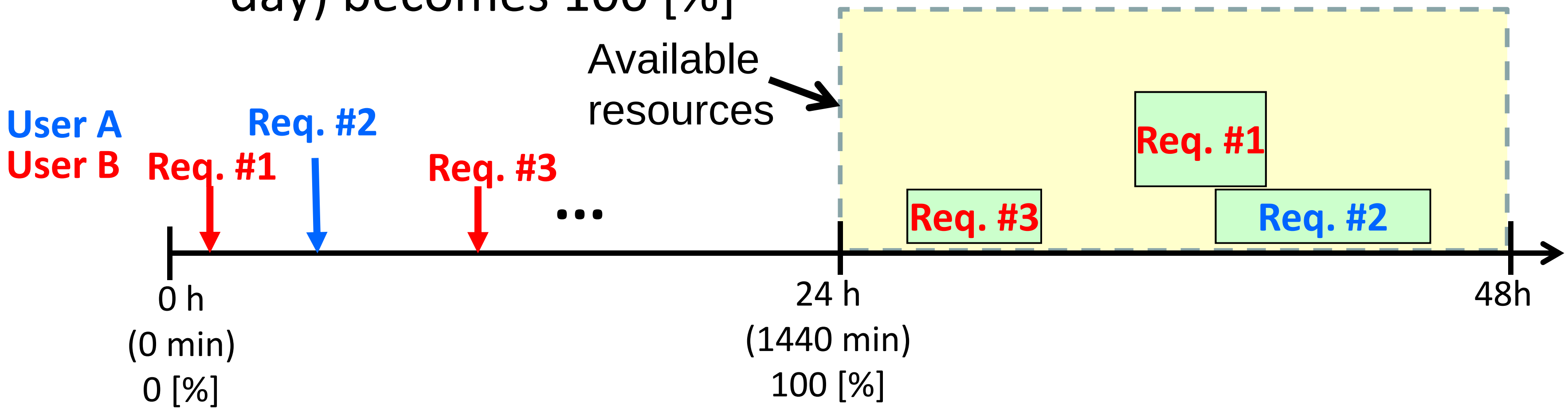
Simulation Settings

Environment Settings	
Comfiguration	GRM=1, NRM=3, CRM=10
# of sites / Domain	4 / N, 3 / S, 3 / U
Domain exchange points	X1{N, S,U}, X2{N, S}
# of CPUs / CPU unit value	N{8, 16, 32, 64}, S{8, 16, 32}, U {8, 16, 32} / 1
Bandwidth [Gbps] / unit value	in-domain : 5 / 5, inter domain : 10 / 3
Resource Requirement Settings	
Users	UserA, UserB
Resource requirement types	Type 1, 2, 3, 4 (Uniform distribution) →
Requested # of CPUs	1, 2, 4, 8 for all sites in all types (Uniform)
Requested bandwidth	1 [Gbps] for all paths in all types
Interval of each user request	Poisson arrivals
Reservation duration (D)	30, 60, 120 [min] (Uniform distribution)
LST - EST + D	D × 3



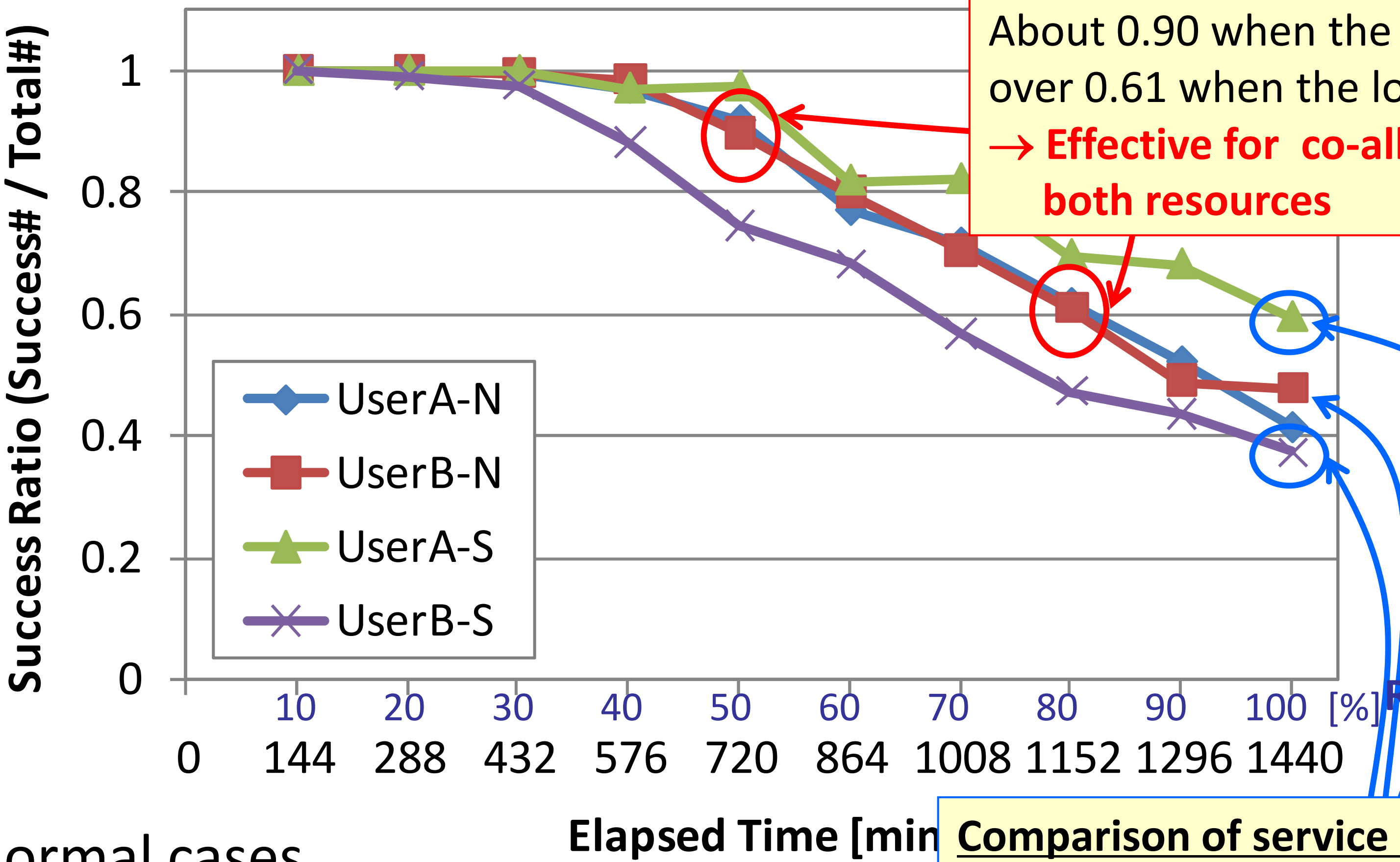
Simulation Scenarios

- In the first 24 hours, each user sends co-allocation requests for the next 24 hour resources
  - The request load (= Ideal resource utilization on the next day) becomes 100 [%]



- # of reservation plans N = 10
  - Time frames are selected equidistantly

Comparison of Co-allocation Success Ratios



Comparison of normal cases

About 0.90 when the load = 50[%], over 0.61 when the load = 80 [%]

→ **Effective for co-allocation of both resources**

Comparison of service levels (SL)

-N : UserA and B are comparable

-S : UserA is 0.60 and UserB is 0.37 when the load = 100[%]

→ **Can take option (C) User priority**

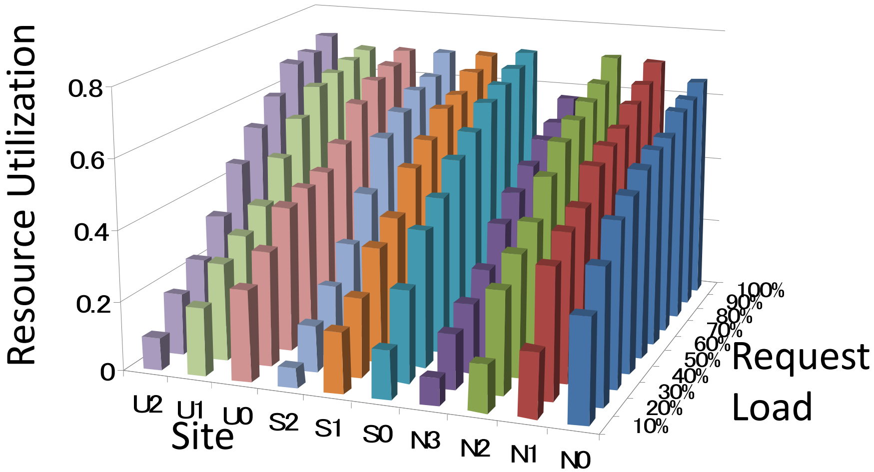
-N : Normal cases

-S : Configured different service levels

- UserB is set to a low priority
- For each UserB request, # of available resources is reduced to half amount

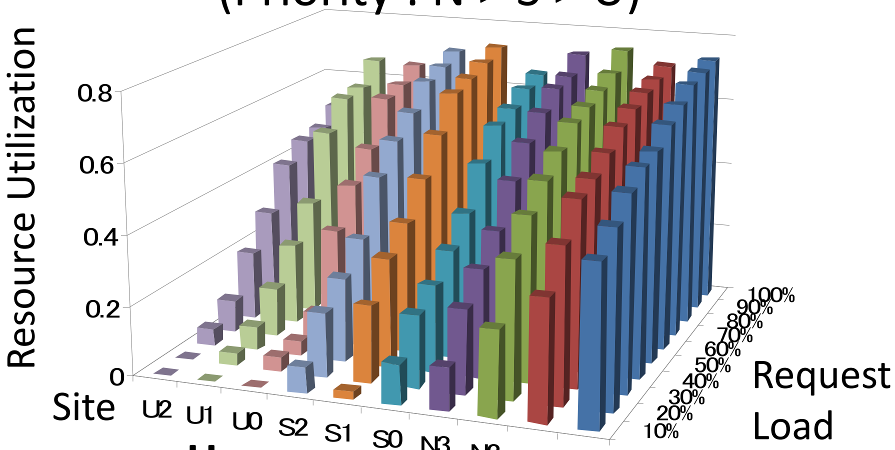
Comparison of Resource Utilizations with administrator options (A) and (B)

(A) Load balancing



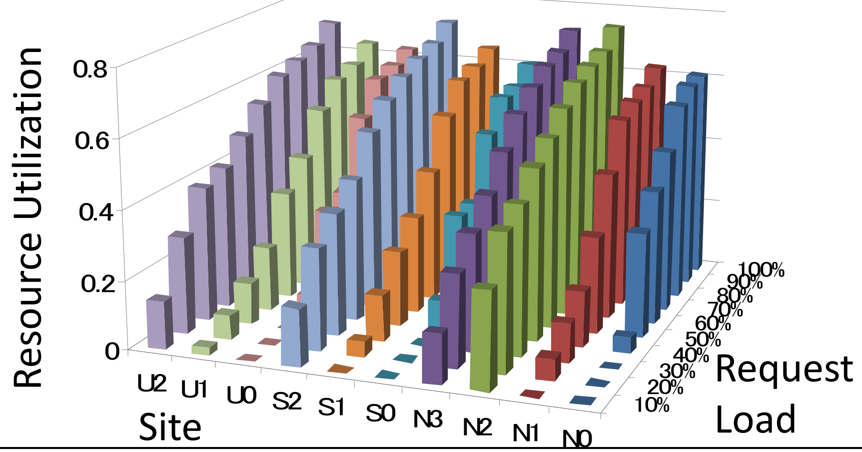
(B1) Preference allocation by domain

(Priority : N > S > U)



(B2) Preference allocation by # of CPUs

(Priority : *3(64) > *2(32) > *1(16) > *0(8))



vc_i is set as follows:

(B1) **N* = 1, S* = 10, U* = 100**

(B2) ***3 = 1, *2 = 10, *1 = 100, *0 = 1000**

Preferred resources are selected first

→ **Can take options (A) and (B)**

Experiments on practical issues

- Investigate if planning times are acceptable for an on-line service
- Compare planning times using
  - Additional constraints
  - Different IP solvers
- IP solvers
  - General IP solver: GLPK (free, but slow)
  - SAT-based solver: MiniSat and Sugar++
    - Sugar++ enables a SAT solver to solve IP problems
- Experimental settings

  CPU: Intel Core2 Quad Q9550 (2.83GHz),
  OS: CentOS 5.0, kernel 2.6.18 x86_64, Memory: 4GB

Comparison of planning times

Additional constraint are effective
Acceptable for an on-line service

MiniSat-st-1 is the best performance

Solver - con	Avg. [sec]	Max. [sec]	σ
GLPK	0.779	8.492	1.721
GLPK-st	0.333	4.205	0.700
MiniSat-st	12.848	216.434	27.914
MiniSat-st-1	1.918	2.753	0.420

GLPK is dominant
→ IP solvers are suitable for our algorithm

"-st" : Additional constraints (P_{max}=2)

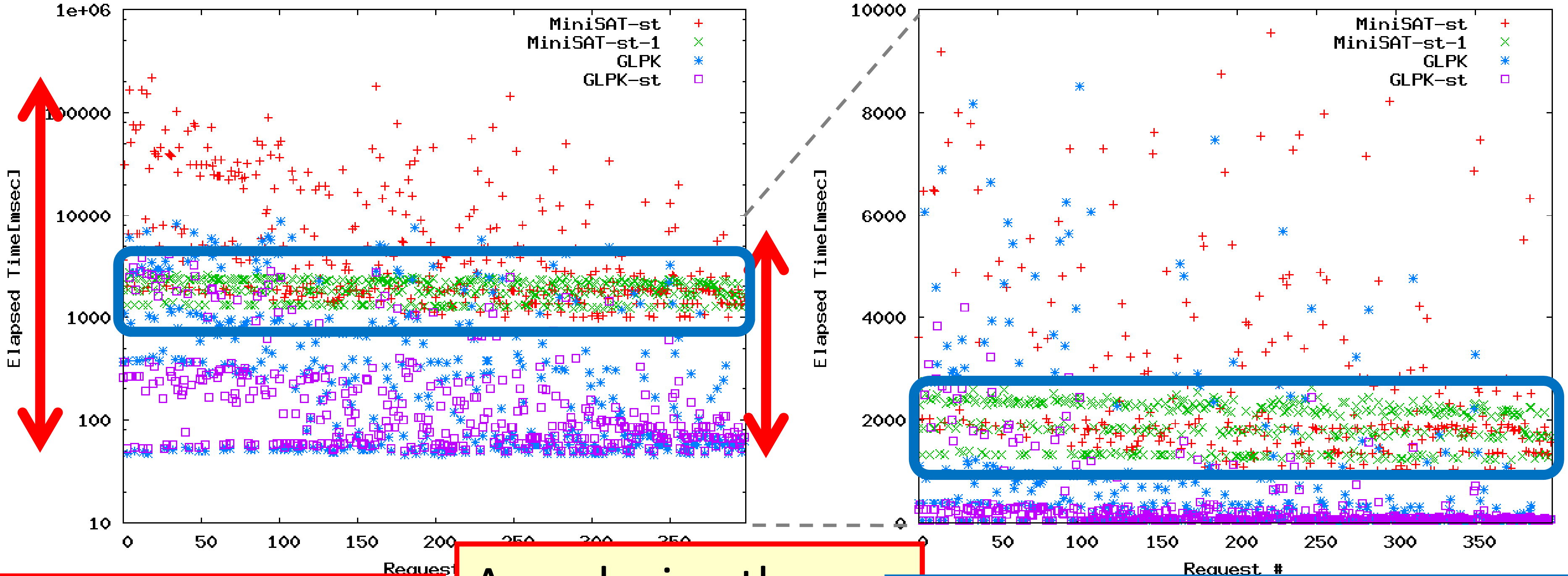
"-1" : # of SAT executions = 1 (Select only one satisfied solution)

Quality of plans : GLPK ≥ GLPK-st = MiniSat-st > MiniSat-st-1

Comparison of the Avg. planning times for each request

Planning times in log scale **Planning times from 0 to 10 [sec]**

GLPK / GLPK-st / MiniSat-st / MiniSat-st-1



While MiniSat-st-1 is stable, the others are disparsed

As reducing the available resources planning times are decreasing

The results of MiniSat-st-1 are proportional to the # of sites in the requirement Types

Discussion

- The coverage of IP problems is expanding
  - Performance of recent computers and the improvement of IP solvers
  - IP calculation times can be reduced by applying suitable constraints and approximate solutions
- Our resource co-allocation model
  - The search area of a single GRC can be localized, because GRCs can consist hierarchically
  - The # of variables scales by the # of "computer sites", not "computers"
  - In practical use, additional constraints will increase, e.g., latency, execution environment, and required data locations

→Modeling as an IP problem is effective for our model

Related Work

They cannot select suitable resources because the first found resources are selected

- Backtrack-based scheduling algorithm [Ando, Aida. 2007]
  - Enables both co-allocation and workflow scheduling
  - Co-allocation times become long and lots of resources are blocked, when the scheduler allocates resources incrementally
- Co-allocation algorithm for NorduGrid [Elmroth, Tordsson, 2009]
  - Search (1) computer sites and (2) paths between the selected sites, sliding a reservation time frame
  - Resource constraints make planning times long
- Co-reservation algorithm based on an optimization problem [Röblitz, 2008]
  - Network model is simple
  - Use all of resource information

No algorithm can take co-allocation options

Conclusions

- We propose an on-line advance reservation-based co-allocation algorithm for compute and network resources
  - Modeled as an integer programming (IP) problem
  - Enable to apply the user and administrator options
- The experiments showed
  - Our algorithm can co-allocate both resources and can take the administrator options
  - Planning times using a general IP solver with additional constraints are acceptable for an on-line service

Future Work

- Improve our algorithm and conduct further experiments on the scalability
- Apply sophisticated SLA and economy models and confirm that our algorithm can also take user options

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