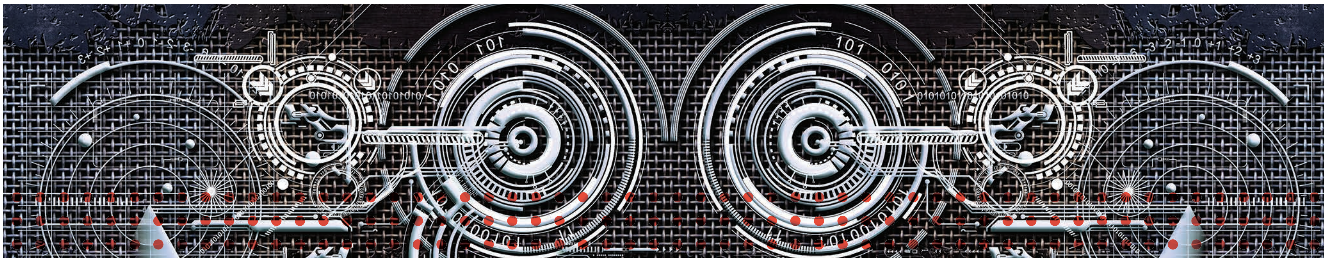

Cloud Brokering: Current Practices and Upcoming Challenges

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This invited article looks at the practical and legal implications of cloud brokering, in which cloud service brokers act as intermediaries between cloud service providers and customers.

The International Organization for Standardization defines a cloud service broker (CSB) as a "cloud service partner that negotiates relationships between cloud service customers and cloud service providers."[1] A cloud service partner is further explained as a "party which is engaged in support of, or auxiliary to, activities of either the cloud service provider or the cloud service customer or both." The second type of partner described in the standard is the cloud auditor. In other words, cloud brokering encompasses a wide range of activities. Essentially, it includes all intermediaries that stand between a cloud service provider (CSP) and a cloud service customer (CSC). The negotiation of relationships is most often understood as a proposition of contract that's satisfying for both customers and providers. Sustainable broker business models must create added value to ensure that CSCs have real interest in using broker services.

Motivations for using broker services vary. First, using these services might be more advantageous from an economical viewpoint: CSBs might offer better conditions to customers than CSPs. On the other hand, CSBs might create new channel and marketing opportunities for CSPs, resulting in a growth of sales.

A CSB might also take care of additional customer demands. For example, the data sent to the cloud might be subject to special security or compliancy regulations, such as specific requirements for data location, encryption, or format. A CSB could select services that fulfill these demands. It might also select offers compatible with the other products and services currently used by the consumer, minimizing the time and costs of transitioning to a new cloud. The CSB's selection could also be motivated by additional aspects, including the trust, reputation, environment-awareness (for example, use of green energy), or social responsibility of CSPs.

The external position of CSBs might also result in the creation of new products based on existing CSP offers. Brokers don't have to be bound by loyalty to a single company. As a result, they can select the most suitable combination of services for their clients. Moreover, their independence allows them to introduce redundancy by simultaneously using different CSPs. In such a case, it might be hard to distinguish between CSBs and CSPs, especially if the former use advanced Web interfaces to automatically provide services to users.

The relationship between the CSC and CSB shall be established in clear terms, allowing further determination of the respective liability. Because the cloud appeared relatively recently on the ICT market, compliance with the law isn't sufficiently clear, and many new legal questions could appear in the future.

Legal Aspects of Cloud Brokering

Legal aspects of cloud brokering touch upon many areas. The major problems connected with this issue are data location, cross-border transfer, portability, access, and accountability.

The security of data in cloud computing is often questioned. Therefore, one of CSPs' main objectives is to ensure the privacy of data as requested by users. Privacy in cloud computing is a complex and delicate issue that's been fiercely debated, in legal as well as technical fields, since the emergence of the first cloud solutions. Most of the legal frameworks applicable to personal data appeared at the end of the last century, when data processing was less advanced. They're therefore largely outdated and difficult to apply to modern data processing.

From the CSB viewpoint, it's important to determine a CSB's position in the data processing chain and the respective liabilities. For example, in the framework of European data protection law, the person who determines the means and purposes of processing is regarded as the data controller, and thus bears almost all of the compliance obligations stemming from Directive 95/46/EC.[2] The CSB that chose the means of processing will be then regarded as the data controller, unless it can show that only nonsubstantial decisions were delegated to it. As the European Commission's Article 29WP nonbinding guidance establishes, the organizational and technical means can be delegated from data controller (user) to data processor without joint control.[3] However, the data controller shall decide on the essential elements of the data processing, including the period in which the data will be processed and who shall have access to the data.

Another important aspect is the data's location. The CSB isn't free to arbitrarily choose the location of the data processing and storage taking into account only technical arguments. Such a decision must be made together with the CSC. The CSB must adhere to national and local obligations. Some national laws might not allow processing or storing specific types of data beyond their respective borders, therefore limiting the CSB's choices (for example, Luxembourg limits the movement of financial data). Regional limitations constitute another issue—for example, in the European Union (EU) data is generally processed within EU borders with certain derogations (the condition being that the non-EU country must ensure an adequate level of protection for personal data). The CSB shall be certain about the types of data, their origin, and compliance with respective laws in both the data controller's place of establishment and the location of the means used for processing or storing data. Depending on the CSB's role in the decision process and in the processing itself, the liability will follow respectively.

Additionally, the types of data in question can influence the choice of CSB, as in the United States, where a sectoral approach to data protection provides a specific regime for health data—the Health Insurance Portability and Accountability Act (HIPAA)—and the privacy of children—the Children's Online Privacy Protection Act (COPPA). Another interesting aspect is contract law. For example, each case of potential violation of EU data protection law is assessed on a case-by-case basis. Therefore, the contract establishing accountability against the factual situation won't prevail. The CSB must have in place technology and organization capable of ensuring that all user requirements will be fulfilled and, at the same time, that the obligations stemming from the law will be observed.

Existing Brokerage Services

The market for CSB services and products is already large and continues to grow. Gartner estimates that the size of the CSB market will reach US$141 billion in 2017, which corresponds to doubling its value in four years.[4] Compared to the ISO, however, Gartner's definition of CSB is more abstract: "[CSB] is an IT role and business model in which a company or other entity adds value to one or more (public or private) cloud services on behalf of one or more consumers of that service via three primary roles including aggregation, integration and customization brokerage" (www.gartner.com/it-glossary/cloud-services-brokerage-csb). This outlook underlines the fact that the main medium used by CSBs is the Internet itself, and its services are accessible using Web interfaces or APIs. The three proposed types of brokering—aggregation, integration, and customization—present various specializations of CSBs. In real-life cases, it's often impossible to clearly classify a company, as many of them work in multiple fields, trying to respond to client needs. Nevertheless, we divide the existing market offerings into these three classes. Table 1 lists all mentioned CSB companies.

Aggregation

Aggregators are CSB companies that provide a platform that brings together multiple CSP services and offers them in a central place. This platform is presented as a unified service and generally includes a system for billing and provisioning services.

Some aggregation CSBs offer a wide variety of choices and serve different types of clients (such as individuals and corporations of different sizes) from many parts of the world. Examples here include Cloud Fuze, which aggregates multiple storage clouds, and Tech Data's TDCloud, an aggregator platform that offers multiple bundles of cloud services on various delivery models of cloud computing. However, CSBs are often regional players, which enables them to focus on a specific market and leverage their knowledge about it. CloudMore, for example, offers cloud services aggregation and activation through partners, and is active in the British Isles and Nordic regions. Clouditalia is an Italian aggregator, offering services to multiple technology and business partners.

Some aggregation CSBs focus on small and medium enterprise (SME) partners. Cloud Compare, an Irish CSB, focuses on facilitating and managing interactions with CSPs for SMEs, addressing a regional and sectoral niche. The HP Aggregation Platform for software as a service (SaaS) enables operators to create a SaaS marketplace addressed to SME customers, who can subscribe to services and use them. This platform offers additional features such as product presentation and discovery. Cloud Nation and Nuvotera are other examples of this class of CSBs.

Marketplaces are a specific type of aggregation CSB. Well-known CSPs, such as Amazon Web Services, Rackspace, Comcast (Upware), and Ingram Micro Cloud, offer their own marketplaces, merging their core service provisioning business with a CSB business model. LuxCloud, operating in Luxembourg, follows a similar business model, combining in-house service developments with a CSB platform, and focusing on security, compliance, and data location. SaaSMax is an online SaaS marketplace matching business cloud applications with resellers and buyers. CloudSolv and Nervogrid marketplaces work on all cloud levels, including many delivery models—SaaS, infrastructure as a service (IaaS), platform as a service (PaaS), hardware as a service (HaaS), and unified communications as a service (UCaaS)—and deployment models. ComputeNext is an IaaS, storage, software, and services marketplace that offers some integration functionalities.

Integration

The IT integrator's responsibility is to create a unified, common system out of a group of existing systems. In the context of cloud computing, this might mean integrating private and public clouds, or even bridging between CSPs. Security of data exchange between all the subsystems and proper sharing of data are the most important requirements for integrating CSB platforms.

Because of these characteristics, most integrators focus on the business-to-business (B2B) model. OpenText Trading Grid is a B2B integration platform for cloud services that includes a gateway, a format translator, and multiple communication and application adapters. Another integrator with global reach is Liaison Technologies, a company focused on data management. SaaS integration CSBs are represented by companies such as the Rype Group, an Australian CSB and SaaS integration provider. There are also matrix platforms, which offer wide integration possibilities. Examples include Dell Boomi, a cloud integration platform; Gravitant, which offers the cloudMatrix CSB platform; InfoSys with its Cloud Ecosystem Hub; and Appirio.

Most of these integration companies are large enterprises, which can be explained by the fact that integrating existing complex business systems can require a wide range of skills and expertise. The final integrated cloud system should be reliable, functional, and delivered on time, which might discourage potential customers from using lesser-known integrators.

Customization

The customization class is perhaps the most sophisticated type of brokering. It might include a combination of aggregation and integration with other added-value services, but also the creation of new original services. Usually, it's implemented in the CSB platform, but in some cases it might include changes in the CSC's workflows. The effort of customizing CSBs can be supported by open source projects, such as CompatibleOne.[5] This project resulted

Table 1. List of discussed cloud service brokers (CSBs) and their websites.

Cloud Service Broker	Website
Amazon Web Services	aws.amazon.com
Appirio	appirio.com
BlueWolf	www.bluewolf.com
Boomi	www.boomi.com
Cloud Compare	www.cloudcompare.ie
Cloud Ecosystem Hub	www.infosys.com/cloud-ecosystem-hub
Cloud Fuze	www.cloudfuze.com
Cloud Nation	www.cloudnation.co
CloudOrbit	www.cloudorbit.com
Cloud Sherpas	www.cloudsherpas.com
Clouditalia	www.clouditalia.com
cloudMatrix	www.gravitant.com/cloudmatrix-overview
CloudMore	web.cloudmore.com
CloudSolv	www.synnex.com/cloudsolv
Comcast (Upware)	upware.comcast.com
ComputeNext	www.computenext.com
Cordys	www.opentext.com/what-we-do/products/business-process-management/process-suite-platform/opentext-cordys
DirectCloud	www.mydirectcloud.com
Green Cloud Technologies	gogreencloud.com
HP Aggregation Platform	h20229.www2.hp.com/partner/ngsd/HPAP4SaaS.html
Ingram Micro Cloud	www.ingrammicrocloud.com
Liaison Technologies	liaison.com
LuxCloud	luxcloud.com
Nephos Technologies	www.nephostechnologies.com
Nervogrid	www.nervogrid.com
Nuvotera	nuvotera.com
Rackspace	www.rackspace.com
SaaSMax	www.saasmax.com
SoftChoice Cloud	softchoicecloud.com
TDCloud	www.techdata.com/tdcloudregroup/Home.aspx
The Rype Group	rype.com.au
Trading Grid	tradinggrid.gxs.com
VerioCatalyst	www.verio.com/veriocatalyst
Virtacore	www.virtacore.com

in a spin-off company called CloudOrbit. OpenText Cordys is a set of proprietary software tools dedicated to the customization of cloud brokering platforms. VerioCatalyst is a platform with a layered architecture. It offers a service provisioning system, an administration platform, and a retail interface with payment and product bundling capabilities.

Customization CSBs are often specialized to offer unique purpose-oriented platforms, such as Virtacore, a company that specializes in disaster recovery and Google Apps. Some companies put additional effort into a specific differentiating feature. For instance, Green Cloud Technologies uses technologies such as VMware, NetApp, and Cisco, and focuses on

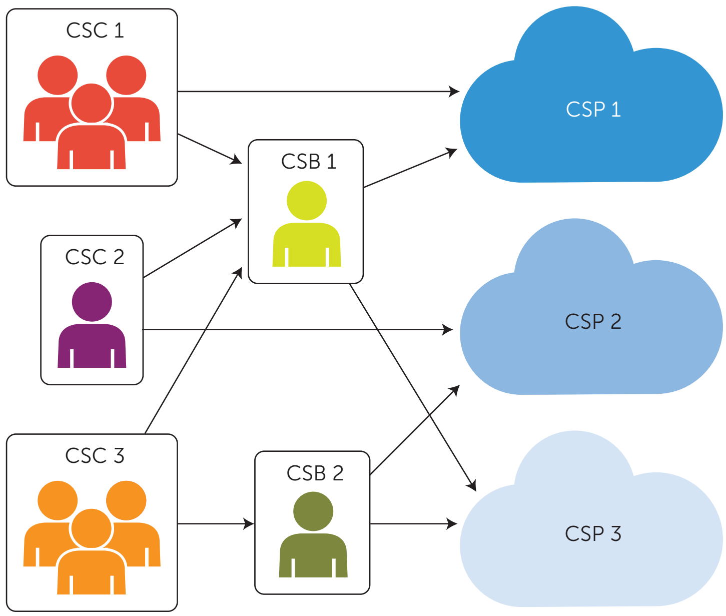

FIGURE 1. Cloud service brokers (CSBs) in a workload submission process, between cloud service consumers (CSCs) and cloud service providers (CSPs).

data security. CSBs such as Nephos Technologies, which is located in the UK, are oriented to local markets. SoftChoice Cloud is a Canadian service provider that helps to manage multiple services in clouds (consultation, implementation, and managed services). Cloud Sherpas is a specialized company that customizes solutions from a small set of partners (Google Apps, Salesforce.com, and ServiceNow). BlueWolf offers customized cloud solution development and management worldwide. Moreover, there are CSBs that offer a wide choice of services, supporting many platforms and devices. DirectCloud is a good example of this type. It's based in Canada, and works with Office 365, SherWeb, and Adobe Creative Cloud.

Open Issues

The widespread offerings of CSBs differ in scope. Some companies propose dedicated products, whereas others present aggregated or integrated platforms for a wide choice of services. Aggregation and customization CSBs often focus on local markets, especially SME-oriented aggregators. Current pricing models of CSPs and CSBs are quite simple. A price list is created for all services offered in their portfolios. They often offer discount bundles for ensuring customer loyalty or promoting long-term resource provisioning. Alternatively, they might offer added-value services, such as new functionalities or guaranties. However, CSBs are less reactive when it comes to answering a specific, custom client need, omitting online price optimization, especially when a customer wants to buy multiple services. Security and trust optimization aspects are also not sufficiently addressed. The CSB research community addresses these challenges by modeling and optimizing CSB settings.

Cloud Brokering Research

The computer science community enthusiastically welcomed the concept of cloud brokering. In the same way that it has created many business opportunities, cloud brokering has contributed new problems and challenges to investigate and solve. Cloud brokering research focuses on the development of brokering and multicloud platforms, and on the optimization of the offer presented by the broker to its customers.

From the resource allocation perspective, a CSB can act as an intermediary in the process of workload submission (see Figure 1). From this perspective, cloud brokering is the process of matching service requests from multiple users to the offers of multiple clouds. The type and granularity of requests depend on the cloud delivery model (for example, applications for SaaS or virtualized resources for IaaS). This approach can further extend the responsibilities of CSBs, which might need to ensure interoperability between clouds.[6]

The first challenge to be addressed by the research community is to create a framework that could practically exploit a wide range of cloud services. Such frameworks could be based on a toolkit (for example, Optimis[7]), middleware (such as mOSAIC[8]), or even an open source cloud broker (CompatibleOne[5]), and facilitate the use of multiple clouds by users. With the support of such solutions, CSBs can focus on their core business—that is, supporting the relationships between CSPs and CSCs.

CSB resource management problems are combinatorial problems related to the mapping problem. The price of the resource allocation is the first objective, but quality-of-service (QoS) objectives (such as response time and user satisfaction) are also important. Keeping in mind additional user requirements, such as security, reliability, and privacy, we can conclude that the problem is multiobjective. The CSB problems are typically NP-hard, similar to the mapping or bin-packing problems. As a result, they can't be optimally solved in a reasonable amount of time.

In the simplified case of IaaS, where CSPs feature standard infrastructures and theoretically have no limit on used resources from the users' perspective, the CSB's problem consists of selecting a CSP and a virtual machine type for each user task. Such a problem is relatively simple when only a single objective is considered, but realistic scenarios often require more. Valid and good quality solutions can be found by tools such as evolutionary computation, including genetic algorithms, simulated annealing, and particle swarm optimization. During a stochastic process, candidate solutions are modified. The selective pressure of the environment, driven by the objective function, leads to convergence toward the best solution. To perform evolutionary computation, it's necessary to provide a common encoding of a solution. In practice for the mapping problem, a candidate solution is encoded as a vector. Each position of the vector corresponds to tasks. The value of each position determines the selected virtual machine type.[9] An alternative approach to solving NP-hard problems is to use problem-specific heuristics.[10]

Another line of research focuses on the brokering market environment. In these works, the different actors in a brokering scenario are modeled as agents.[11] The optimization of the brokering is achieved by negotiations between agents[12] and auctions among vendors to offer the best price.[13] Agent models can be interesting for CSBs, as they inherently include distribution of control and market theory or game theory elements, such as models of rationality and iterative decision making. An important area of research is multiagent organizations, in particular the direction of dynamic and online reorganization, which is necessary in real-life CSB environments.[14]

The state-of-the-art research addresses many challenges that aren't yet implemented in industrial and commercial solutions. On the other hand, researchers often neglect particularities of real problems, which can require further specialization and additional efforts at the implementation level.

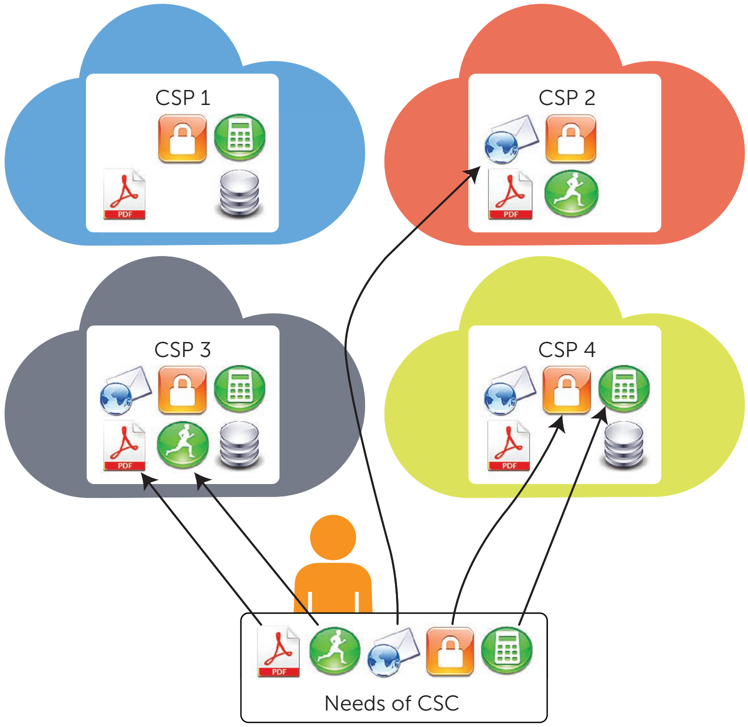

FIGURE 2. The Internet shopping optimization problem (ISOP) in a cloud computing scenario. A cloud service customer (CSC) selects its cloud services from the available cloud service providers' (CSPs') offers to optimize its objectives, such as price, quality of service or trust. (Icons by Everaldo Coelho.)

Cloud Brokering from the Customers' Viewpoint

E-business, including e-commerce, is an active part of modern societies. The continuously growing integration of technology into our daily business and administrative operations makes it necessary to adapt to the inevitable evolution. The problem of managing a multiple-item shopping list over several shopping locations is called the *Internet shopping optimization problem* (ISOP).[15] This problem arises when a customer wants to buy a number of products from Internet stores but spend as little money as possible. One of the first observations is that buying from different providers increases the total delivery cost, because each shop charges individually for delivery (but only once for a set of items bought in that shop). The ISOP has proven to be strongly NP-hard. Because there are no polynomial-time exact algorithms, heuristic algorithms can be used to find good solutions that balance results quality (as close to optimum as possible) and computation time.[16] A more detailed version of the ISOP that accounts for price discounts focuses on problem definition and complexity analysis and introduces some basic algorithms.[17]

From a technical viewpoint, there are many similarities between the cloud brokering problem and the ISOP from the customer perspective. Let's say a client (a CSC) wants to buy some cloud services (see Figure 2). The client has precise requirements, including an e-mail account, a virtual training assistant, and an office suite. The CSB could be treated as an ISOP instance selling services as products delivered by various CSPs. The problem accounts for the charge for setting up services, which is similar to ISOP shipping costs, and proposes discounts based, for example, on product connections. That is, if you buy both an office suite and encrypted storage from the same CSP, you will obtain a discount. A CSB receives many offers from providers worldwide. The goal is to prepare the lowest possible bill. The CSB could provide the optimized offer for the customer's bundle. Adopting some ideas from the ISOP (or even applying known ISOP algorithms) could enhance applications that are similar in manner to current price comparison sites. Customers could enter such a website, and put all wanted products and services into their baskets. A virtual CSB could then examine the available CSP offerings and propose the best combination to the customer.

Data and service interoperability is critical for CSBs, who want to offer a seamless experience to their users.

The data and service interoperability problems are still not fully solved. Such interoperability is critical for CSBs, because they want to offer a seamless experience to their users. Integration CSBs can make some profit by offering a solution that bridges different cloud interfaces. However, vendor lock-in might decrease opportunities to perform brokering, as customers' initial choice might affect their future migration possibilities. The need for data portability is also recognized by lawmakers. In the recent reform of the EU's data protection framework, the right to data portability requires the data controller to provide user data in an electronic and structured format if the data subject requests it. There's also a need to foster development and adoption of cloud computing standards.

The development of the whole cloud computing environment strictly depends on advancements in a wide adoption of reliable, low-latency, and high-bandwidth networks. Performance and reliable networks are even more important for CSBs, because improvements in the communication infrastructure enable them to target more CSCs, use services from more CSPs, and, last but not least, integrate services from different CSPs.

The question of CSBs' place in the business landscape is still unresolved. Some alternative models often partially overlap cloud service brokering. One such model is cloud federation, in which interoperable cloud systems run by independent CSPs share or sublet their resources. A CSP in a cloud federation can be seen as a broker when it looks for additional capacities, for example, when its users' demand is larger than its available capacity. Another scenario is when provisioning resources from one CSP is more expensive than renting them from other CSPs. In the case of a CSC using marketplaces directly, cloud brokering might become the responsibility of each company's IT team (for example, deciding whether to use an in-house or outsourced solution). Such a trend would make CSB research even more needed and widely used.

Cloud security is another issue magnified by cloud service brokering. The security of a complex system is as strong as the security of its weakest element. If a bundle of services is offered by multiple providers, users might feel that their security level is lower than if they used a single provider. The corresponding lack of trust could result in a substantial loss of profits, and CSBs must therefore mitigate this risk.

As in many new, real-life computing topics, there's a disparity between research and practice. The researchers often solve simplified models, or focus on simple cases. The practitioners, in turn, favor solutions that are reliable and simple, yet effective in complex, real-world scenarios. The future and success of CSBs rely on constant advances and a skillful balancing of these two trends.

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