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Chapter 5

Integrating public and private clouds: Challenges and solutions

Ravi Kumar Vankayalapati

Cloud AI ML Engineer, Equinix, Dallas, USA.
ravikumar.vankayalapti.research@gmail.com

Abstract

Integrating public and private clouds into a cohesive hybrid cloud environment offers organizations the ability to balance scalability, security, and customization. However, this integration poses challenges such as interoperability, data synchronization, security risks, and performance consistency across disparate systems. This abstract explores these challenges and presents solutions like API integrations, containerization, microservices, and automation tools for seamless workload management. It also highlights the importance of unified governance frameworks and compliance management to ensure smooth operations. By addressing these issues, businesses can leverage the strengths of both public and private clouds, driving innovation, efficiency, and scalability in their IT infrastructure.

Keywords

Hybrid Cloud, Public Cloud, Private Cloud, Cloud Integration, Interoperability, Data Synchronization, Security Risks, Performance Consistency, API Integrations, Containerization, Microservices, Automation, Workload Management, Cloud Governance, Compliance Management, Cloud Solutions, Scalability, IT Infrastructure, Cloud Optimization.

5.1. Introduction

The idea of this essay is to delve into the current thinking around the issues, challenges, and solutions for integrating public and private clouds. There is a growing reliance on cloud computing to amplify business agility, enhance the optimization of IT resources,

reduce the energy usage, and provide cost savings (Ramanakar et al., 2023). Keeping this in mind, there is a growing interest in integrating public and private clouds to leverage the advantages of both to achieve operational excellence. The goal is to investigate the challenges and find solutions for seamlessly integrating public and private clouds. To accomplish that, it will be necessary to first understand the features, advantages, and constraints of both public and private cloud computing. The topics to be discussed include an overview, cloud deployment and service models, challenges in integrating public and private clouds, related solutions, and future perspectives. For business readers it can be quite difficult reading so much content presented online at once which is why there are companies that will help. Small adjustments have also been made to the text to better communicate professionalism and expertise.

Getting started, a seamless integration/operation of a cloud system is of utmost importance, not to mention the integration between two clouds, public and private. The rest of this essay is organized as follows. The next section provides an overview of cloud computing, including cloud deployment models and cloud service models. Challenges in integrating public and private clouds are then discussed, followed by related solutions. The essay concludes with a look at future trends of integrating public and private clouds (Syed, 2017). Cloud computing has become an essential component in modern business operations, providing flexibility, scalability, and cost-effectiveness. As organizations increasingly adopt cloud solutions, the integration of public and private clouds—often referred to as a hybrid cloud model—has gained significant attention. This integration allows businesses to leverage the benefits of both models: the scalability and cost-efficiency of public clouds and the control, security, and customization of private clouds. However, the seamless operation and integration of these two cloud environments present several challenges, including data interoperability, security concerns, and complexity in management. This essay explores these challenges and investigates potential solutions, providing a comprehensive overview of cloud computing, including deployment and service models. It also discusses the future prospects of hybrid cloud integration, offering insights for businesses seeking to optimize their IT resources, improve agility, and reduce operational costs through effective cloud integration.

5.2. Understanding Public and Private Clouds

A private cloud is an IT capability that offers many of the advantages of a public cloud, however it is dedicated to a single organization’s use. Private clouds are typically physically isolated and leverage an organization’s existing IT infrastructure (Danda, 2023). The isolation gives the organization additional control over security and

performance, and is therefore a better fit for many critical workloads such as electronic health records. Private clouds however do not generally offer the same economies of scale as public clouds. In general a private cloud can only be built using the same sizeable investments in virtualization and automation that allow public clouds to be cost-effective. Public and private clouds are distinguished by four chief attributes: deployment, locate, manage, and the need for trust. Public clouds naturally support off-premise deployments, whereas private clouds must be deployed on-premise or in a hosted environment. As a result, public and private clouds are normally located in different data centers, cities, or even countries. Public and private clouds vary in a number of important ways, particularly how they are managed and the level of trust they require. Public clouds follow a one-size-fits-all philosophy that sacrifices control for simplicity and economies of scale. Private clouds deliver a much higher level of control, but require significant finesse and expertise to manage. Public clouds can be queried and compared using the Web. To evaluate a private cloud a site visit and extensive auditing are required. More than anything else, the difference between public and private clouds is the level of trust required. Public clouds are designed for complete strangers to share computational resources and are inherently multi-tenant. Private clouds build on an organization's existing hardware and so can be trust-based.

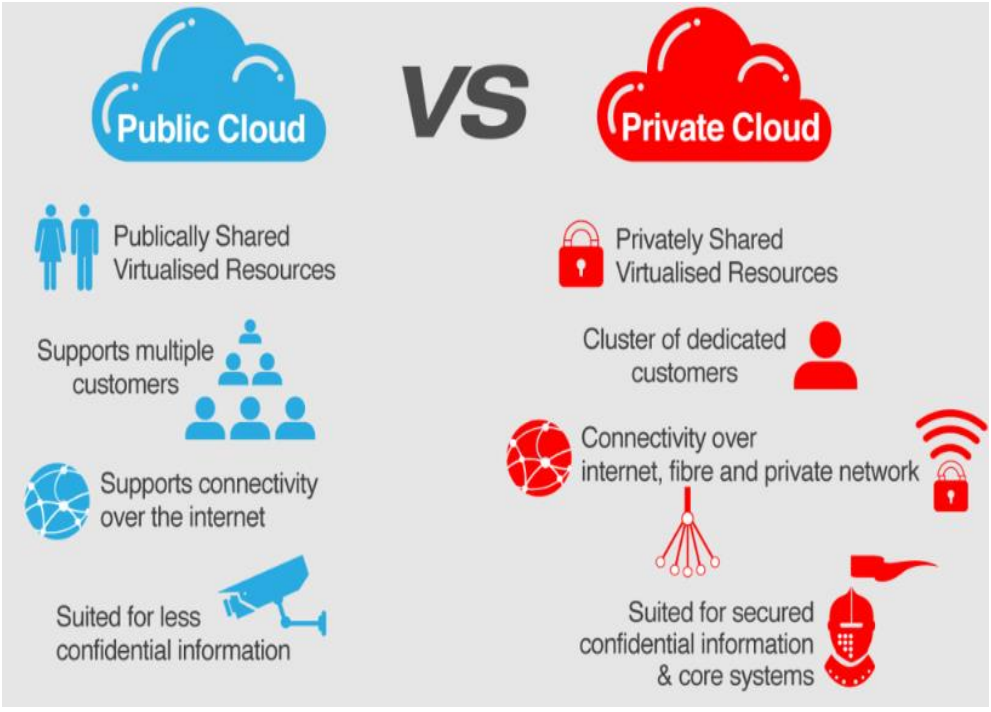

Fig 5.1: Integrating Public & Private Clouds

Equations 1: Security Equation (Data Protection and Threat Resistance)

$$S = E(x) \times T \times (1 - R)$$

Where:

- S is the overall **security** level,
- $E(x)$ represents how securely the data is stored or transmitted,
- T is the ability of the system to detect threats (e.g., firewalls, intrusion detection),
- R reflects how quickly the system can respond to an attack.

5.2.1. Definition and Characteristics

A cloud computing model is a service model involving a virtualized and scalable pool of computing, storage and network resources with a minimum level of management required, over the internet or another network infrastructure. According to the cloud's location, it may be categorized as public, private or hybrid. A public cloud is easily accessible through the open internet and shares resources with other cloud users. In a sense, virtual machines are similar to a service through a utility, consumers can access on-demand instances of the service at any time (Shakir, 2024). Private cloud tackles the worries of losing control over the IT infrastructure by offering a dedicated infrastructure for a single organization. Traditionally, universities require to install enterprise systems to operate major services. With the emergence of cloud computing technology, universities can rent cloud services commercially, reduce investment in hardware, and utilize faster and less expensive service. A private cloud can offer the same features as a public cloud and can be utilized exclusively and provide a dedicated environment. After analysis and work on the use of a public cloud, this paper intends to adopt the private cloud model where a private cloud is built with university resources. The distinguishing features and economic concerns of both public and private clouds are also discussed. Followed by a brief overrun of the hybrid cloud.

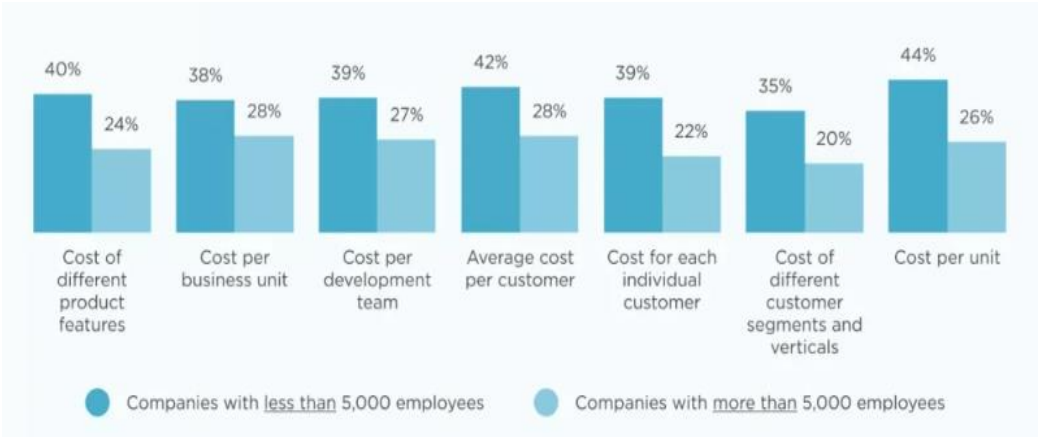

Fig: Cloud Cost Optimization Statistics

5.2.2. Key Differences

Public Cloud Public cloud, often referred to as on-demand computing, is a computing model that is based on a pay-as-you-go pricing model and is popular for its cost effectiveness. With the rapid growth of the cloud market in recent years, a large number of public cloud providers have emerged to provide various resource provisioning and payment possibilities. Proponents see cloud computing as the computing paradigm of the future and argue for the significant potential to save capital expenditure on defining, developing and maintaining large service systems (Nampalli, 2024). It is argued that public cloud is especially suitable for developing service-oriented applications since building such a system is time and labour consuming and the usage of resources tends to be varied. Thus public clouds offer fast and elastic provisioning of resources and can also dynamically adjust the application's infrastructure by taking into account the actual workload. Public Clouds are more or less modeled after a very large data center that can provide massive amounts of resources, thus concerning their size they are able to cope with demanding computing workloads. Since a very large data center is much more cost-effective than what it may be privately owned, Public Clouds are likely to achieve a substantial cost advantage, allowing IT infrastructure costs to be taken advantage of, enabling other IT investments.

5.3. Benefits of Integrating Public and Private Clouds

Strategically choosing the allocation of workloads across public and private clouds may increase the operational resilience of the workload, enabling services that are both redundant and can operate without their counterpart. Essentially, this resilience offers an additional benefit of potential cost savings. The workload is better protected against outages, enabling the service to be provided even with disruptions in any of the clouds. If both public and private components of the workload are required for service, the integration strategies lower the probability of an outage that disrupts the service. Workloads provisioned on the private cloud offer stability compared to the usage of the public cloud, where a new allocation may be unexpectedly terminated. Increased redundancy of the public and private components of the workload is also beneficial when the private countermeasure can be brought up much quicker than the equivalent public part of the workload (Kothapalli et al., 2022). Workloads provisioned on the public cloud can be scaled based on demand significantly quicker than workloads provisioned on the private cloud. This allows the workload to more closely follow the, likely varying, demand, greatly improving the resource optimization of the service. Finally, strategic design of public and private parts of the workload allows more flexibility regarding resource optimization, cost management, and resilience, potentially offering organizations significant advantages in a highly competitive environment. Additionally, many public clouds offer advanced tools and services that allow the rapid delivery of new services. Such services could foster the offering of more complex products or improve the development capabilities for service delivery. In such a case, integrating the public and private cloud may be a crucial step in the innovation strategy of the organizations, enabling the swift adoption of new technologies and services that would not be viable otherwise.

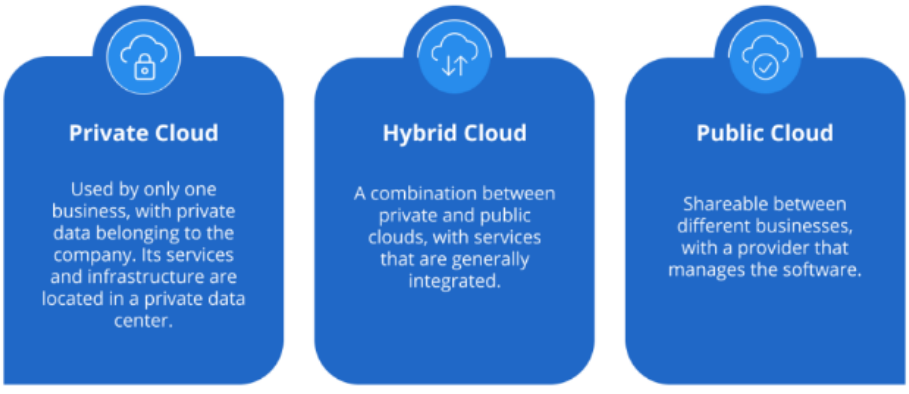

Fig 5.2: Benefits of Hybrid, Public and Private Clouds

5.4. Challenges in Integration

Public and private cloud environments use various protocols and technologies to provide cloud services. Some widely used cloud environments include EC2, Eucalyptus, Open Nebula, and OpenStack, all of which use unique APIs to perform service management calls. So, when there is a requirement for private and public cloud environments to work together, it is challenging to establish seamless integration (Subhash et al., 2022). The UCI working group unravels and assesses all potential challenges to form a comprehensive view of the current state, as well as providing insights into potential implications for future work.

Cost management is vital because hardware and software resource requirements in each of the cloud environments must be carefully balanced. This is the most common factor when determining which services to run on which cloud types. There is a danger of vendor trapping for organizations because the cloud environment may try to bind them with a particular virtualization technology, operating system, or cloud management system that makes it very undesirable to convert or switch the cloud technology later.

Equation 2: Customization Equation (Tailoring Resources to Specific Needs)

$$Cu = \sum_{s \in S} (R_s \times C_s)$$

Where:

- Cu is the **customization** level,
- R_s represents the resources allocated to each service or application s,
- C_s is a weight indicating the priority or intensity of customization for each service.

5.4.1. Security and Compliance Issues

Most organizations now store crucial data both internal private clouds and on remote public cloud platforms. Migrating information securely between these multiple kinds of cloud systems or just ensuring that data held in cross-cloud platforms is consistent can be a major headache - especially when considering the high likelihood that different cloud services will be running disparate software. But help is at hand for beleaguered cloud manager admins. Recent research investigates the possibilities for solving these problems

by looking at the approach taken by Google, and reveals ways of extending the capabilities of existing cloud management tools (Sondinti et al., 2023). For organizations running hybrid public-private cloud systems, exchanging or moving data between these platforms can open up security and compliance concerns. An attacker that compromises or intercepts data from the public cloud side of such a network could have a means of extracting login credentials or other confidential information, for instance. As is more often the case, man in the middle attacks on the public network between the disparate cloud environments could offer a straightforward way for data interception or compromise. The most direct way of mitigating the risks here is to enable data encryption in transit, advises the study. However, the researchers point out it is "inescapably complex" to apply this technique in the case of data transformation or migration occurring between cloud systems that are fundamentally different. It is also important to have tight access controls both between the public and private cloud and at each side of the integrated cloud system.

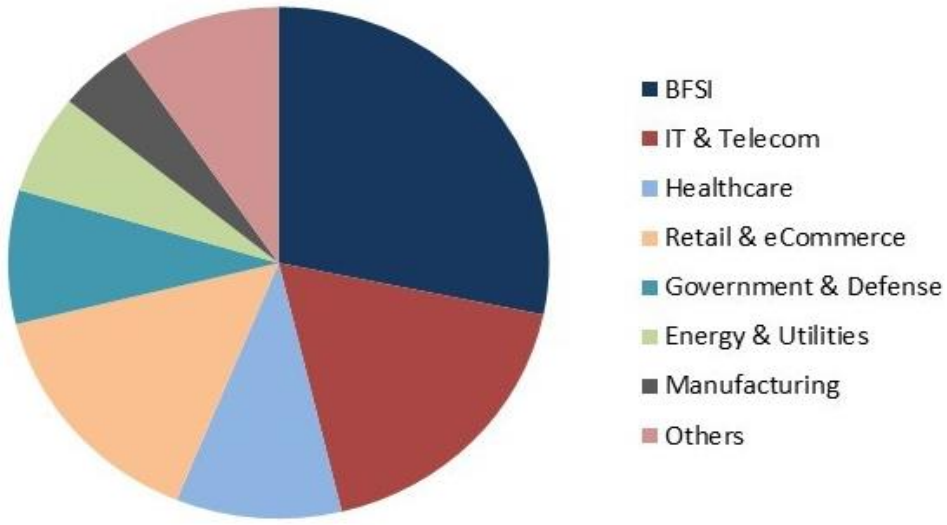

Fig: Public Cloud Market Size, Growth & Forecast

5.4.2. Data Interoperability

Data interoperability is a crucial aspect of cloud federation, fostering efficient data exchange between public and private clouds. However, intersite data interoperability is challenging because of different data formats and standards used by heterogeneous IT

platforms. If data should flow smoothly across these platforms, data on one platform should be available in a format compatible with its counterpart on another platform. Addressing data interoperability between cloud platforms is nontrivial, mainly due to such a large effort in data mapping and transformation processes. For instance, multi-cloud applications involving different public and private clouds may be data-intensive (Vankayalapati et al., 2023). Consequently, ensuring smooth data flow between involved clouds requires compatible data sources and applications between the platforms, which is nontrivial owing to the heterogeneity of APIs and data formats. Therefore, for the smooth communication and data exchange among involved systems, data on both internal and external clouds should be available in formats compatible with each other. This can be facilitated by adopting universal standards for data exchange. For instance, data analytics involve working with substantial amounts of data, and this data may be distributed across heterogeneous platforms, including public and private clouds. Since different platforms may store data in distinct formats, inconsistent data may result on the platforms side.

5.5. Solutions and Best Practices

In the era of the digital economy, applications and services based on clouds, such as infrastructure as a service (IaaS) and platform as a service (PaaS), are widely used by many corporations. Some corporations have started using multi-cloud environments with both private and public clouds to benefit from the advantages of each cloud. However, new challenges have emerged. To use cloud services effectively and securely, it is important to provide transparent and secure IT environments across all kinds of cloud environments, including private clouds on their premises and public clouds. This requires a viewpoint approach to address the challenges faced by corporations in integrating both private and public cloud environments, as well as providing a set of suggestions and best practices to conquer such challenges.

When both private and public cloud environments are used, a sound integration results from the system or platform level. Therefore, the integration needs to be committed to a clear plan and strategy before starting. To facilitate the incorporation process in private and public cloud environments, a strategic roadmap is proposed for four critical steps: preparation, assessment, configuration, and management. The existing system and cloud environments should be seen first before starting the integration process to facilitate further steps (Maguluri et al., 2022). Also, the expected results of the migration to cloud environments (private and public clouds) need to be understood. Therefore, each of the mentioned steps is subdivided into several sub-steps with an explanation of concrete

measures that can be taken to achieve better integration. As a practical suggestion, strategic preparation and an embodiment of the roadmap are discussed.

5.5.1. Hybrid Cloud Management Platforms

Given the benefits of hybrid cloud, cloud management platforms that effectively manage public and private clouds have been developed. Hybrid cloud management platforms enable organizations to acquire, deploy, monitor, maintain, and scale resources on multiple public cloud providers and on-premises private cloud environments in a simpler way. These platforms provide a common interface to manage resources in different environments. It is mentioned that cloud management platforms "enable seamless management of cloud resources and honoring users' QoS requirements, specifying and enforcing Service Level Agreements (SLAs)". The resulting management platforms are then able to provide mechanisms for the discovery of the best bargaining cloud provider and to automate the deployment and management chain of application components. A cloud management platform therefore assumes a major role by filling the gap between the functionalities available in cloud resources and the ones required by applications. With cloud management platforms, organizations can obtain centralized control over resources in different environments, and apps can be more easily deployed and managed on different clouds. Apps may move freely between internal (private cloud) and external (public cloud) environments as with minimal impact. Automation in workload management is crucial for a cloud environment, it is highlighted that "infrastructures require automation to efficiently allocate resources correctly to the workload and to react to the dynamic demands of a workload by increasing or decreasing the resources available to it." It is mentioned that one of the great advantages of hybrid clouds is the compatibility with different cloud environments, which allows organizations to adapt and "quickly adjust their capabilities to reflect business needs or User Level Agreements".

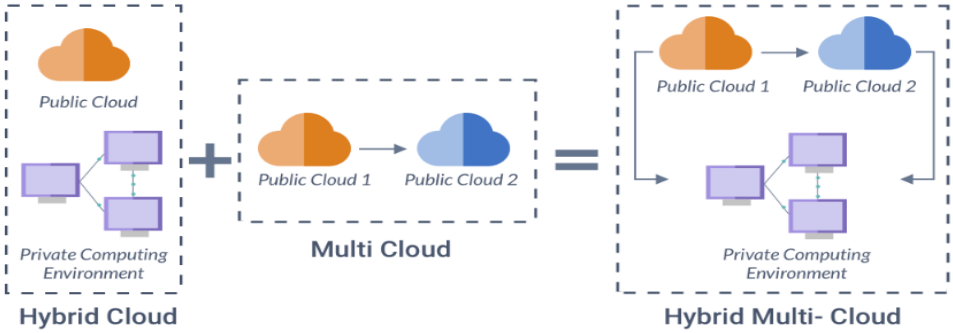

Fig 5.3: Hybrid Multi-Cloud - Management

5.5.2. Security Measures

Access control is an extremely important aspect of securing confidential data in this age of GDPR, CCPA, HIPAA etc. For customers holding very sensitive data, read-write permissions are shadowed by read-only permissions. User access logs are retained within the systems for a period of 6 months. As standard, user machine access requires a password (changing every 90 days), 2FA, and for more sensitive data, the addition of location-based whitelists, meaning users can ONLY access data from machines connected to trusted networks. It goes almost without mention that the 2FA isn't reliant on just one method of confirmation – SMS and Authenticator apps tend to be favored. Admin access requires public keys with passphrases, and another biometric token. The link encryption by the firewall is widely regarded to provide the ability to understand packet payloads, hence the desirability to segment traffic elsewhere. A raft of vulnerabilities are baked into most of the cloud services as a function of its age – significant go-to-market pressure exists, security comes as a secondary concern. So, as part of the cloud development lifecycle, and to help ensure security is at the forefront of the design process, customers' scans the appliance for vulnerabilities, as it would in the design of any network connected device. One further security requirement dictates the use of cloud services is the need for access/permissions to allow external configurations to be added – there are a limited number of partner API's for each service vendor. In order to mitigate the chances of data breach and liability to strictly enforced data barring and control standards, it is most often necessary to work closely with such providers to shape the service accordingly, as opposed to developing a solution completely in-house. Also, certified security standards are only met by the cloud service providers.

5.6. Case Studies

Case study 1: In the banking and insurance industry, Nbank, in addition to the traditional on-premises data center, also deployed a hybrid cloud consisting of two private clouds and a public cloud. It is necessary to ensure reliable and efficient application and data access between the traditional data center, the private cloud, and the public cloud, implement flexible and controllable data backup and disaster recovery, and build a low-latency hybrid cloud application backbone to avoid switching and ensure user experience. The financial hybrid cloud solution is adopted. The financial traffic from the traditional data center to the public cloud tunnel of the business system is based on the dynamic routing of the cloud, and the end-to-end latency is strictly controlled.

Case study 2: In the education industry, the university establishes a cloud service platform between schools and industry parks to provide cloud services such as online training and

video conferencing. The platform consists of a public cloud and several private clouds of different schools. In order to protect the privacy of school data and ensure smooth access between public and private clouds, this dedicated service group is set to isolate the private resources of the school. In addition, the hybrid public cloud deployment mode ensures low costs and good privacy. Private cloud decentralization to the private cloud of each school can ensure that the data and resources of each school are isolated, ensuring the privacy of the data of each school, and meanwhile, it also reduces the cross-cloud interaction between the public and private clouds and reduces the communication latency and time overhead.

5.7. Conclusion

The development and social acceptance of cloud computing services have triggered the transition of both small and large organizations to cloud business models. Although the adoption of cloud services is no longer a question of whether, but a question of when and how, policy makers and business analysts are still struggling to get informed about the competitive and societal consequences of this transition. Much has been written about the innovations brought by the cloud revolution. The brokerage concept, orchestrated services, infrastructure virtualization, new business models, and both top-down and bottom-up development patterns are among the thousands of research contributions on this issue. The integration of cloud services is today a reality and there is a colored range of innovative solutions from middleware transformation engines to standard APIs. Nonetheless, there has been little attention to the overall competiveness and to the contribution to the global economy of these early-integration cloud sourcing solutions. This objective is the motivation driving this paper. It presents the results of research that have been carried out during a 14-month attendance to a European-based project - launched to experiment with blended cloud applications. The collaboration postulates drawn in the project have forged both qualitative dynamics and competitive advantages leading to sustained structural development and market solidity.

5.7.1. Future Trends

The resources and services offered on the cloud have polarized rapidly in the past decade. Applications are now aiming to leverage the cloud infrastructure by making use of heterogeneous resources from multiple providers. This manifests the emergence of new computing architectures. This unprecedented change in the cloud computing environment is radiating a number of scientific and societal areas. Novel trends and directions are

considered for investigating meaningful research in order to foster the formulation of the upcoming generation's computing systems. In conclusion, it is revealed that the application of mobile edge computing engenders enhancements in the load balancing amongst edge nodes, energy efficiency improvement, and latency mitigation.

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