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VNPaaS: Realizing Platform as a Service using Network Function Virtualization

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Abstract: The advent of cloud computing is causing a far reaching impact on traditional IT infrastructures and has drastically changed the way traditional businesses operate. Platform as a service is a cloud computing model that provides a platform for application developers and enterprises with all the necessary hardware, software, runtime and development tools that are necessary to build, test and deploy applications without having to worry about infrastructure maintenance and upgrades. But traditional PaaS solutions are inflexible and unsuited for real-time scaling and dynamic bandwidth requirements of today's enterprises. With network function virtualisation, it's possible to replace existing network functions with virtualized functions to realise a Virtual Network Platform as a Service model that provides users with run-time scaling, resource pooling, dynamic resource allocation and customization capabilities making it a viable alternative to traditional Platform as a Service solutions.

Keywords: Network Function Virtualization, Platform as a Service, Virtual Network Functions, Virtual Machines, cloud computing, orchestration, customization, scaling.

I. INTRODUCTION

In today's world of technology and internet, cloud computingis beginning to play an increasingly critical role. The advent of cloud computing and cloud based services has really changed the way businesses operate [1]. According to the National Institute of Standards and Technology(NIST) [2], "Cloud computing is a model for enabling ubiquitous network access to a shared pool of configurable computing resources (for e.g. servers, storage, applications, networks etc.) that can be quickly provisioned with minimal service provider interaction or management effort". Thus, cloud computing, or in simpler terms referred to as a "cloud", focuses on maximizing resource utilization of shared resources so that resources can be dynamically reallocated as per demand [1]. Cloud computing providers generally offer cloud based services using three major service models. The cloud service models are classified based on the level of abstraction and the amount of user control that a specific model provides and are often represented in the form of a cloud computing stack illustrated in Fig. 1 [3].

At the bottom of the stack resides the actual data centre that comprises of storage, networking and other services.These services can be abstracted by service providers and offered as a service to end-users based on three basic service models namely:

- Infrastructure as a Service (IaaS): It is the most basic service model that offers remote data centre infrastructure such as storage, networking, virtual machines, servers and network services (e.g. firewalls) as an on-demand service [4]. Thus, rather than having to purchase in-house hardware that will require continuous maintenance, clients of IaaS can instead access the required infrastructure remotely as a fully outsourced service on demand. This will eliminate the hassle of continuous management and maintenance of in-house hardware and allows efficient hardware resource sharing among multiple users.

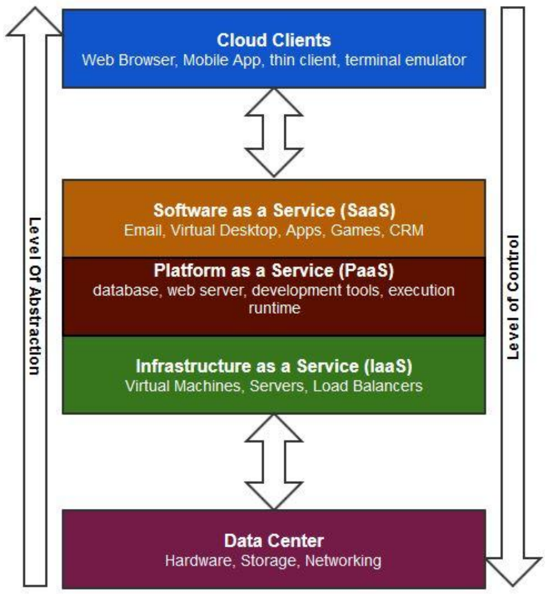

Fig.1 Cloud Computing Stack

- Platform as a Service (PaaS): In a PaaS model, service providers deliver a computing platform that typically includes an operating system, database, execution environment, web server and other tools to app developers. This enables effective development and deployment of applications without the hassle and complexity of purchasing, configuring and managing all the hardware and software resources necessary to build custom applications [5]. Thus, PaaS makes the development, deployment and testing of applications simple, rapid and cost-effective.
- Software as a Service (SaaS): This model is used by cloud providers to deliver software applications such as email, games, apps, virtual desktop etc. over the web [6]. The applications are managed by a third-party

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vendor and are accessed by clients using an interface. With SaaS, an application provider licenses software to customers either as a service on demand via a subscription or at no charge when revenue can be generated by alternate sources such as advertisements.Since SaaS uses a web-delivery model, it eliminates the need to install and run applications on individual systems. Instead, most SaaS applications can be run directly from a web browser without downloads or installations although some apps require plugins [7].

Cloud services are generally provided to clients using any of the above three service models using cloud clients. Typical cloud clients include web browsers, mobile apps, terminal emulators and thin clients [8]. Table I below illustrates the typical end users and service providers of the three cloud service models.

TABLE I CLOUD SERVICE MODELS

Cloud Service Model	End Users	Service Providers
Infrastructure as a Service	System admins, network architects	Amazon Web Services, Amazon EC2, Rackspace, Google Compute Engine, Joyent, VMWare Hyper-V, Oracle Virtual Box
Platform as a Service	Business Analysts, Software and Web Developers	Apprenda, Google App Engine, Windows Azure, Rollbase, force.com, Amazon elastic beanstalk, VMWare Cloud Foundry
Software as a Service	IT, Finance, Sales, Marketing	CISCO WebEX, Microsoft 365, gmail, Yahoo!Mail, Citrix GoToMeeting, Google App Store, NetSuite, SAP Business objects, Lotus Notes

II. PLATFORM AS A SERVICE

Platform as a service (PaaS) is a service model that abstracts the computing platform thereby facilitating rapid application development without the hassle and complexity of having to purchase, maintain and configure hardware and software required to build applications. The computing platform typically comprises of an operating system together with an integrated development environment (IDE) that can be accessed by app developers over the web [9]. Thus, PaaS provides a framework that developers can use to build, test and customize applications. Enterprise operators that provide PaaS services manage the operating system, IDE, virtualization, servers, storage, networking and other hardware and software services requested by clients [10]. Fig. 2 illustrates the high level architecture of a typical PaaS model [11].In addition to providing a platform IDE to develop applications, PaaS service providers also provide additional services such as data security, backup and recovery, application hosting and scalability. Such an abstraction allows developers to focus on application development without having to worry about the underlying hardware and software that is being used to build custom applications [9]-[11].

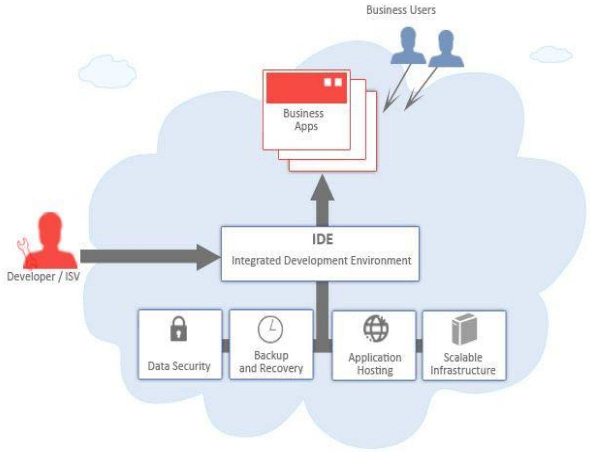

Fig. 2 PaaS High Level Architecture

Fig.3 below illustrates the series of steps that an application developer has to follow to build an app using a PaaS platform vis-à-vis legacy platforms [9].

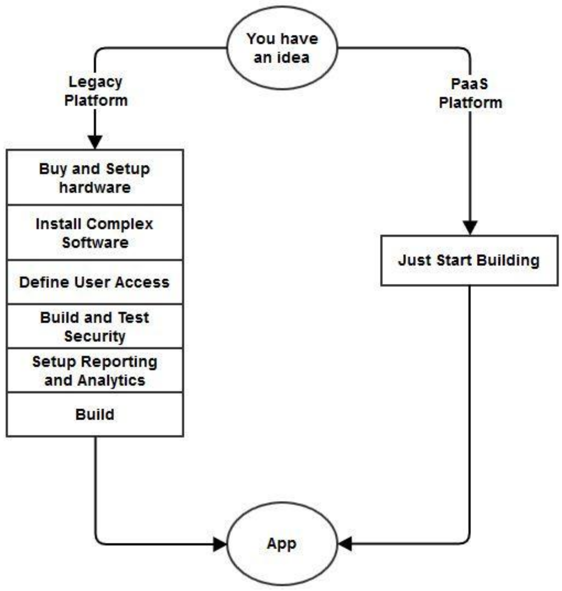

Fig. 3 PaaS v/s Legacy Platforms to build an app

A. PaaS Characteristics

PaaS can be distinguished from other cloud service models based on the following characteristics [8], [10]:

- Multi-tenant architecture: An architecture wherein multiple concurrent users utilize the same application development platform concurrently.
- PaaS provides integration with databases and web services using common standards.

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- Services: PaaS provides services to build, test, deploy and maintain applications.
- Built-in scalability of deployed software such as failover and load balancing.
- Web based user interface tools to create, test and deploy different user interface scenarios.
- Development Team Collaboration support: Some PaaS solutions provide application developers withadditional tools for project planning and communication.

B. PaaS Use Cases

PaaS which generally provides a platform to develop software comes in two different variants described below [8].

- PaaS can be used as a collaborative platform for software development that focuses on workflow management irrespective of the data source being used for the application. A typical example of this approach is Heroku, a PaaS that uses Ruby on Rails development language.
- PaaS can also be used as a platform that facilitates the creation of software by harnessing the data from an application. This type of PaaS is meant to create applications with a common data form or type. A typical example for this type of platform is the Force.com PaaS from Salesforce.com that is generally used to build applications that work in the Salesforce Customer Relationship Management (CRM).

Table II below summarizes the cardinal features of a typical PaaS platform [9].

TABLE II PAAS PLATFORM FEATURES

Sl. No	**PaaS Feature**	**Description**
1.	Abstraction	OS, middleware, Integrated Development Environment, physical infrastructure and databases
2.	Service Unit	Containers (e.g. RedHat), Application Services (e.g. messaging)
3.	Primary Use Case	Provides standard application and containers to developers and testers. Also allows for dynamic management of infrastructure resources to support scaling and extensibility capabilities.
4.	Advanced Use Cases	Automated Testing Environment, integration with continuous integration and development systems.
5.	End Users	Application Developers, Web developers and business analysts.
6.	Tools	Force.com, Windows Azure, VMware Cloud Foundry, Google App Engine, Amazon Elastic Beanstalk, Apprenda, Rollbase.

III.NETWORK FUNCTION VIRTUALIZATION

Network Function Virtualization (NFV) is an initiative by European Telecommunications Standards Institute (ETSI) that proposes to use the standard IT virtualization technologies to virtualize entire classes of network code functions into building blocks that may be connected or chained to provide communication services [12]-[14].The network code functions so virtualized are called Virtual Network Functions (VNF). VNF's consist of one or more virtual machines (VM's) running different software and processes on top of standard high-volume storage, switches, servers or cloud computing infrastructure rather than using proprietary dedicated hardware for each network function [13]. This results in a decoupling of network functions from dedicated hardware such as routers, firewalls, load balancers and other devices[13]. Such a virtualization of network services will reduce the amount of proprietary hardware required to provide network services.This means that network admins no longer need to purchase dedicated hardware devices to build a service chain. Since additional capacity can be added through software, system admins no longer need to overprovision their data centres resulting in a reduction of Operational Expenses (OPex) and Capital Expenses (CAPex). For example, if an application running on a VM requires more bandwidth, the admin can move the VM to another physical server or provision another VM on the current server to share a part of the load. This flexibility provides enterprises with an agile network that can be tailored based upon changing business needs or network service requirements [14].

A. NFV Architecture

ETSI has a working group (WG) called the Industry Specifications Group (ISG) that is currently developing requirement specifications and architecture for NFV [12]. A simplified version of the ETSI-ISG proposed NFV architecture is depicted in Fig. 4 below.

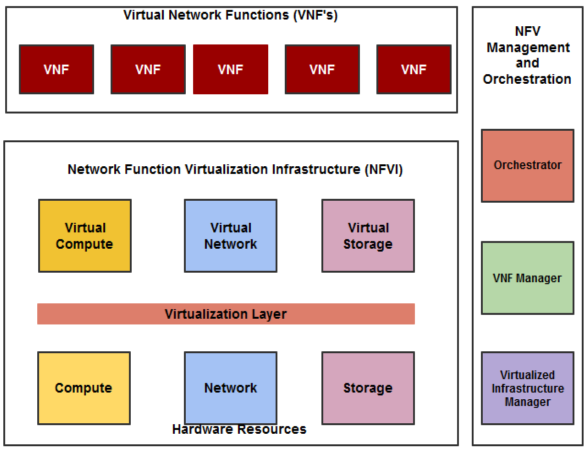

Fig.4 NFV Architecture Block Diagram

NFV typically has three major subcomponents namely:

- Virtualized Network Functions (VNF): They are software implementation of actual network functions that are generally deployed on a Network Function Virtualization Infrastructure (NFVI). ETSI-ISG

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proposes to develop open standards for VNF's so that the same VNF's can be used cutting across vendor configurations thereby promoting vendor neutrality [12].

- Network Function Virtualization Infrastructure (NFVI): NFVI comprises of the hardware and software components that combine to form a framework on which VNF's are deployed. The hardware components typically comprise of compute, networking and storage devices while the software components are their virtualized counterparts. The hardware and software components are separated by a virtualization layer that acts as an interface between the two. NFVI can span several locations and the network connecting these locations is considered to be a part of NFVI [13].
- Network functions virtualization management and orchestration architectural framework (NFV-MANO Architectural Framework): NFV-MANO comprises of functional blocks, data stores used by these blocks and interfaces through which these blocks communicate in order to manage and orchestrate NFVI and VNF's. In order to build scalable and reliable services, NFV requires the network to instantiate, monitor and maintain NFV instances. These characteristics are called carrier-grade features allocated to the orchestration layer to manage VNF's irrespective of the underlying technology in the VNF [13].

B. NFV Use Cases

With the implementation of VNF's using open standards, the same VNF can be used across multiple vendor platforms. This ensures vendor independence. Further, more complex services can be built by combining multiple VNF instances in a sequence, a notion known as service chaining [14]. Also, the virtualization of network functions using VM's provides network admins with the flexibility to host multiple VM's on common hardware. New VM's can be dynamically added or an existing VM can be moved to another server thus enabling resource pooling and dynamic resource allocation [22]. Table III below lists the potential uses cases of NFV architecture [15].

TABLE III NFV USE CASES

Sl. No	**Use Case**	**Description**
1.	Infrastructure as a Service	IaaS mandates pooling of computer network and storage resource something which the resource pooling character in NFV can provide
2.	Virtual Network Function as a Service	To meet resource crunch and minimize spending, enterprises are aiming to virtualize the enterprise CPE (Access router) into the operator's network. The enterprise acts as a consumer of the VNF provided by the operator eliminating the need for the enterprise to invest in additional capital to procure advanced networking features.
3.	Platform as a Service	Since VNF can increase the flexibility to share resources and decrease management costs, the service providers can provide a suite of infrastructure and applications as a platform that on which enterprises can deploy their network applications.
4.	VNF Forwarding Graphs	A Network Function (NF) forwarding graphs defines the sequence of NF's that packets traverse over a cable. Using VNF, NF forwarding graphs are virtualized in a way that VNF forwarding graphs provide virtual connectivity between virtual appliances (VNF's)
5.	Virtualized Mobile Core Network	NFV can reduce the complexity and operational issues of a mobile core N/W by leveraging standard IT virtualization techniques to consolidate different types of network equipment onto industry standard high volume storage, switches and servers. This reduces the Total Cost of Ownership (TCO) of a mobile core N/W
6.	Virtualized Mobile Base Station	Virtualization of mobile base stations leverage standard IT virtualization technology to realize some part of the Radio Access Network(RAN) nodes onto standard IT servers, storage and switches. It enables dynamic resource pooling, traffic load balancing resulting in reduced energy consumption.
7.	Virtualized Home Environment	A typical home N/W generally includes a Residential Gateway (RGW) for Internet and VOIP services and a Set Top Box (STB) for media service. With the availability of high bandwidth access and the emergence of NFV technology facilitates virtualization of home environments requiring only simple, lost cost devices at customer premises.

IV. VNPAAS: REALIZING PLATFORM AS A SERVICE USING NFV

Network resources are seldom used entirely by operators. Today, many operators tend to share enterprise applications on the service provider infrastructures using traditional PaaS configurations. But traditional PaaS systems have specific network functions that are tied to vendor specific hardware devices such as routers, firewalls and load balancers. This makes the PaaS solution

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restrictive in nature and this further aggravates scalability and dynamic provisioning issues [10]. By replacing traditional network functions with virtualized network functions hosted on VM's, service providers are able to gain the required flexibility [15]. This facilitates dynamic scaling, resource pooling and multi-tenant resource allocation by way of allocating new VM's or moving existing VM's to a different hardware. Thus the usage of VNF's for PaaS enables us to achieve a Virtual Network Platform as a Service (VNPaaS) technology. Fig. 5 illustrates the architecture of the proposed VNPaaS.

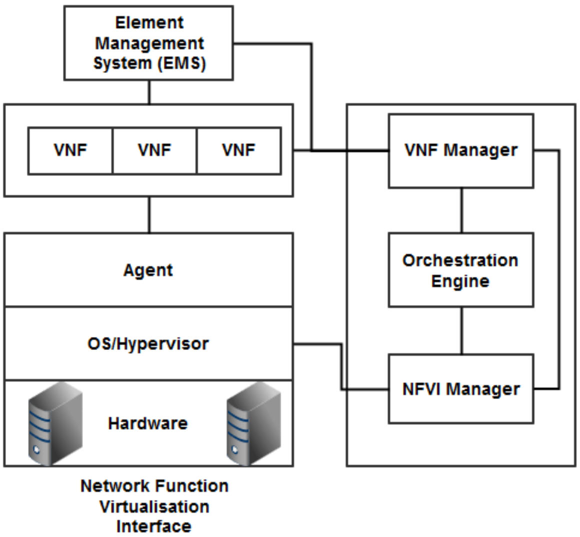

Fig. 5 VNPaaS Architecture Block Diagram

The proposed VNPaaS will have the cloud hardware and software such as the cloud OS, hypervisors, cloud agents, networking and storage host on the Network Function Virtualisation Interface (NFVI) at the service provider'spremises. NFVI is managed and controlled by a NFVI manager [11]-[13]. The actual cloud functions are then exposed to the outside world via VNF's that are controlled by a VNF manager. The VNF's hosted on VM's provide the required flexibility to scale and dynamically allocate the requested services.The entire infrastructure is managed and orchestrated by an orchestration manager that resides in NFV-MANO subcomponent of the NFV architecture [14]. The VNF's hosted on VM's together with the cloud infrastructure hosted on NFVI provide enterprises with a platform to build, deploy, test and host carrier-grade applications. Since multiple VNF's can be hosted on common hardware, it's possible for a single operator site to be serving multiple enterprise customers [16]. This is illustrated in Fig. 6 below.

Fig. 6 illustrates the three different entities Enterprise A, Enterprise B and an Operator sharing a single service provider's network through virtualized interfaces (VNF's) [16].

While the management controls of the applications hosted remain with the enterprises, the actual control and maintenance of PaaS hardware and software is carried out

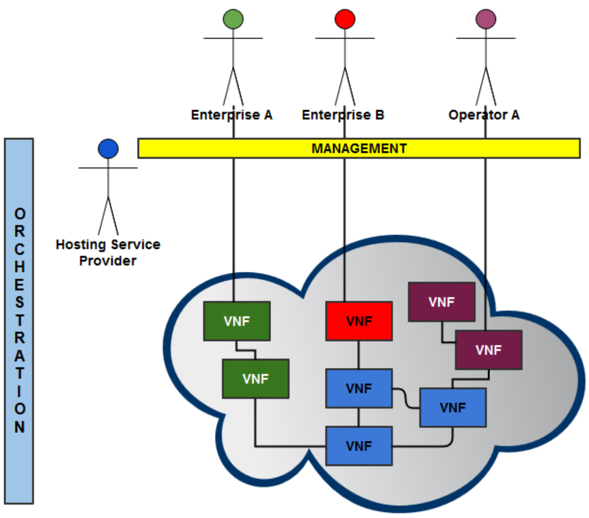

Fig. 6 Multiple Enterprises hosted by a service provider over VNPaaS

by the service providers. Thus enterprises can focus on application development without the hassle of maintaining any infrastructure [18]-[19]. Further, VNPaaS only provides a basic platform to enterprises. The flexibility offered by VNF orchestration manager allows enterprises to customize the platform settings to suite their specific requirements. The kind of services provided by a VNPaaS can vary from a simple firewall service for a single enterprise to an entire business communication suite based on IP Multimedia Subsystem (IMS) network to a customer [20]. Also a service can be orchestrated out of existing VNF elements, deploying new elements or a combination of both.

Consider the example of an email service hosted by a service provider for an enterprise [15]. Within the scope of NFV, an email server can be considered as yet another virtual network function. In a typical email VNPaaS, the service provider will provide the installation of an email server sans any configuration such as mailboxes, mail domains, user configurations etc. The enterprise is given full admin control so that it can apply all configurations on its own. Further, the enterprise may choose to deploy other VNF instances connected to the email server to implement advanced uses cases such as filters and spam protection. Thus an email VNPaaS will have all the basic email settings preconfigured by the service provider while the enterprise can further customize it as per requirements. The enterprise can then access the mailboxes via an interface provided by the service provider. The actual email server is hidden behind the frontend VNF's provided by the hosting service provider [19].

A. Challenges and issues in implementing VNPaaS

Despite the obvious advantages offered by a VNPaaS over traditional PaaS model, VNPaaS implementation comes with its own implementation and deployment challenges. Some of the common issues encountered while implementing VNPaaS over a typical NFV network are explained in Table IV below [15], [17], [19], [22], [25].

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TABLE IV VNPAAS IMPLEMENTATION CHALLENGES

Sl.No	Challenge	Description
1	Access Control	Access to VNF API calls should be based on an authorized user identity to prevent unauthorized access to VNF's owned by a client.
2	Workload Separation	Since VNPaaS can have multiple enterprises hosted on a single infrastructure, it's essential to clearly identify and demarcate the workloads of each enterprise to ensure efficient resource utilization.
3	Resource Usage Limit	Both infrastructure resources and VNF's need to provide an interface to measure, limit and guarantee the amount of resources used by each client in order to ensure a fair distribution of resources between various parties.
4	Management Interface Protection	The management interfaces provided to enterprises to control their VNPaaS may be exposed to an unauthorized 3rd party without the knowledge of the service provider. Thus a sophisticated isolation of the service is required to prevent any intrusions into the management domain of the particular service.
5	Accounting	VNPaaS should implement accounting to keep a track of the resource utilization by each party. This is required for statistical reporting and analysis.
6	Tools	Since VNPaaS allows enterprises to define their own custom virtual networks, the VNPaaS framework must provide the enterprises with the necessary tools to support the creation of virtual networks using VNF's.

B. Advantages of VNPaaS over traditional PaaS

PaaS systems typically provide application developers with a platform with the entire hardware, software and development environment for developers to build test and deploy their applications. Thus, developers can focus on application development without having to worry about infrastructure maintenance. This facilitates rapid application development relieving the app developers from tedious hardware maintenance, software upgrades and other configuration related issues. In addition to these advantages offered by traditional PaaS systems, VNPaaS systems provide additional advantages that further simplify application development and deployment. Table V discusses the advantages offered by VNPaaS over traditional PaaS architectures [16], [21], [23], [24], [25].

TABLE V ADVANTAGES OF VNPAAS

Sl. No	Advantage	Description
1.	Resource Pooling	Since VNPaaS keeps a track of individual workload and utilization characteristics of a given client, it is able to effectively pool the available resource and distribute them efficiently across consumers resulting in an efficient resource distribution.
2.	Dynamic Resource Allocation	If additional bandwidth is requested, new VNF's can be created or an existing VNF can be redeployed for the requesting party. This facilitates dynamic allocation of resources.
3.	Customization	Each enterprise can not only use existing VNF's but also deploy new VNF's that can offer additional services. VNPaaS allows enterprise to customize the VNF's to suit the specific requirements of an enterprise.
4.	Multi-tenancy	Since network functions are now virtualized and hosted on VM's, a single VNPaaS infrastructure can now service multiple clients in parallel.
5.	Dynamic Scalability	A VNPaaS is dynamically scalable by way of addition of new VNF VM's or moving an existing to a different hardware. Also, since the management interface provided to an enterprise remains unchanged, new hardware and software resources can be added dynamically without affecting the existing services.

V. CONCLUSION

The advent of cloud computing and cloud based services has impacted traditional IT infrastructures considerably and has drastically changed the way businesses operate.

Platform as a Service is a cloud computing modelthat provides application developers and enterprises with a platform that provides all the necessary hardware, software, development environment and tools required to build, test and deploy applications without having to worry about maintaining the cloud infrastructure. This promotes a cost-effective, rapid application development. However, traditional PaaS suffers from a couple of drawbacks in that it's quite inflexible making dynamic resource allocation and real-time scaling a challenge. With Network Function Virtualization, it is possible to virtualize network functions and host them on VM's. Thus the resultant PaaS platform hosted on NFV architecture uses VNF's as a substitute for actual network functions. This allows for resource pooling, dynamic resource allocation and scalability since existing VNF VM's can beeasily moved to another client as per requirement or new VM's can be easily deployed. Although, VNPaaS has some initial implementation challenges related to security, access control, management interface protection, resource usage limits among others, VNPaaS with its flexible and agile nature allowsenterprises to customize the VNF's allocated to them in order to support advanced configurations. Further, an efficient accounting, statistical reporting and workload separation of infrastructure resources allows for a fair and efficient resource distribution. VNPaaS is an emerging technology and all the shortcomings mentioned are expected to be resolved in future enhancements of this solution. With all the compelling advantages offered by a VNPaaS over traditional PaaS solutions, VNPaaS is certain to replace traditional PaaS in the years to come.

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