



Interactive Realtime Multimedia Applications
on Service Oriented Infrastructures

Interactive Realtime Multimedia Applications on SOIs

Advancements in Real-Time Virtualized Computing



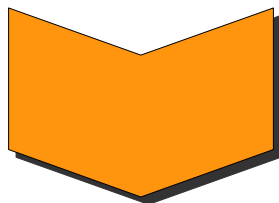
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Introduction

- High availability of broadband connections at affordable rates



- New paradigms of computing
 - **Distributed** computing
 - Not only **best-effort** remote access
 - But also remote **real-time interaction**

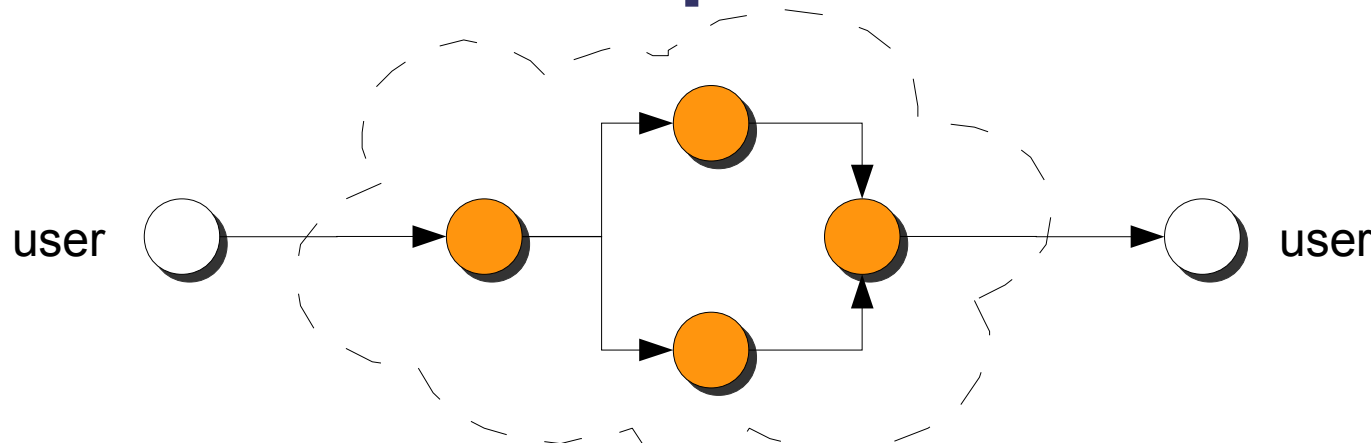
- New business models
 - From provisioning of network bandwidth
 - To provisioning of **distributed services** and **applications**
 - With **real-time/QoS constraints**
- User perspective/expectations
 - From buying costly equipments
 - To **renting** computing power, storage and services at **affordable rates**

- Provider perspective/expectations
 - High equipment (and infrastructure development) costs covered by renting them to **thousands** of users
- Resource management policies
 - High resource saturation levels
 - Overbooking strategies
 - Exploiting **statistical knowledge** about **actual usage** of services by users

Problem presentation

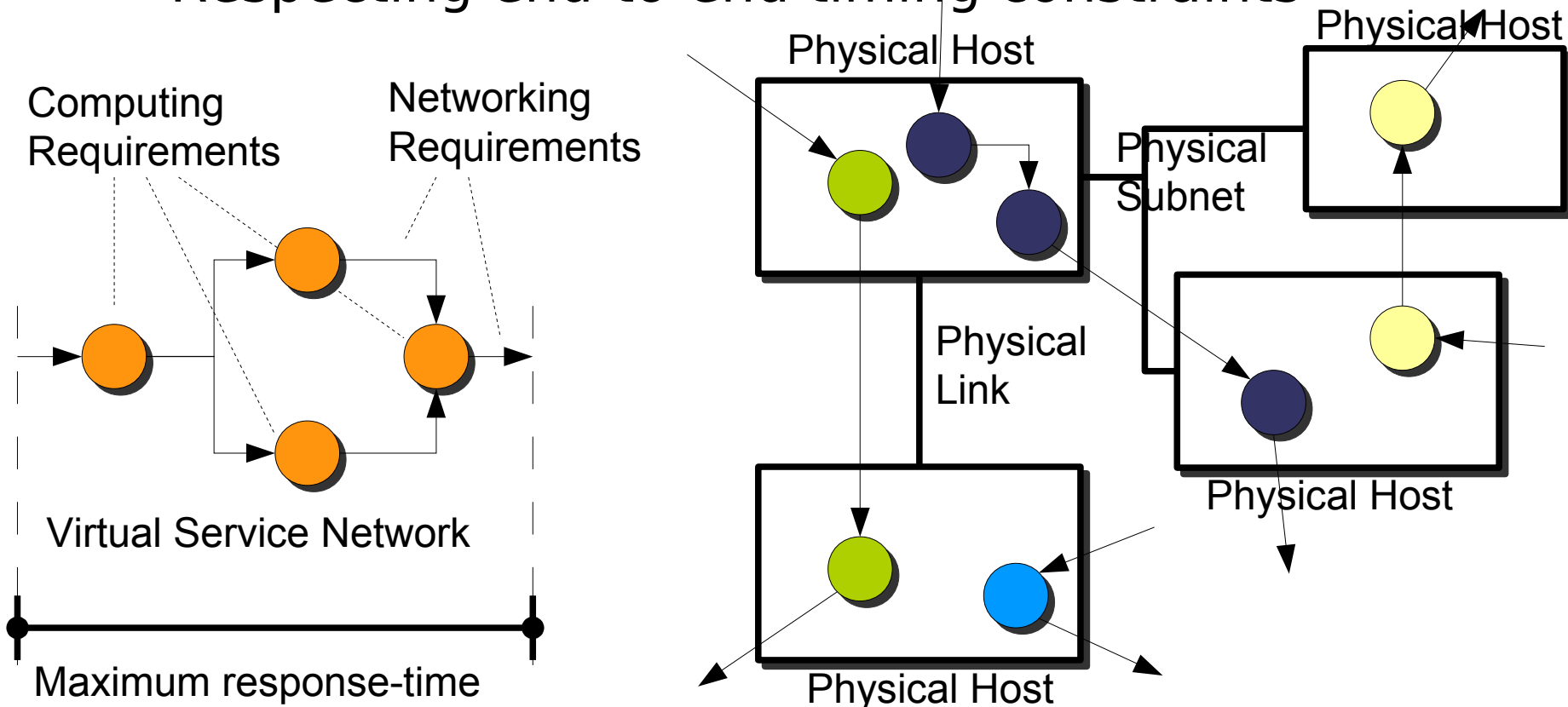
Problem presentation

- Distributed real-time interactive applications characterised by:
 - **Periodic activation** of a distributed workflow
 - Low resource saturation levels
 - **End-to-end response-time constraints**



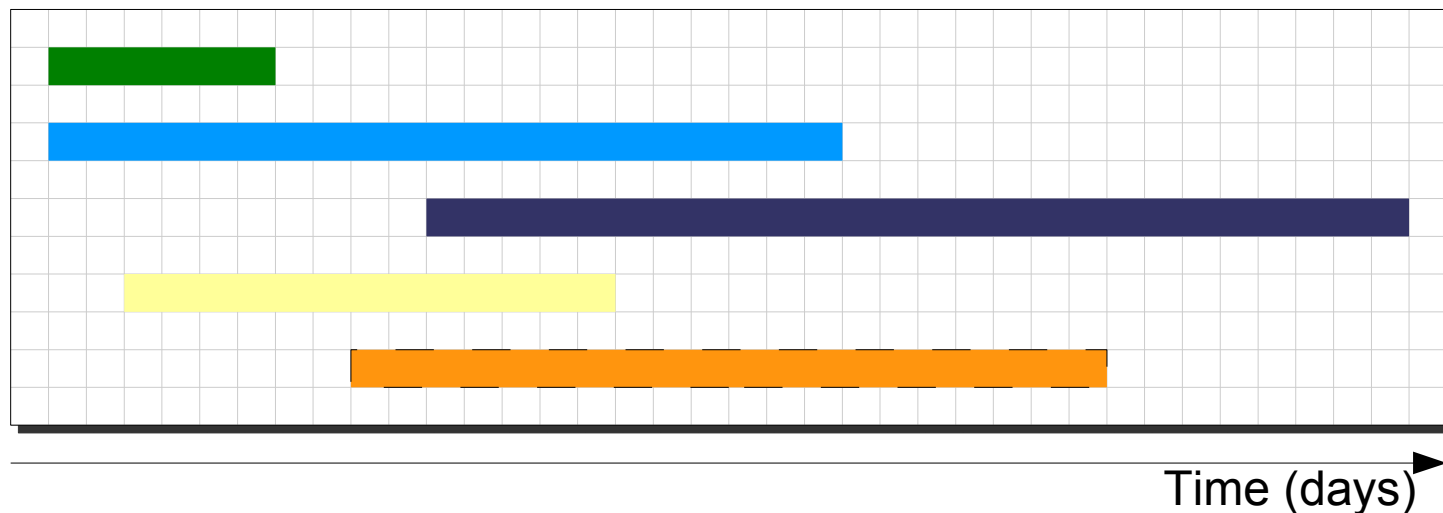
Problem presentation

- Optimum deployment of VSNs on PNs
 - Given computing/network requirements
 - Respecting end-to-end timing constraints



Problem presentation

- Optimum deployment of VSNs on PNs
 - Considering expected usage time-horizon (**advance reservations**)
 - Periods of overlapping reservations

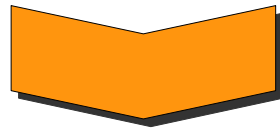


Envisioned approach

- **Temporal isolation** among independent application workflows
 - Time-sharing of computing nodes
 - Through **real-time scheduling** at the OS/kernel level
 - Time-sharing of network links
 - Through **QoS-aware scheduling** of the medium (e.g., Wf²Q+)

- Widely available **POSIX schedulers**
 - Priority-based
 - No temporal isolation
(high-priority tasks may arbitrarily delay low-priority ones)
 - Theoretical 69% utilisation bound
(for real-time tasks)
- **IRMOS real-time scheduler**
 - Hierarchical deadline/priority-based
 - Provides temporal isolation/enforcement
 - Theoretical 100% utilisation bound

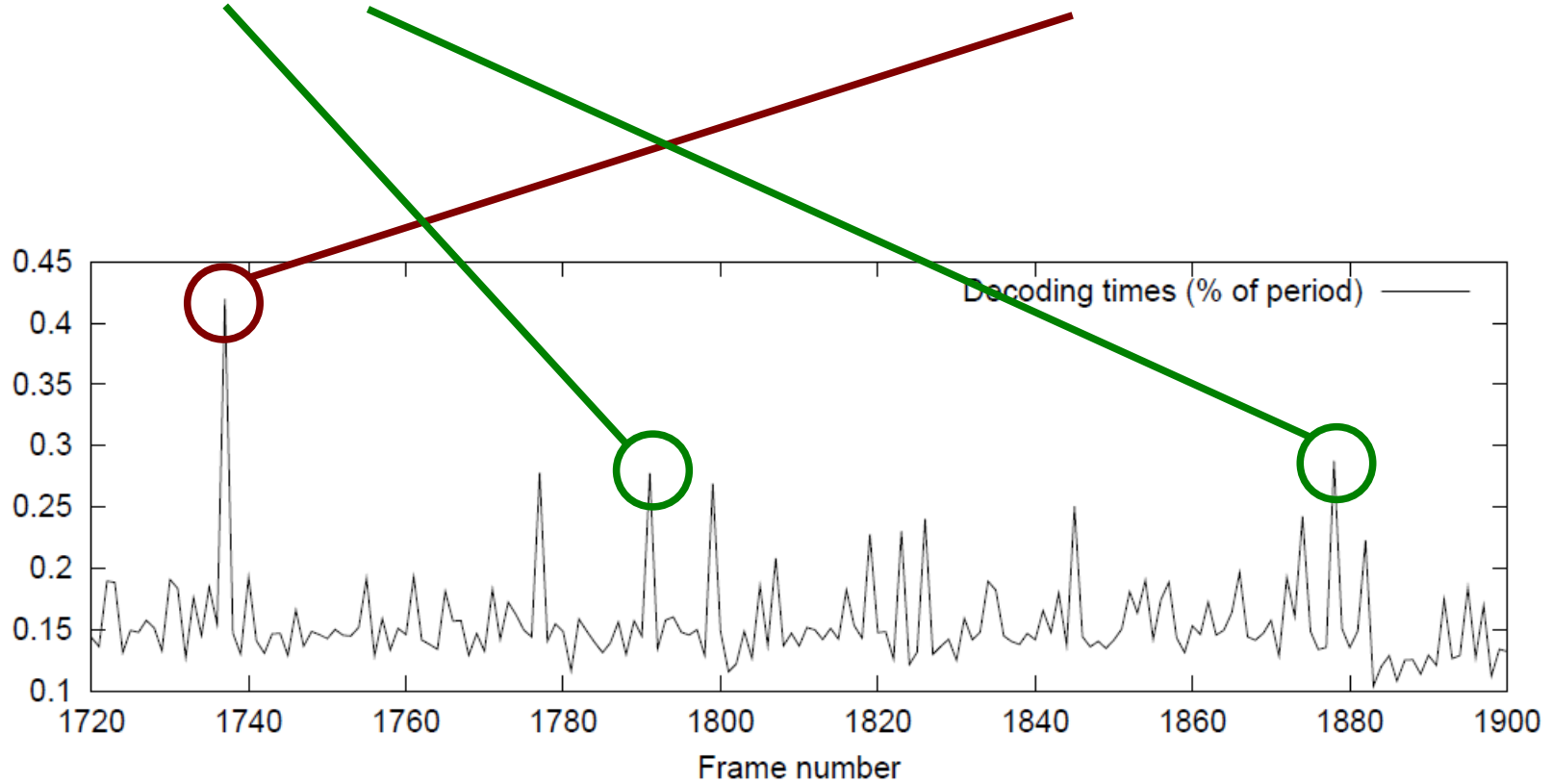
- Focus on **soft real-time** applications



- Probabilistic guarantees
 - **Response-time** guarantees
 - Minimum probability of respecting the end-to-end deadline constraint (vs deterministic, WCET-based)
 - **Availability** guarantees
 - Minimum probability of finding the resources available when actually activating the service

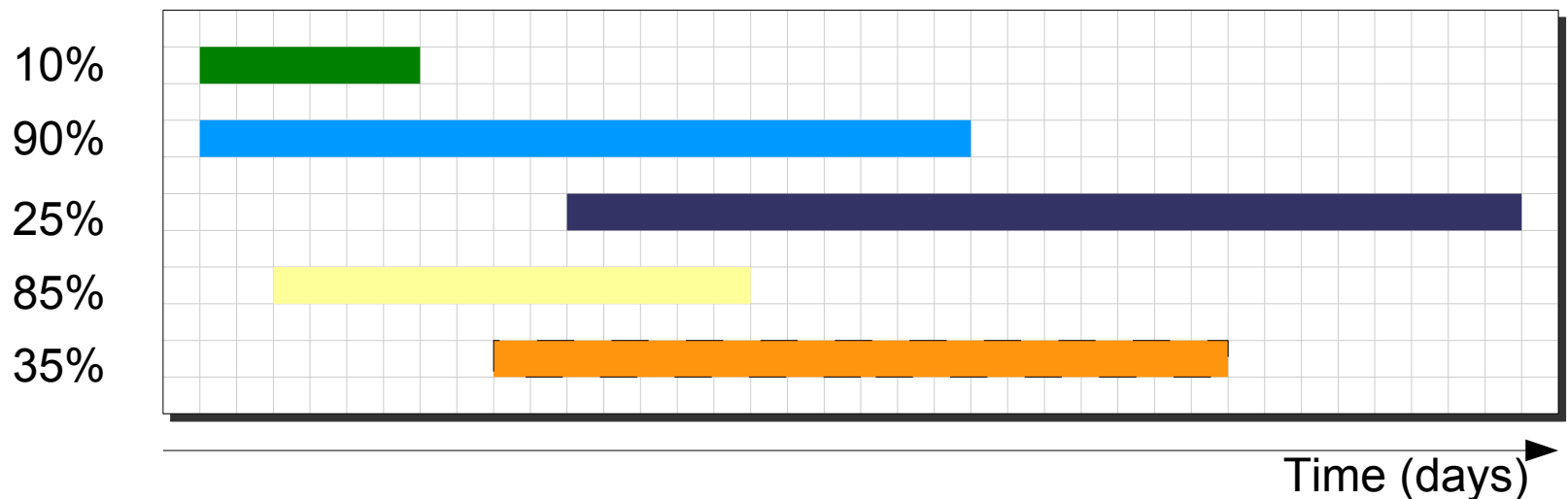
Probabilistic response-time guarantees

- Tune allocation on computation-time **percentile** (instead of WCET)



Probabilistic availability guarantees

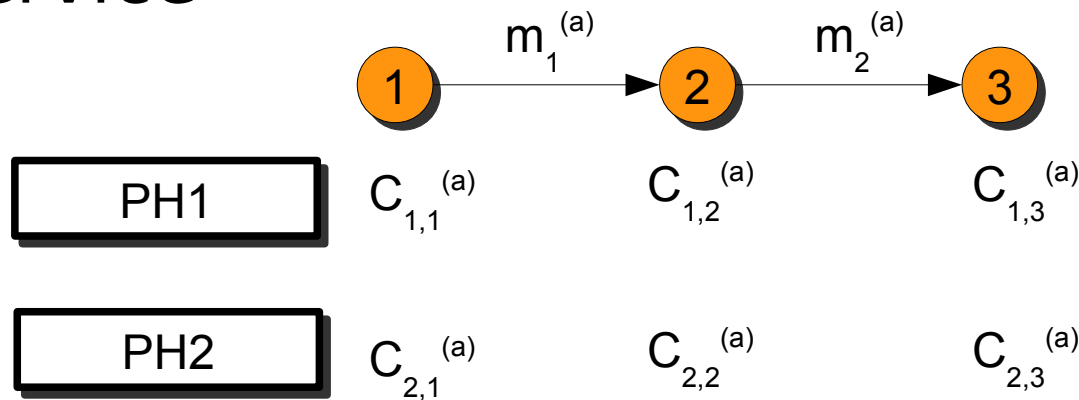
- Applications sharing the same PH may be independently activated
- Provider relies on actual probabilities of activation for admitted & new services



Modelling

Modelling real-time application workflows

- Application $A^{(a)}$ is a pipeline of services
 - $C_{i,j}^{(a)}$: computation-time of i -th service when deployed on j -th PH
 - $m_i^{(a)}$: size of data from i -th to $(i+1)$ -th service



Modelling computing response-time



Reservation-based real-time scheduling

- A service is assigned (Q_i, d_i) parameters

- Q time units (**budget**) reserved every time window of d time units (**period**)

- Service response-time due to computing:

$$\text{ceil}(C_{i,j}/Q_i) * d_i$$

- If $Q_i \geq C_{i,j}$, then response-time is d_i

- Schedulability constraint:
(U_j is max CPU capacity)

$$\forall j \in \mathcal{H}, \sum_{a \in \mathcal{A}} \frac{\sum_{i \in \mathcal{A}(a)} x_{i,j}^{(a)} c_{i,j}^{(a)}}{d_i^{(a)}} \leq U_j$$

Modelling network response-time

- Each transmission from i -th to $(i+1)$ -th service is reserved a bandwidth of b_i

- Data transmission time $\frac{m_i^{(a)}}{b_i^{(a)}} + L_s$

(L_s is a maximum fixed latency depending on the subnet)

- Schedulability constraint:
(B_s max link capacity)

$$\forall s \in \mathcal{S}, \quad \sum_{\substack{a \in \mathcal{A} \\ i \in \tilde{\mathcal{A}}(a)}} y_{i,s}^{(a)} b_i^{(a)} \leq B_s$$

Modelling end-to-end response-time

□ End-to-end response-time

$$\rho^{(a)} = \sum_{i \in \mathcal{A}^{(a)}} \left(d_i^{(a)} + \frac{m_i^{(a)}}{b_i^{(a)}} + \sum_{s \in \mathcal{S}} y_{i,s}^{(a)} L_s \right)$$

□ Variables

- $d_i^{(a)}$ (real): relative computing deadline
- $b_i^{(a)}$ (real): network bandwidth
- $x_{i,j}^{(a)}$ (boolean): i-th node on j-th host
- $y_{i,s}^{(a)}$ (boolean): i-th node on s-th subnet
(derivate)

Objective of optimization

- Cost due to turn-on of j -th host in each time-slot I_h : ζ_j
- Gain from accepting new service $G^{(a)}$
- Minimize cost due to new hosts to turn on for admitting new services

$$\min_{x_{i,j}^{(a)}, y_{i,s}^{(a)}, d_i^{(a)}, b_i^{(a)}} \sum_{I_h \in \mathcal{G}} \sum_{j \in \mathcal{H}_{off}(I_h)} \zeta_j m_{j,h}$$

■ constraints

$$\begin{cases} Km_{j,h} \geq \sum_{a \in \mathcal{A}(\min I_h), i \in \mathcal{A}^{(a)}} x_{i,j}^{(a)} \\ m_{j,h} \leq \sum_{a \in \mathcal{A}(\min I_h), i \in \mathcal{A}^{(a)}} x_{i,j}^{(a)} \end{cases} \quad \forall I_h \in \mathcal{G}$$

Probabilistic response-time guarantee

□ Deterministic setting

- Assumptions (Worst-Case figures):

- $C_{i,j}^{(a)} \leq Q_i^{(a)}$; $m_i^{(a)} / b_i^{(a)} + L_s^{(a)} \leq T^{(a)}$

- Goal: $\rho^{(a)} \leq R^{(a)}$

□ Probabilistic setting

- Assumptions (probabilistic figures):

- $\Pr\{C_{i,j}^{(a)} \leq Q_i^{(a)}\} \geq \alpha_i^{(a)}$

- $\Pr\{m_i^{(a)} \leq M_i^{(a)}\} \geq \beta_i^{(a)}$

- Goal $\Pr\{\rho^{(a)} \leq R^{(a)}\} \geq \phi^{(a)}$

- Constraint: $\prod_{i \in \mathcal{A}^{(a)}} \alpha_i^{(a)} \beta_i^{(a)} \geq \phi^{(a)}$

Probabilistic availability guarantee

- Leverage of **actual average activation rates** of services $r^{(a)} \ll 1/T^{(a)}$
- Probability that service is active in I_h :

$$\pi_i^{(a)} = r^{(a)} d_i^{(a)} \quad \pi_{i,j}^{(a)} \triangleq r^{(a)} d_i^{(a)} x_{i,j}$$

- For each time-slot I_h , prob. of enough bandwidth for all services in \mathcal{B} :

$$P_{j, \mathcal{B}}(I_h) = \prod_{a \in \mathcal{B}} \pi_{i,j}^{(a)} \prod_{a \in \mathcal{A}(I_h) \setminus \mathcal{B}} \overline{\pi_{i,j}^{(a)}}$$

Probabilistic availability guarantee

- Probability $\xi^{(a)}$ of having enough computing bandwidth for all services

$$\begin{aligned}
 & \sum_{I_h \in \mathcal{G}(a)} \frac{tn_h}{f^{(a)} - s^{(a)}} \prod_{j \in \mathcal{H}} \sum_{\mathcal{B} \subset \mathcal{A}(I_h) \setminus \{a\}} v_{\mathcal{B} \cup \{a\}}^j \cdot \\
 & \cdot \prod_{b \in \mathcal{B}} \prod_{i \in \mathcal{A}(b)} \pi_{i,j}^{(b)} \prod_{b \in \mathcal{A}(I_h) \setminus \{a\} \setminus \mathcal{B}} \prod_{i \in \mathcal{A}(b)} \overline{\pi_{i,j}^{(b)}} \cdot \\
 & \cdot \prod_{s \in \mathcal{S}} \sum_{\mathcal{B} \subset \mathcal{A}(I_h) \setminus \{a\}} w_{\mathcal{B} \cup \{a\}}^s \cdot \\
 & \cdot \prod_{b \in \mathcal{B}} \prod_{i \in \mathcal{A}(b)} \pi_{i, \{s\}}^{(b)} \prod_{b \in \mathcal{A}(I_h) \setminus \{a\} \setminus \mathcal{B}} \prod_{i \in \mathcal{A}(b)} \overline{\pi_{i, \{s\}}^{(b)}} \geq \xi^{(a)}, \forall a
 \end{aligned}$$

Probabilistic optimization objective

- We introduce
 - Penalty $P^{(a)}$ due to SLA violation
- Minimize expected gain minus costs:

$$\min_{x_{i,j}^{(a)}, y_{i,s}^{(a)}, d_i^{(a)}, b_i^{(a)}} \sum_{I_h \in \mathcal{G}} \sum_{j \in \mathcal{H}_{off}(I_h)} \zeta_j m_{j,h} - \sum_{a \in \mathcal{A}} x^{(a)} \left(G^{(a)} - \overline{\xi^{(a)}} P^{(a)} \right) \quad (20)$$

- Finally, we obtained a Mixed-Integer Non-Linear Programming (MINLP) optimization problem

Conclusions and future work

- We tackled the problem of
 - allocation of distributed applications
 - with real-time timing constraints
 - over a physical network
 - under both deterministic and probabilistic guarantees in terms of
 - End-to-end response-time
 - Application availability at run-time
 - optimizing various system-wide metrics
- We modelled it as a MINLP problem

- Validate the technique through simulation or real implementation
- Address scalability issues when deploying over large physical networks
 - via hierarchical approaches
 - via heuristics-based inexact solvers
- Refined optimization objectives
- Consider migration of already allocated virtualized services
- Extensions to non-linear workflows

- T. Cucinotta, K. Konstanteli, T. Varvarigou, "*Advance Reservations for Distributed Real-Time Workflows with Probabilistic Service Guarantees*," in Proceedings of the IEEE International Conference on Service-Oriented Computing and Applications (SOCA 2009), December 2009, Taipei, Taiwan
- K. Kostanteli, D. Kyriazis, T. Varvarigou, T. Cucinotta, G. Anastasi, "*Real-time guarantees in flexible advance reservations*," 2nd IEEE International Workshop on Real-Time Service-Oriented Architecture and Applications (RTSOAA 2009), Seattle, Washington, July 2009
- T. Cucinotta, G. Anastasi, L. Abeni "*Respecting temporal constraints in virtualised services*," in Proceedings of the 2nd IEEE International Workshop on Real-Time Service-Oriented Architecture and Applications (RTSOAA 2009), Seattle, Washington, July 2009
- F. Checconi, T. Cucinotta, D. Faggioli, G. Lipari, "*Hierarchical Multiprocessor CPU Reservations for the Linux Kernel*," in 5th International Workshop on Operating Systems Platforms for Embedded Real-Time Applications (OSPERT 2009), Dublin, Ireland, June 2009
- T. Cucinotta, G. Anastasi, L. Abeni, "*Real-Time Virtual Machines*," in 29th Real-Time System Symposium (RTSS 2008) - WiP Session, Barcelona, December 2008

Thanks for your attention

Questions ?