Offline-First Strategies in Multi-Cloud Environments

A Survey on the Applicability of Workload Placement in Sky Computing

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Introduction

- The project **SKY CONTROL** in cooperation with **Systrade GmbH** and funded by the **Federal Ministry for Economic Affairs and Energy (BMWE)**.
- It started in **02/2025** and is set for two years till **01/2027**.
- The central aspects of SKY CONTROL:
  - **Cost control in multi-cloud environments**
    - Development of control and planning tool for insights into resource usage across multiple cloud providers, with visualization for easier comprehension.
  - **Risk management in multi-cloud environments**
    - Evaluation of risks based on asset criticality, data sensitivity, and compliance standards.

Contributions for SMEs

SKY CONTROL aims to provide transparency into the properties of the entire infrastructure and its components. The project is designed to be highly adaptable, leveraging both existing and emerging technologies!

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Introduction

Sky Computing

SKY CONTROL leverages the **Sky Computing** paradigm, which is an evolution of cloud computing. But what is Sky Computing?

- Cloud computing has become a significant technology for companies.
- Larger enterprises increasingly use cloud computing and expand over multiple providers $\Rightarrow$ **Multi-Cloud**!
- Multi-cloud setups have the following benefits:
  - **Reduction of provider dependency**
  - **Cost optimization**
  - **Business continuity through partial redundancy**
  - **Selection of the best service offerings for the respective application**

Question?

How to make (multi) cloud computing setups attractive and adoptable for SMEs?

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Introduction

- There are many different cloud computing offerings by different vendors (Amazon Web Services, Google Cloud Platform, Microsoft Azure).
- Each of the vendors uses different APIs for the management and interaction with the services.
- The prices for the individual services differ from vendor to vendor.
- The overview of the prices and the integration of the APIs is a huge challenge, especially for SMEs! ⇒ (See Slide 19)

Question?

How to leverage the benefits of multi-cloud setups for SMEs and find answers to the questions posed in this section?

Idea!

Develop a framework which incorporates tools for the management, the analysis of costs and the overview of complex infrastructures for SMEs! ⇒ **SKY CONTROL**

Computing of the future? – Quote from 1961

- The following section 2 presents the foundation for the SKY CONTROL framework.
- The background, concepts and ideas behind the framework will be introduced.
- The origin of the project is **Cloud Computing**.

"computation may someday be organized as a public utility, just as the telephone system is a public utility. We can envisage computer service companies whose subscribers are connected to them [...]. Each subscriber needs to pay only for the capacity that he actually uses, but he has access to all programming languages characteristic of a very large system." – John McCarthy

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Challenges in Multi-Cloud setups

Benefits

+ **Multiple Provider**
  - **Best-of-Breed Services:** Selection of cloud providers based on their strengths in specific areas (e.g., data storage, machine learning, global reach).
  - **Avoiding Vendor Lock-in:** Mitigating the risk of vendor lock-in by not becoming overly reliant on a single provider.
+ **Workload Optimization**
  - **Tailored Workloads:** Deployment of workloads on the most suitable cloud platform.
  - **Performance Efficiency:** Usage of providers that offer optimal performance for specific applications or services.

Challenges

− **Cost Management:**
  - **Cost Comparison:** Comparison of pricing across different providers to take advantage.
− **Risk Management and Resilience:**
  - **Disaster Recovery:** Enhancing disaster recovery and business continuity by spreading critical services and data.
− **Compliance and Governance:**
  - **Regulatory Compliance:** Usage of different providers to meet specific compliance requirements that vary by region or industry.
  - **Unified Governance:** Implementation of a unified governance framework that manages and enforces policies across all cloud platforms.

Interoperability of cloud services – A historical view

The Internet

- In the early 1960s several groups were developing packet switching technology.
- The early networks lacked interoperability and therefore only niche technologies developed.
- Robert Kahn introduced the ARPANET with open architecture, that formed TCP/IP networks.
- The ARPANET developed to the Internet as we know it now $\Rightarrow$ *The Network of networks*

Question

What does this mean in the context of cloud computing? Can we build *The Cloud of clouds*?

Sky Computing – Analogy to Internet

Internet	Sky Computing
Router	Server
Autonomous System	Datacenter / Availability Zone
Internet Service Provider	Cloud Service Provider
Enterprise Network	Private Cloud
Internet Protocol	Compatibility Layer
BGP	Intercloud Layer

Source

Stoica, Ion, and Scott Shenker. "From cloud computing to sky computing". *Proceedings of the Workshop on Hot Topics in Operating Systems*. 2021.

Sky Computing

Sky Computing

- Applications should run in/on any cloud provider without managing deployments in individual clouds!
- Applications should be movable from one cloud to another without hardships! (Just like packets in networks)
- Applications build for one cloud should also be operational in other providers clouds! (Instant multi-cloud)

Sky Computing

Sky computing is a new paradigm, which aims at interoperable cloud services. It shall fulfill the vision of utility computing and applications should be able to run on any cloud provider.

How to reach the goal?

Sky computing tries building on an infrastructure consisting of multiple and heterogeneous, competing commercial cloud providers. *No standardization of the clouds!*

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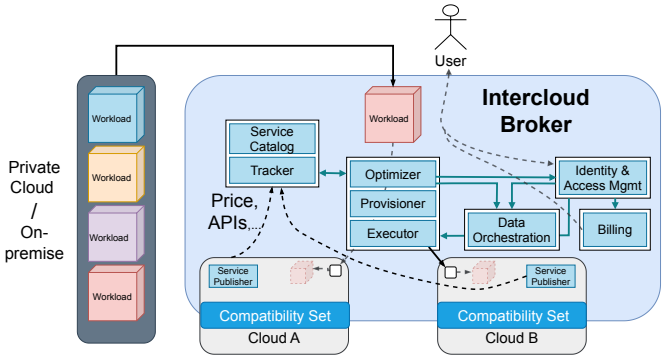
Sky Computing – Intercloud Broker

Stoica



What about the modules **Identity & Access Mgmt**, **Billing** and **Data Orchestration**?
⇒ **Central components of SKY CONTROL!**

Stoica, I. "Sky computing: Opportunities and challenges". *In Studies in Systems, Decision and Control* (pp. 15–27), 2024.

- **Service Catalog**
  - Contains location and API information of services.
- **Tracker**
  - Tracks resource availability across clouds and their locations.
- **Optimizer**
  - Computes an optimal placement of the applications and may perform re-optimization.
- **Provisioner**
  - Allocating the resources with all dependencies automatically (Terraform, etc.).
- **Executor**
  - Packages each application's tasks and runs them on the resources allocated by the provisioner.

SKY CONTROL

We are faced with a twofold problem for users of hybrid multi-cloud infrastructures:

1. **Effective cost control and management in hybrid infrastructures:**
   - Recording fixed and ongoing costs and monitoring (preferably in real time) all costs and resource consumption (especially energy) across all systems of a complex hybrid infrastructure.
   - Transparent visualization of costs and dynamic optimization, partially automated.
2. **Security of information assets, information security management:**
   - A systematic and up-to-date assessment of the security/protection level of subsystems and the criticality of the information assets on them.

We introduce SKY CONTROL as a novel framework, which is is designed to cope with the challenges SMEs face when using multi-cloud deployments. The overview of the costs of the services used by the companies is very challenging and is a major drawback in the choice of such architectures. Another very important point is the overview and analysis of potential security risks and governance of the company's assets.

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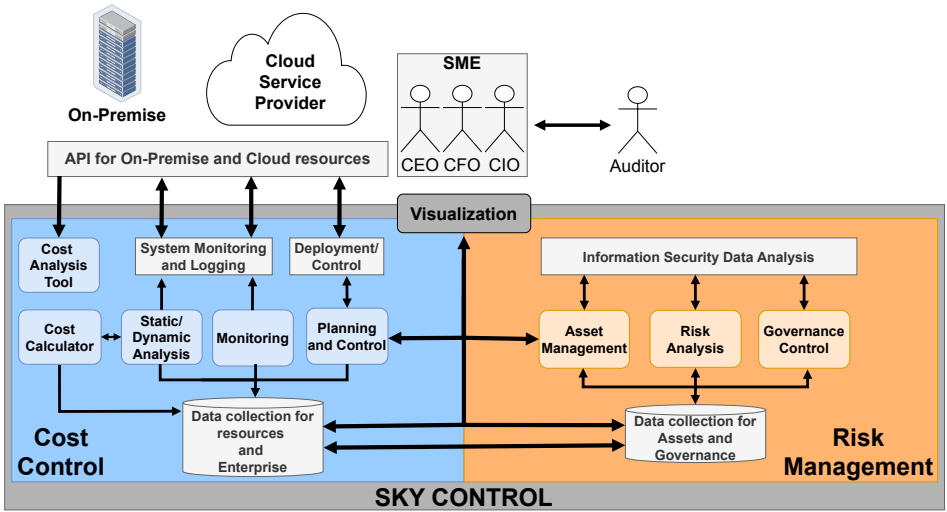
SKY CONTROL – Architecture



SKY CONTROL – Architecture

Cost Control

- Responsible for the analysis, calculation, and visualization of on-premise and cloud resources.
- Takes care of the static analysis of the resources by analyzing the metadata.
- Static attributes are information such as the ID of the resource, the characteristics of the (virtual) resource, and hardware capabilities (CPU information, main memory size, etc.).
- The dynamic analysis focuses on the attributes of the resources, such as the consumption of CPU, main memory, and bandwidth (for Ingres and Egress).

Risk Management

- Responsible for the analysis and management of assets of the customer.
- The module collects information on the assets for detailed insights that can be stored for analysis.
- This component gives insight into the expected threats and the classification of risks for the individual assets and the whole company.
- This is a crucial basis for governance in complex multi-cloud environments.
- The database for audits is important for the fulfillment of governance requirements and makes SMEs more compatible with bigger companies.

SKY CONTROL – Concepts

- Automation plays a decisive role in the technical/architectural concept for SKY CONTROL
- The use of open source tools for the functionality is essential.
- Tools and concepts from the SASE (Secure Access Service Edge) shall be incorporated ⇒ modules for **Identity & Access Mgmt**, **Billing** and **Data Orchestration**.
- Another technological basis for the development of SKY CONTROL is the sky computing concept (Stoica et al., see section 2).

SKY CONTROL marks the first concrete implementation of the innovative sky computing concept for small-medium enterprises.

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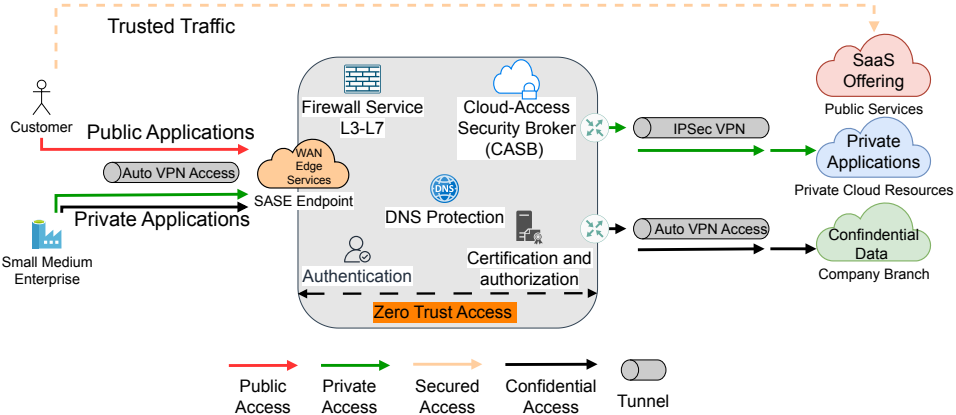
Application of SASE ⇒ Identity & Access Mgmt + ZTNA



Publications so far

- **SKY CONTROL: A novel concept for a vendor-agnostic multi-cloud framework to optimize cost control and risk management for small and medium-sized enterprises**. Christian Baun, Henry-Norbert Cocos, Martin Kappes. *Proceedings of the Tenth International Congress on Information and Communication Technology (ICICT 2025)*, 02/2025, London, United Kingdom.

- **The Evolution of Cloud Computing Towards a Vendor Agnostic Market Place Using the SKY CONTROL Framework**. Henry-Norbert Cocos, Christian Baun, Martin Kappes. *In Proceedings of the 15th International Conference on Cloud Computing and Services Science (CLOSER 2025)*, ISBN 978-989-758-747-4, ISSN 2184-5042, pages 211-218. DOI: 10.5220/0013361200003950.
  $\Rightarrow$ **(Won Best Poster Award!)**

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Expected impact of the project

- SKY CONTROL takes a holistic view of the value of digital assets and the costs of their storage and processing.
- The analysis of costs and protection of critical data and its processing goes far beyond the classic performance analysis.
- SKY CONTROL has the ambitious goal of optimizing the factors of costs and risks and to implement it in real-time wherever possible.
- In the medium to long term, a solution such as SKY CONTROL could also have a macroeconomic impact.

If this were to create a market, cloud offerings could be traded in the manner of stocks at a stock exchange. Even companies themselves could monetize idle resources without evoking security risks.

Early findings in the project

- All major CSPs provide an open API for cost information retrieval!
  - **AWS Price List Bulk API**
  - **Azure Retail Prices REST API**
  - **Google Cloud Billing API**
- However... Requesting data for services result in large queries ⇒ **e.g Amazon returns > 6 GB!**
- The data retrieved is not normalized! ⇒ **e.g. Azure returns SKU-IDs (Stock Keeping Units) for services (hard to comprehend and filter!)**
- Keeping data of pricing up to date is very challenging ⇒ **vendors can change prices often and do not inform customers!**
- The API endpoint of the pricing information can be subject to changes ⇒ **These changes will not be advertised by the CSP!**

These early findings only apply to static pricing! Dynamic behaviour of services is not included!

Integration of Offline-First Strategies in SKY CONTROL

- The SKY CONTROL project is a great vehicle for my research!
- On-Prem Workloads of SMEs should and could be migrated to the cloud!
- The use and incorporation of SASE is a good start for the implementation $\Rightarrow$ **SDN as a network basis + ZTNA for securing access and use!**
- Offline-First Strategies in the SKY CONTROL project can be an additional Model in the calculation of prices for workload operation and applied to multi-cloud environments!

The future work of the integration of Offline-First-Strategies into the SKY CONTROL project is very promising!´

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Conclusion

- The SKY CONTROL framework offers a promising solution for SMEs facing the complexity of managing multi-cloud environments.
- By combining cost control with risk management, it addresses two critical challenges:
  - **Optimizing resource allocation**
  - **Safeguarding sensitive data**
- SKY CONTROL's dynamic analysis, real-time cost tracking, and risk assessment tools provide SMEs with greater transparency and control over their IT infrastructure.
- The application of sky computing enhances the flexibility and efficiency of multi-cloud setups, offering SMEs a competitive edge in today's cloud-driven landscape.

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Future Work

- **Development of a taxonomy for CSP prices and services.**
- **Development of a price calculation and estimation tool for services.**
- **Development of a provisioning tool for the deployment of services (on-premise and cloud).**
- **Incorporation of Offline-First Strategies into the SKY CONTROL project!**
  $\Rightarrow$ Solving the problem of **data gravity**!

Data Gravity

Data gravity describes the tendency for applications to run in the same cloud as their data, mainly due to high data transfer latency and significant egress costs when moving data between clouds. This is a major obstacle for multi-cloud applications! Stoica et al. propose using overlay routing (SDN), multiple instances (redundancy), and parallel TCP connections to speed up data movement. For structured data optimizations like copy-on-access, caching, and prefetching can be used.

Feedback and discussion

Since the project has started and is in an early stage, we are very interested in your feedback!

The project is realized in cooperation with the company **Systrade GmbH**.

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