IBM Global Technology Services
Thought Leadership White Paper

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Getting cloud computing right

The key to business success in a cloud adoption is a robust, proven architecture.

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Introduction

Today's CIOs and business leaders from industry and governments around the globe are challenged to stay competitive and meet business objectives. Aligning the enterprise IT model with the business, controlling costs and keeping pace with the rapid rate of innovation are critical.

As a consequence, interest in cloud computing is very strong. In one IBM study, between 45 and 55 percent of IT leaders surveyed reported implementing or planning to implement a private cloud project[1] and 91 percent of the 2,000 IT professionals responding to the most recent IBM Tech Trends Survey anticipate that in five years cloud computing will overtake traditional on-premises computing as the primary way organizations acquire IT.[2]

The reasons cited are compelling. Early adopters of cloud computing—including IBM's own IT organization and IBM customers—have already realized significant benefits, including:

- Reducing IT labor cost by up to 50 percent in configuration, operations, management and monitoring
- Reducing server and application provisioning cycle times from weeks to minutes
- Improving quality, eliminating up to 30 percent of software defects
- Lowering end-user IT support costs by up to 40 percent.

With the growing adoption of cloud computing there has been a concurrent growth in the number and variety of vendors in the marketplace with cloud offerings. These providers range from established IT industry leaders like IBM to software as a service vendors leveraging cloud computing to broaden their scope—Salesforce.com, for example—to players leveraging other domain expertise or partnerships to enter the cloud arena, such as Amazon, Google, Cisco and VMware, along with numerous telecommunications and hosting service providers.

The more crowded this marketplace becomes, the more challenging it is for CIOs to select the right cloud vendor to meet the organization's needs. And as the applications deployed on private or public clouds move up the value chain and into the enterprise computing realm, the stakes increase as well—with selection criteria shifting from an emphasis on price to considerations such as security, reliability, scalability, control and tooling, and a trusted vendor relationship.

The importance of a proven cloud reference architecture

Cloud computing can potentially be a disruptive change to the way an enterprise's IT services are delivered. We propose that examining a candidate cloud solution provider's reference architecture should be a standard element of a CIO's cloud vendor evaluation strategy. To that end, in this paper we will describe the proven cloud computing reference architecture that IBM employs in building private clouds for clients, private clouds that house IBM internal applications and the IBM Cloud that supports our public cloud service offerings. This same reference architecture is reflected in the design of IBM cloud appliances (bundled hardware and software for cloud implementation) and IBM cloud service management software products.

Cloud computing must be enabled with effective security, resiliency, service management, governance, business planning and lifecycle management. These are the components of an effective and comprehensive cloud architecture that will enable the enterprise to control the environment more effectively, optimize productivity, reduce associated labor costs and ensure a resilient, safe environment for business users. By delivering best practices in a standardized, methodical way, this reference architecture ensures consistency and quality across IBM development and delivery projects. IBM's cloud reference architecture:

- Is based on open standards
- Delivers robust security, governance, compliance and privacy capabilities
- Combines powerful automation and services management (low touch) with rich business management functions for fully integrated, top-to-bottom management of cloud infrastructure and cloud services
- Supports the full spectrum of cloud service models, including infrastructure as a service (IaaS), platform as a service (PaaS), software as a service (SaaS) and business process as a service (BPaaS)
- Enables the flexible scaling and resiliency required for successful cloud economics and ROI
- Facilitates seamless integration into existing customers' environments
- Is based on our industry-leading expertise with SOA for building services and service-oriented architectures.

Employing best practices for continuous improvement

Developed by the IBM cloud computing architecture board—comprising technology leaders from IBM Research and IBM's software, systems and services organizations—the reference architecture is derived from extensive client interaction combined with IBM's extensive capabilities and experience in building industrial strength IT systems and SOA solutions. Moreover, a process of continuous improvement (see Figure 1) helps ensure that the reference architecture is both responsive to real-world implementation experiences and technology developments via IBM products and evolving design specifications.

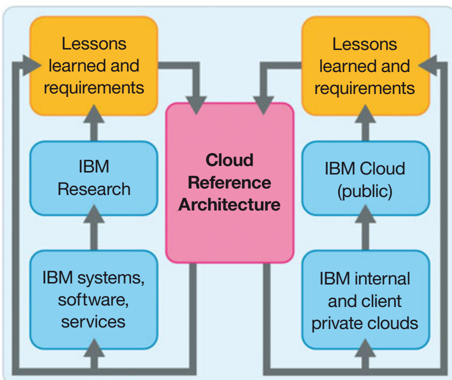

Figure 1: Continuous improvement helps ensure that both real-world experiences and technology advancements from IBM Research are integrated into IBM's cloud reference architecture and management components.

This reference architecture provides specifications not only for the physical components of a cloud implementation (network, compute, storage, virtualization), but as importantly for the software components required to run operational and business management processes. It also defines governance policies tailored for the environment or organization.

IBM's cloud reference architecture provides detailed documentation of all components, including how to realize each component for cloud-scale efficiencies. More than a single-use diagram for a discrete implementation, it is a comprehensive, tightly integrated compilation of documents that describe in detail how to build a management platform for delivering any type of service—and includes use cases, non-functional requirements, components, operations, security, performance and scalability, resiliency, consumability considerations, cloud service creation guidance and much more. Various aspects are covered in different documents, and in the aggregate these documents make up the reference architecture. This loose-coupling approach allows architectural elements to be refined independently, focusing subject matter expertise and enabling parallel development and rapid innovation. A set of architectural principles (see sidebar *Principles guiding IBM's architectural decisions*) guides IBM cloud architects across the entire development process.

Following the continuous improvement strategy, IBM has recently extended the reference architecture to address two industry-specific requirement sets. For telecommunications service providers, offering cloud-based services is a key strategy for business expansion and revenue growth. The IBM Cloud Service Provider Platform (CSP2) solution design captures the unique requirements and operational models within the cloud that will enable service providers to create, manage and monetize high-volume, large-scale multitenant, blended cloud-based services. For the healthcare industry, IBM has extended the reference architecture to address, for example, data privacy concerns in developing cloud-based collaborative care solutions for physicians and patients.

Principles guiding IBM's cloud architecture decisions

An architectural principle is an overarching guideline or paradigm driving decisions across the entire architecture development process. IBM established three principles that guide IBM cloud architects in defining the detailed components of each module:

- **Efficiency principle.** Design for cloud-scale efficiencies and time-to-deliver/time-to-change metrics when realizing cloud characteristics such as elasticity, self-service access and flexible sourcing. Objective: drive down costs per service instance hour and time to response by orders of magnitude.
- **Lightweight principle.** Support lean and lightweight service management policies, processes and technologies with an eliminate-standardize-optimize evolutionary approach. Objective: radical exploitation of standardization in cloud environments to reduce management costs.
- **Economies-of-scale principle.** Identify and leverage commonality in cloud service design. Objective: Optimize sharing of management components and infrastructure across cloud services to reduce capital expense, operating expense and time to market.

Defining the requirements for industrial strength cloud service delivery

IBM's cloud reference architecture addresses the three major roles in any cloud computing environment: cloud service provider, cloud service creator and cloud service consumer (see Figure 2). With this strict separation of concerns, the cloud architecture enables specific perspectives to be assumed in order to understand the requirements, expectations and value propositions placed upon the system, and the supporting capabilities necessary to fulfill these requirements.

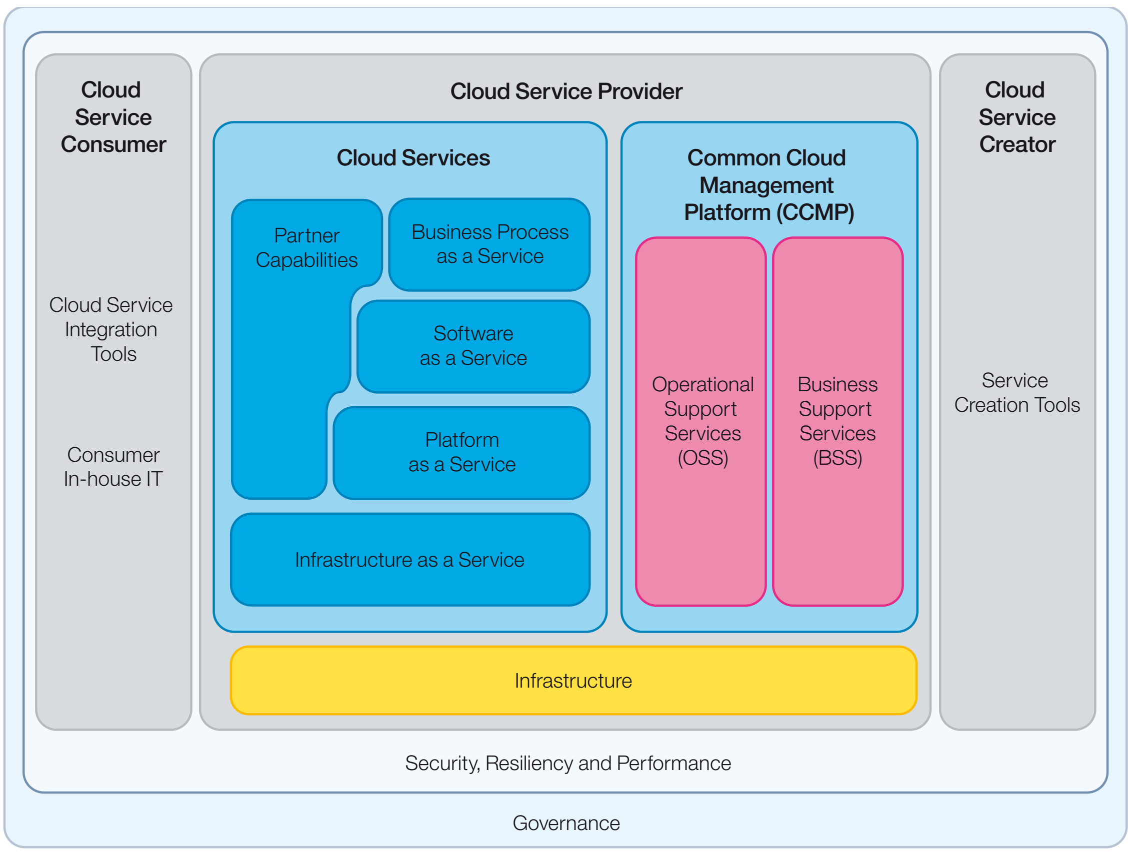

Figure 2: This high-level diagram illustrates how the cloud reference architecture developed by IBM addresses the requirements of all participants in the cloud ecosystem: cloud service providers, cloud service creators and cloud consumers.

- From the service consumer's perspective, a simplified interface is needed with well-understood service offerings, pricing and contracts. The value proposition for the service consumer is to get fast, on-demand access to the service they need while only paying for the period of time the service is used.
- From the service provider's perspective, a highly efficient service delivery and service support infrastructure and organization are needed in order to provide differentiated, well-understood, standardized and high-quality services to end users. Service management makes it possible for significant economies of scale to be achieved. A self-service portal allows exposing a well-defined set of services in a highly automated fashion at a very attractive cost point.
- From the service creator's perspective, a tooling environment is needed for modeling and assembling service elements (virtual images, for example) as well as an effective means of managing the service lifecycle.

Providing end-to-end, workload-appropriate qualities of service

In IBM's cloud reference architecture, security, resiliency, performance and consumability underpin all other service provider components: the common cloud management platform, the cloud services layer and the physical infrastructure layer. This approach is critical to maintaining consistency in how various non-functional requirements are executed at each of these other layers of the architecture. For example, if a security policy at the highest level defines that customer information cannot leave the country, then at the lower level of physical resources, disk space must be allocated only in the country where the data originates.

IBM's reference architecture specifications incorporate proven security and reliability technologies as well as simplified security management and enforcement. Built on IBM's published security framework as well as extensive industry security leadership, IBM security surrounding clouds focuses on developing trusted virtual domains, authentication, isolation management, policy and integrity management, and access control (see Figure 3)—resulting in cloud environments that are secure by design. Within the context of the reference architecture, IBM can work with clients to tailor a private or public security implementation to meet the requirements of different workloads.

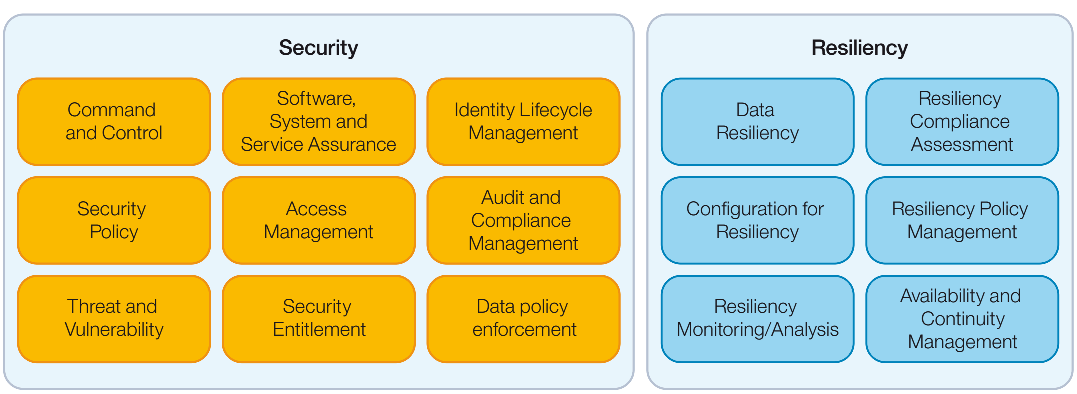

Figure 3: Cloud security and resiliency architecture components.

Although IBM's cloud security architecture is built on decades of experience with mainframe architectures and industry-leading experience in service security in enterprise solutions, security for virtualized resources in a public, multitenant cloud environment is still very much a work in progress across the IT industry. IBM continuously invests in research and development of stronger isolation at all levels of the network, server, hypervisor, process and storage infrastructure to support massive multitenancy and hybrid clouds.

The key security focus areas for the cloud services layer include:

- Federated identity, authorization and entitlements
- Audit and compliance reporting
- Intrusion detection and prevention
- Secure separation of subscriber domains
- Secure integration with existing enterprise security infrastructure.

IBM's reference architecture is designed to provide security services in a highly dynamic and agile fashion, potentially under very complex trust relationships in a large and open user population where there are no pre-established relationships between cloud provider and subscriber. IBM's approach also enables fine-tuning of execution to match the security requirements of different types of workloads.

While many cloud vendor implementations focus on specific protocols, such as OpenID for identity federation, and favor specific architectural styles, such as representational state transfer (REST), it is IBM's point of view that enterprise-class cloud computing must not limit its users to a specific protocol or style, but rather offer flexibility and choice. IBM supports REST-based interfaces and protocols where appropriate. Additionally, IBM's cloud reference architecture addresses establishing and managing consistent policies for entitlements and access control—which are needed to ensure that the underlying components of a cloud service maintain data confidentiality and adhere to compliance regulations.

For example, a medical research application pulls data from clinical and billing services from multiple hospitals, so patient names and other personally identifiable information must be removed from all sources. The centralized entitlements management service specified in the reference architecture can help ensure that common policy is defined and enforced to protect patient confidentiality across all cloud services.

Common cloud management platform: optimizing service delivery through visibility, control and automation

Well-designed cloud architectures and solutions must address the difficult realities of "layers of complexity" in distributed IT environments. While much industry discussion has focused on infrastructure (network, compute, storage), significant challenges also exist in achieving the low-touch automation required to successfully scale to economically successful cloud solutions. Masking complexity for users, supporting cloud business models and managing heterogeneous, distributed environments are the top service management challenges for any cloud architecture.

To address these challenges—and to enable the standardization and scaling required for cloud computing—IBM's reference architecture establishes a common cloud management platform (CCMP) that integrates the operational and business management of all layers of the cloud environment, including the CCMP itself. The CCMP exposes a set of management services which are generally needed for the delivery and management of any cloud service—across infrastructure-, platform-, software- and business process-as-a-service. Cloud service developers use the services provided by the CCMP to realize the economies of scale, reuse and standardization required for achieving the extremely high degrees of efficiency associated with any cloud computing environment. In a traditional IT environment it is common to see a software component developed uniquely for different areas of the business—so that accounts receivable uses one billing application, for example, while web commerce uses a different one. With IBM's common cloud management platform, the service provider deploys one billing application or other software component and may reuse that instance as appropriate.

Four cloud service delivery models: a helpful taxonomy

Infrastructure cloud services ("infrastructure as a service" or IaaS)—The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).[4]

Platform cloud services ("platform as a service" or PaaS)—The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.[5]

Application cloud services ("software as a service" or SaaS)—The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based email). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.[6]

Business process cloud services ("business process as a service" or BPaaS)—Business process services are any business process (horizontal or vertical) delivered through the cloud service model (multitenant, self-service provisioning, elastic scaling and usage metering or pricing) via the Internet with access via web-centric interfaces and exploiting web-oriented cloud architecture. The BPaaS provider is responsible for the related business function(s).

The CCMP is comprised of two modules: operational support services (OSS) and business support services (BSS) (see Figure 4). The IBM reference architecture decomposes each module into components and sub-components or functions required for creating a CCMP implementation. For each module, the reference architecture includes a detailed component model that:

- Defines each component and sub-component, including how the components are different from the traditional enterprise IT management scope
- Incorporates industry standards, including ITIL-based best practices for service management
- Provides product-neutral guidance (specification) on how each functional component should be scoped and realized to support cloud-scale efficiencies and costs
- Details the relationships and dependencies between individual components, including diagrams and textual descriptions of component interfaces
- Identifies candidate IBM software products (internal applications for use in IBM clouds as well as IBM commercial software products) that CCMP implementation teams can use. These include IBM Tivoli® service management and cloud computing products; IBM WebSphere® portal and application server products; and IBM DB2® database software.

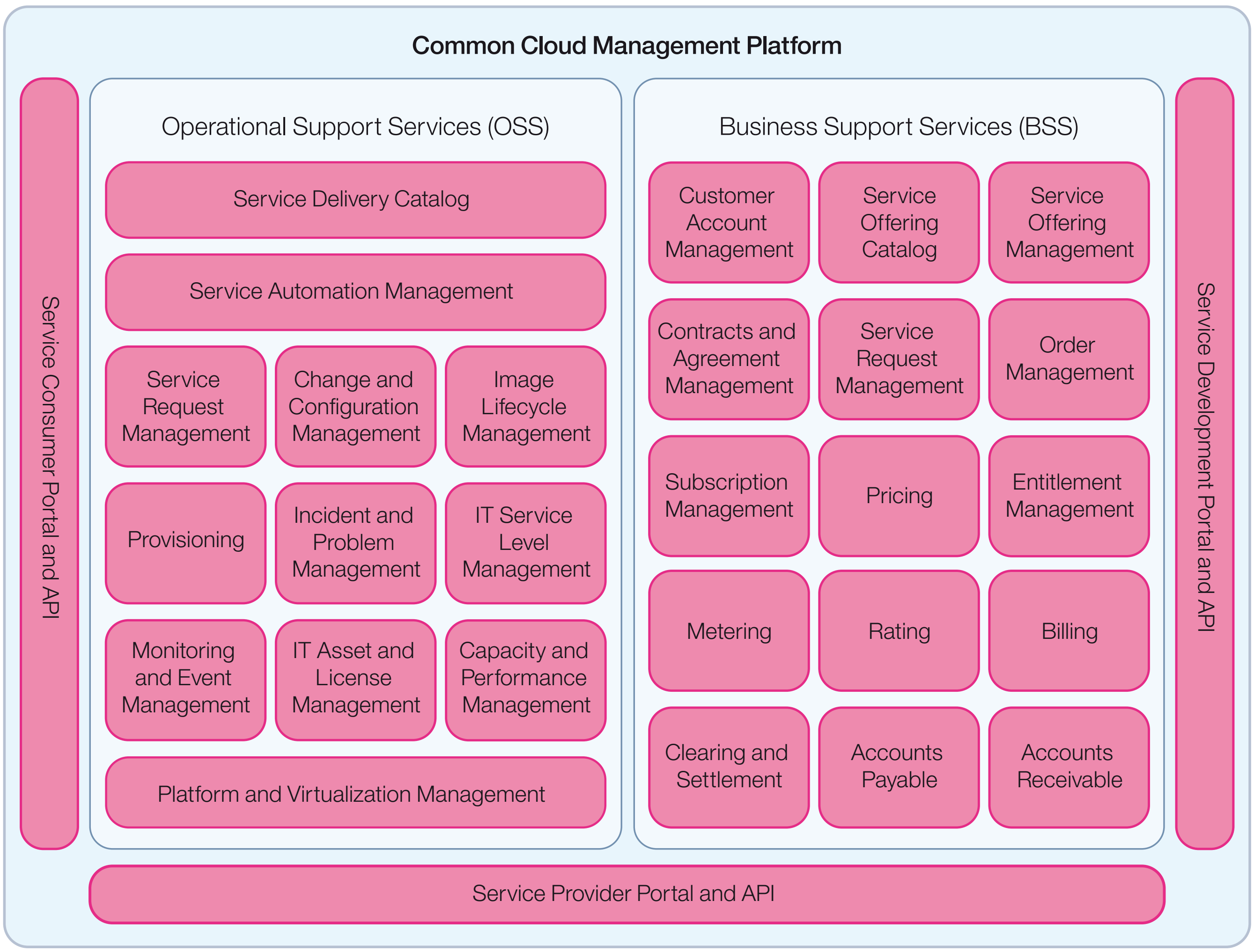

Figure 4: The components of the Common Cloud Management Platform execute the operational and business management of all layers of the cloud environment, including the CCMP itself.

Operational Support Services

The OSS module defines the set of systems management services that may be exploited by cloud service developers. Many of the management domains specified in the OSS (see Figure 4) can also be encountered in traditionally managed data centers, such as monitoring and event management, provisioning, incident and problem management. Although these management domains are conceptually the same in both traditional and cloud IT environments, in a cloud architecture these domains can be implemented in very different ways.

Consider, for example, incident and problem management. If a physical server fails in a traditional IT environment, a trouble ticket is opened and assigned to a systems administrator for manual (and therefore costly) intervention and resolution. If the problem is not resolved in the time specified by service level agreements, it may be escalated until it is resolved. If a physical server fails in a cloud environment, new virtual machines (and their applications) are automatically brought up on another physical server where resources are available, without delaying handling the incident with a long, drawn-out investigation of the failed physical machine. This approach is typically referred to as "replace vs. repair," based on the assumption that manually repairing things is often more complex than just replacing them. Clearly, this is not possible for all workload types. SLAs and root cause analysis still has to be done for broken physical machines, but it gives inspiration on how management processes can be realized in novel ways. It is this kind of rules-based response to hardware failure—zero touch administration and "lights out" automated operation at a much lower cost—that characterizes service management in the cloud and is described in the IBM Cloud Computing reference architecture.

Business Support Services

The BSS module defines the capabilities required to enable the business management of one or more specific managed cloud services. For example, the billing service component of the BSS must be capable of performing billing for the consumption of virtual machine resources (infrastructure as a service), a multitenancy capable middleware platform (platform as a service) and a multitenancy application such as collaboration or customer relationship management (software as a service).

Other components of the BSS (see Figure 4) address service management and automation at the user interface level. These capabilities include a user-friendly self-service interface and service offering catalog through which consumers select, configure, arrange payment for and discontinue cloud services. The BSS delivers the functions required to operate a self-service cloud business. These include automated, rules-based execution of pricing, contracts and agreements, invoicing, and clearing and settlement. The BSS also provides business management capabilities, including offering, customer, subscriber, order, fulfillment and entitlement management.

Enabling the business side of the cloud services paradigm

Cloud services represent any type of IT capability that is offered by the cloud service provider to cloud service consumers. Typical categories of cloud services are infrastructure, platform, software or business process services. In contrast to traditional IT services, cloud services have attributes associated with cloud computing, such as a pay-per-use model, self-service acquisition of services, flexible scaling, and sharing of underlying IT resources.

In the IBM cloud reference architecture, the CCMP is designed to enable these cloud-specific capabilities through the OSS—while handling the ongoing management of all of the provider's cloud service instances—while the BSS is responsible for handling all business-relevant aspects of a cloud service.

Supporting an open, vendor-neutral approach to infrastructure

The infrastructure layer of the cloud reference architecture comprises all hardware infrastructure elements needed to provide cloud services. This includes facilities as well as the server, storage and network resources and how those resources are deployed and connected within a data center. It is important to note that in a true cloud environment, significant engineering and thinking must be invested for selecting and deploying these infrastructure elements to achieve minimal costs in combination with optimal performance, scalability, security and resiliency.

A key factor to consider in evaluating a cloud reference architecture is how these typically virtualized resources will be managed. As a vendor designing, implementing or managing private cloud implementations for customers—either on premises or outsourced—IBM's reference architecture is vendor and technology neutral. This approach means that IT organizations have greater flexibility in repurposing existing physical server, storage and network resources for use in a cloud environment.

Simplifying service development and adoption with standards-based tools

In evaluating vendors for enterprise-class cloud solutions, consider also the way a vendor's reference architecture supports the tools that service creators and service consumers use to develop and integrate cloud services. Some cloud platforms are highly proprietary, and in turn require developers to use proprietary tools and develop to proprietary standards, resulting in high switching costs to move logic, data or applications from one cloud service provider to another.

IBM's approach to cloud computing focuses on open standards such as Java®, JEE, Web 2.0, Ajax, Unified Modeling Language and Eclipse as well as broad support for IBM and non-IBM hardware platforms, operating systems, virtualization platforms and hypervisors. IBM Tivoli service management and automation software as well as IBM WebSphere middleware and IBM DB2 information management software are standards based and support interoperability. Similarly, IBM offers a range of products and technologies, including the IBM Rational® family of products, designed to support industry standards and enable rapid, cost-effective development and testing of cloud services. IBM also offers services based on its industry-leading SOA services and experience.

The reference architecture builds on existing SOA reference architecture standards[3] and defines open standards support for several categories of tools used by service creators and service consumers. These include:

Service creation tools: Service creation tools are used to create new cloud services. These include tools for developing runtime components, such as virtual machine images or SaaS applications, as well as tools supporting the development of cloud service-specific management configurations and artifacts for all OSS and BSS components. These configurations and artifacts define how the CCMP OSS and BSS functionality is used in the context of the respective cloud service.

Service integration tools: It is important for customers to be able to integrate cloud services with in-house IT. This functionality is specifically relevant in the context of hybrid clouds, where seamless integrated management and usage of different cloud services and in-house IT is critical. IBM and IBM Business Partners offer a range of service integration tools and services for both in-house and hybrid cloud integration, extending services from existing SOA solutions.

External partners help extend cloud capabilities

As an extension of its philosophy of an open, vendor-neutral approach to cloud computing, IBM works with an ecosystem of IBM Business Partners to accelerate and optimize the journey to a cloud environment. This ecosystem will continue to grow as cloud computing matures and expands to include new workloads. IBM works with independent software vendors (ISVs) to enable them to deliver their applications on IBM public clouds in an IBM-hosted environment. IBM's partner ecosystem also includes companies that offer software development platforms, open-source toolkits, virtualization technology and platform services that can provide cloud customers the capabilities for delivery success and the ability to meet and even exceed their own business case milestones. IBM is also making it easier for ISV and enterprise software developers to gain cloud computing skills with no-charge access to online workshops, skills tutorials, and social networking tools.

Real-world examples of cloud services built on the IBM reference architecture

IBM employs a well-defined process for using the cloud reference architecture to implement numerous clouds that are operational today and delivering value to IBM clients and the company itself. Our experience demonstrates that using the cloud reference architecture significantly reduces the time and resources required to define, build and deploy cloud infrastructures and realize business value.

The reference architecture supports the detailed design of the cloud solution in three major steps:

1. Define the requirements (both functional and non-functional) for the cloud implementation by leveraging and extending the defined roles, use cases and non-functional requirements from the reference architecture. Furthermore, the reference architecture defines a step-by-step process for creating new cloud services as the basis for capturing requirements associated with each new service that the cloud implementation will deliver. Finally, the reference architecture provides the considerations for the consumability of the cloud services that can be used to impose further requirements on the implementation.
2. The logical design of the cloud solution can be derived from the detailed architecture overview provided by the reference architecture. The architect/designer can choose from existing solution patterns to guide the design, choose the applicable architectural components that are needed to support the requirements, and choose the appropriate products to implement the components.
3. The physical design of the cloud solution defines the details of the implementation. The first step is to choose the detailed components and nodes from those defined in the reference architecture that will form the basis of the implementation. These are augmented with the definition of the service flows (derived from those provided by the reference architecture) of the automated management processes. The final step is to lay out the details of the solution deployment, including nodes, networking and topologies.

The above design approach is further supported by the reference architecture through the definition of applicable architectural decisions, standards and detailed technical domains (e.g., scalability and performance) that can be used to guide the solution design and implementation details. Note that the reference architecture provides this support in terms of documented work products that cover each of the areas discussed above, and is consistent with the solution design methodology used across IBM.

Moreover, as we will describe in the two examples that follow, the reference architecture can equally accommodate the different requirements of public and private clouds as well as varying use cases:

- Development and test services on the IBM public cloud. The Smart Business Development and Test on the IBM Cloud service is designed to augment and enhance software development and delivery capabilities, particularly in large enterprises where IT departments handle hundreds of development projects every year. Unlike traditional development environments, developers can log on to IBM Smart Business Development and Test on the IBM Cloud and get access to customizable virtual machines in minutes. To help customers leverage existing investments, these new services support development across heterogeneous environments, including Java, Open Source, .NET and the IBM Rational Jazz framework. The IBM Smart Business Development and Test on the IBM Cloud provides the following features to software developers and testers: instant self-service provisioning of development and test environments; a dynamic and elastic environment to support an organizations' test lab and build infrastructure; metered pricing.
- A private, internal development and test cloud for IBM. The IBM CIO operations department needed a self-service testing environment to support developers in multiple different IT organizations within IBM. The main objective of the cloud implementation was to reduce the time and cost required to build and manage development and test environments. The CIO implemented a cloud computing environment using IBM Integrated Service Management solutions to create a service-oriented approach that allows developers and testers to quickly provision, deprovision, power on, power off and change the size of their virtual machines. The cloud implementation improved service by reducing the engagement and deployment time for provisioning a new image from about five days to one hour; decreased capital costs by enabling the CIO to support more people with fewer systems; shortened the testing life cycle; and lowered end-user costs by providing billing based on services consumed.

As described above, the first step in using the reference architecture to implement a cloud service is to document the service-specific user roles, use cases, non-functional requirements and consumability characteristics, guided by a dedicated work product around cloud service creation. For each of these areas, the reference architecture provides a "starter set" of standard requirements. For example, the reference architecture defines several dozen use cases, grouped into "packages" along the cloud service life cycle. Table 1 shows an extract of user roles defined in the reference architecture, with examples of specific user roles identified for the IBM public and private development and test (dev/test) cloud services. Similarly, Table 2 shows a sampling of standard and service-specific use cases.

Reference architecture example user roles	Smart Business Development and Test on the IBM Cloud	A private, internal development and test cloud for IBM
Cloud Service Provider	**IBM Smart Business Development and Test service delivery team**	**IBM CIO operations department**
Deployment Architect	GTS Architect Engineer responsible for deploying integrated service delivery management components in IBM service delivery data center	IBM CIO IT Engineering Engineer responsible for deploying integrated service delivery management components in IBM CIO data center
Security and Risk Manager	GTS Security Team, IBM Service Delivery	ITB CIO Security Department
Cloud Service Creator	**IBM Smart Business Development and Test developers**	**IBM CIO engineering department**
Offering Manager	Project lead for IBM Smart Business Development and Test on the IBM Cloud	Project lead for IBM CIO private cloud project
Cloud Service Consumer	**Various companies and users of the service**	**Various IBM developers**
Consumer Business Manager	Company Business Manager	IBM Line of Business IT manager
Consumer End User	Company end users	IBM CIO Line of Business end users

Table 1. Comparison of example user roles.

Reference architecture example use cases	Smart Business Development and Test on the IBM Cloud	A private, internal development and test cloud for IBM
Self-guided information and education	Educate end users about the capabilities of the Smart Business Development and Test on the IBM Cloud offering and on how to use the self-service portal	Educate end users on how to use the self-service portal
Sales channel	Primarily web sales channel	Internal communications via IT managers
Enable customers for consuming managed services	Registration and subscription management	Project onboarding

Table 2. Comparison of example use cases.

Documenting the decisions made for each service-specific aspect of a cloud implementation results in work product documents. These in turn feed requirements into the next step for using the cloud reference architecture: developing the implementation-specific architecture overview diagram of the cloud implementation. The reference architecture overview diagram serves as the starting point for this exercise. In Figure 5, we can see where the service-specific requirements for the public and private cloud services resulted in different implementation-specific approaches for certain components of the OSS, BSS and Cloud Services elements, and where components could be reused from the reference architecture without customization.

For example, both the public and private cloud services need to provide the following features to software developers and testers: instant self-service provisioning of development and test environments, and a dynamic and elastic environment to support changing demand for services. The areas highlighted in green on Figure 5 show how both the public and private service architectures utilize OSS components to orchestrate the cloud service delivery along with the supporting components necessary to ensure effective service delivery: the respective portals for requesting, activating and accessing the services for both the service consumer and provider, the service delivery catalog and service request manager components to handle the requests from the service consumer, and the provisioning component to build up the virtual development/test environments associated with the request.

While both public and private cloud services employ the metering components of the BSS, the implementation of support for consumers from outside IBM—in the case of IBM Smart Business Development and Test on the IBM Cloud—is quite different compared to supporting internal IBM consumers as part of the private cloud implemented by the CIO organization. These differences are identified in the user roles, use cases, non-functional requirements and all resulting work products as provided by the reference architecture. The areas highlighted in orange in Figure 5 indicate components of the BSS that the architecture teams addressed uniquely for the public cloud service, including the subscriber management component to handle users; the pricing/rating component to handle the various pricing options; and the accounting and billing component to manage payments.

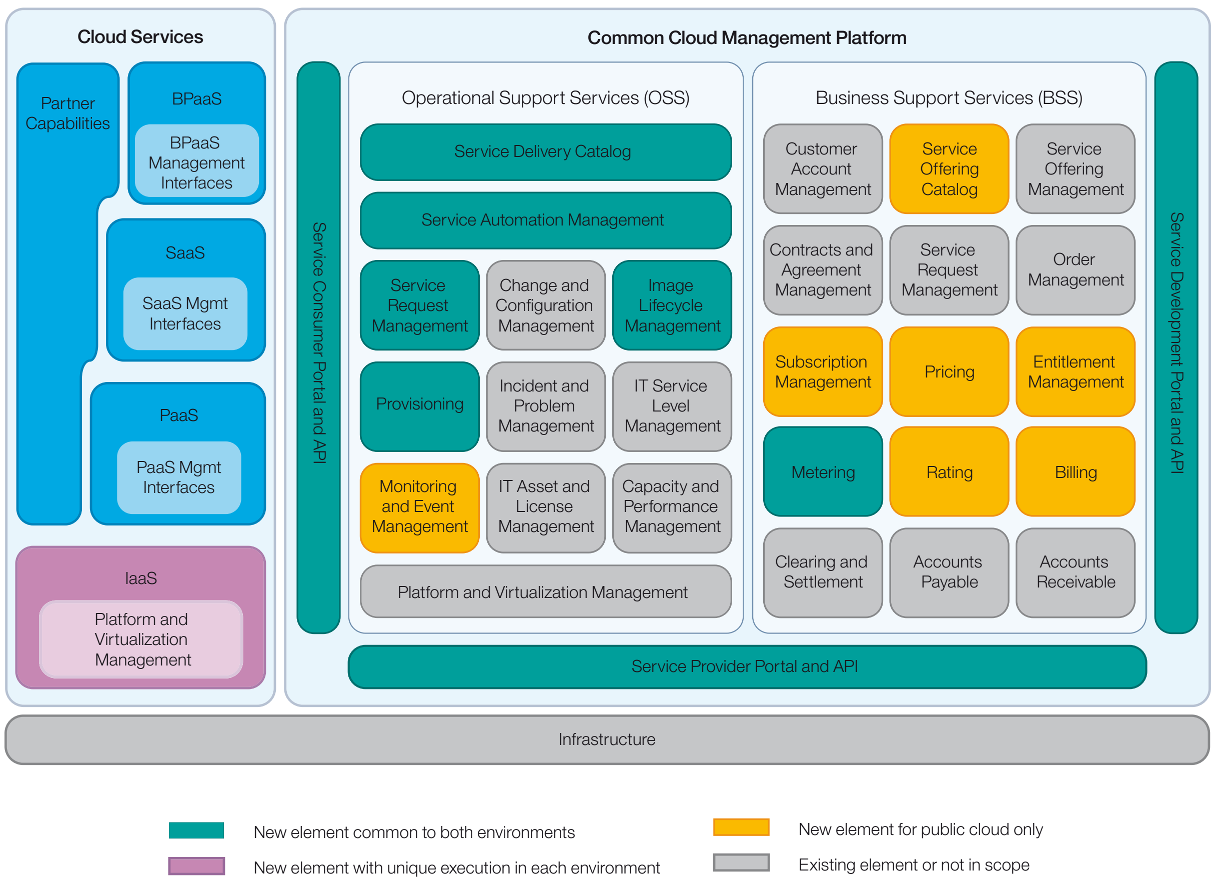

Figure 5: Some architecture elements are implemented differently to accommodate requirements specific to public and private clouds.

The reference architecture was also used in defining the architectural overview of the cloud services themselves (see element shaded in purple in Figure 5). The operating system components of each dev/test environment, for example, reflect the specific needs of each end user group, with the public cloud environment supporting both Microsoft® Windows® and Red Hat Enterprise Linux service instances, while the internal dev/test cloud is designed to support only Linux.

Similarly, the software for the public cloud service—consisting of development and runtime applications delivered as virtual machine images through the cloud—is designed to support several development environments, based on marketplace demand. These include IBM DB2 information management systems, IBM WebSphere Application Server and IBM WebSphere MQ, to name a few. For the internal development environment, the cloud service only needs to support the IBM corporate standard environment.

Once the architecture overview for a new cloud service is defined, architects can focus on specifying the OSS, BSS and cloud service component models, operational models, service flows that result in the final implementation—again working from the reference architecture-level models for domain-specific and cross-domain areas as the starting point. As a key part of this approach, architectural decisions and implementation-specific standards are also captured and documented.

When IBM employs the reference architecture to build cloud projects like the two just discussed, the resulting service-specific architecture is captured as an applied pattern. These applied patterns can then be reused to further accelerate development of similar new cloud services.

IBM provides a comprehensive set of cloud capabilities

- **Technology, tools, and skilled resources to help clients plan, build and deliver cloud services.** IBM provides clear economic value and helps the client work through the right mix of delivery models and choices by workload to reap the maximum benefit.
- **A proven, common architecture** for the design, build and management of all services across the IBM portfolio, including the cloud environment. The IBM architecture captures the aggregate experience of hundreds of IBM experts in building cloud environments and service-oriented architectures, across all divisions specializing in hardware, software, service management, research, and security.
- **Unequalled experience and expertise** with hybrid cloud solutions.
- **Global relevance.** IBM has partners, delivery centers, and a worldwide network of partners in 174 countries. IBM also has the experience of running a globally integrated enterprise and understands what it takes to make a global company run.
- **IT flexibility.** Easy connectivity across a wide infrastructure and ecosystem of partners.
- **Robust and secure cloud solutions,** based on the demanding needs for clear visibility of assets, complex data governance, and security and resilience of the solution.
- **Simplicity of design.** From sourcing to usage to maintenance, IBM cloud solutions are designed to be simple, intuitive and based on how people actually work.
- **Open standards.** IBM has taken a leadership role in developing standards for cloud computing built on current architecture, industry and open standards, including SOA, assuring consistency and compatibility across all cloud platforms.

Summary

Cloud computing promises a new approach to IT economics—but also presents new challenges. Everyone, from the CIO to the enterprise end user, has come to expect a new standard from technology, including masking complexity, providing enterprise-class security, delivering “dial tone” reliability, and wrapping it all in a friendly, easy to use self service package. These expectations are fueled in part by users’ personal consumer experiences with companies such as Amazon and Google.

Companies are moving ahead with cloud computing projects as a way to address end user expectations while reducing costs. Because cloud computing can potentially be a disruptive change to the way an enterprise’s IT services are delivered, the stakes are high when it comes to selecting a cloud vendor. One way CIOs can narrow the selection gap is by examining candidate vendors’ reference architecture for cloud.

IBM has a proven reference architecture for building and managing cloud solutions, providing an integrated approach that uses the same standards and processes across the entire portfolio of products and services. IBM’s expertise and experience in designing, building and implementing cloud solutions—beginning with its own—offers clients the confidence of knowing that they are engaging not just a provider, but a trusted partner in their IT endeavors. The IBM Cloud Computing reference architecture builds on IBM’s industry-leading experience and success in implementing SOA solutions.

In the final analysis, cloud computing is not just about data center technology. It’s about streamlining business processes to make organizations and people more strategic, more responsive to change and more oriented to service delivery. With experience at all levels—from technology, consulting and strategy services to business processes—IBM is uniquely positioned to collaborate with clients and enable them to reap the significant benefits of cloud computing.

For more information

To learn how IBM is working with organizations around the world to help them design, build and implement cloud computing, please contact your IBM marketing representative or IBM Business Partner, or visit the following website: **ibm.com**/cloud

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