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Evolution of Cloud Computing and Related Distributed Computing Architectures

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Abstract - The aim of this paper is to present a survey of various computing models for computation intensive applications. The concept of Distributed Computing is introduced and evolution of Cloud Computing and associated technologies has been presented. The new concept of IoT and New Computing Paradigms like edge computing and fog computing have been briefly explained.

Key Words: *Cloud Computing, Distributed Computing, Multicore Architecture, Loosely Coupled Systems, Grid Computing.*

1. INTRODUCTION

Necessity of ability to process massive amounts of data and perform complex computations at high speeds has given rise to new developments for high performance computing architectures. These high-performance computing architectures are needed in following areas

- Science and Engineering: The specific area may include Computational fluid dynamics (aero-plane wings), Climate modeling, Structural mechanics, Materials science (new materials), Astrophysical simulation (data from telescope) etc.
- Healthcare: This includes examples like Drug discovery (interaction with human cells), Cancer diagnosis, Cardiovascular diagnosis etc.
- Business: Here, the major applications are Financial risk Modeling, Analyzes portfolios, Transaction processing, Data Warehouses and many more.
- AI: These is the state-of-the-art applications based on Machine learning, Deep learning, Agentic AI, Autonomous driving (self-driving cars) etc.

2. The High Performance Computing (HPC) journey

HPC journey was started even when the first computer was developed. However, with the increase in computing required newer architectures supporting complex computations were evolved[7].

2.1 Uni-Processor Systems: For solving small problems, *uniprocessor* sequential computers have been sufficient for years. In present arena also, the latest advances in hardware technology are good enough to solve many small problems on a single PC, having a single central processing unit, Main Memory based on Von Newmann model.

Fig -1: Uni-processor Architecture

2.2 Multi-Processors and Parallel Computing (Tightly Coupled):

For scientific applications, multiprocessor systems are used. More than one processing unit is used which share the main memory and peripherals to simultaneously process programs.

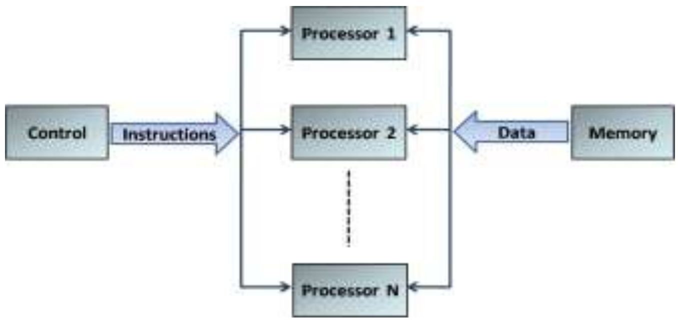

Fig -2: A Multiprocessor System

A multiprocessor has two or four or eight or more processors. However, for complex computational problems like whether forecasting, or space applications, massive parallelism was required. Supercomputers may have thousands of processors and Peta FLOPS floating point operations per second. However, such computers were very expensive and only privileged organizations with huge funding could afford (e.g DRDO, C-DAC etc.).

2.2 Multi-Core Processors

With the increase clock in speed, the power consumption and heat generation are very high, that is harmful for environment. To improve performance, multi-core processors with two or more CPUs (**cores**) were fabricated on same die (Chip Multi processor or CMP).

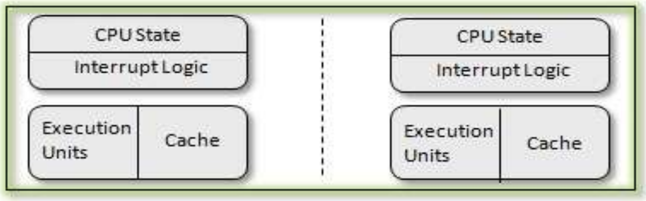

Fig -3: Multicore Architecture

Prior to multi-core architecture, Intel used this technology, where one physical processor was treated as logically two cores.

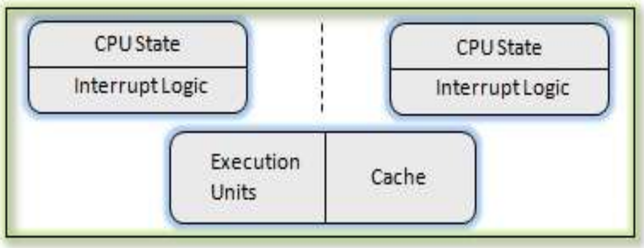

Fig -4: Hyperthreading Concept

Dedicated Parallel Machines (tightly coupled systems) are expensive with limited computing power storage due to **scale-up architecture**. In a **computer network**, autonomous computers are connected which can communicate with each other (called loosely coupled system). Networks don't have centralized control of and are used for explicit **resource sharing** on users' request. Distributed systems act like a virtual uniprocessor system, which can generate huge computing power. This uses computer network as a backbone but software system has ownership of all resources, allocated in transparent manner. Distributed systems are highly scalable to serve large number of users that can grow exponentially (**Scale-out architecture**). Distributed systems use a **loosely coupled hardware** (i.e. a computer network) but **tightly coupled software**. Types of distributed architecture include Computing Cluster, Server form, P2P, Grid Computing, Cloud etc.

2.3 Cluster Computing:

Several inexpensive computers, generally identical (e.g. Beowulf Cluster), work together as a single entity, connected using high speed LAN. Gives better performance & fault tolerance. The main benefits are scalability, availability and performance. The basic components are: nodes, cluster OS, network switching hardware.

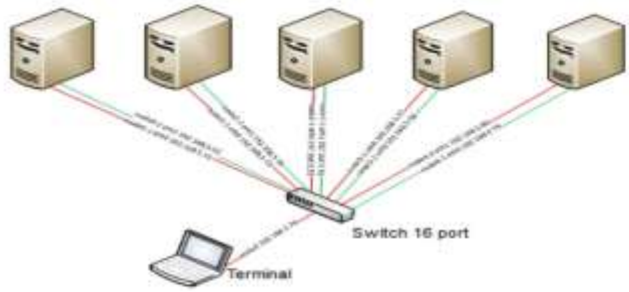

Fig -5:

2.4 Grid Computing:

Multiple clusters at different locations which are loosely coupled and heterogeneous. Involves sharing of resources like computers, applications, data, storage and network resources which are geographically dispersed, but coordinate with each other. Utility computing just like electrical grid as envisaged in MULTICS OS project (predecessor of UNIX)[6]

Fig -6: Computing Gris with Interconnected Clusters

Peer-to-Peer (P2P) computing: Computers are connected to each other in a computer network without the need of a central server. Used for file sharing, instant messaging, online gaming etc.

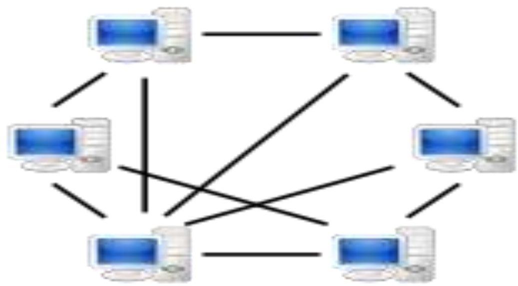

Fig -7: Peer-to Peer Networking

3. CLOUD COMPUTING MODEL:

Cloud Computing enables on-demand access to a shared pool of configurable resources (e.g., networks, servers, storage, applications, and services) Cloud computing is integration of

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grid computing, and virtualization concept. These resources can be rapidly provisioned and released with minimal management efforts. In this model, a cloud service provider maintains cloud infrastructure in form Data Centers with huge computing capabilities in form of servers, nodes and storage area network.

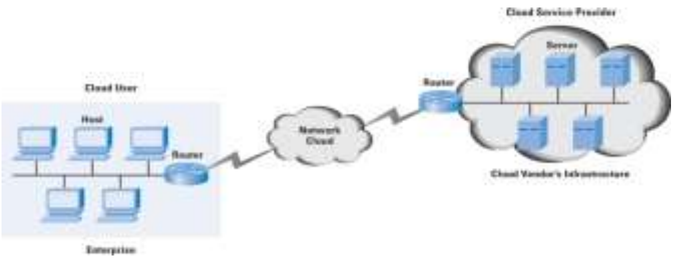

Fig -8: Cloud Computing Architecture

3.1 Cloud Service Models

The service providers may provide some services based on following service models [1,4]:

Infrastructure-as-a-Service (IaaS): The service provider may provide infrastructure in form of virtual machines (VMs) storage with specified configuration based on CPU, Memory, Secondary storage and network bandwidth requirement.

Platform as-a-Service (PaaS): PaaS includes services application development platforms like Software framework e.g. Java/Python/.Net and databases like SQL, Oracle etc.

Software-as-a-Service (SaaS): Using Software as a service, the cloud user may have direct access to the software like business applications, multimedia applications and web services without actually acquiring computing infrastructure and software professionals thus eliminating any upfront cost.

Which service model is to be used depends on nature of organization and specific requirements of the company. The above services are available on pay-per-use basis and resources are dynamically provisioned based on computing needs i.e. the number and configuration of resources can vary[5].

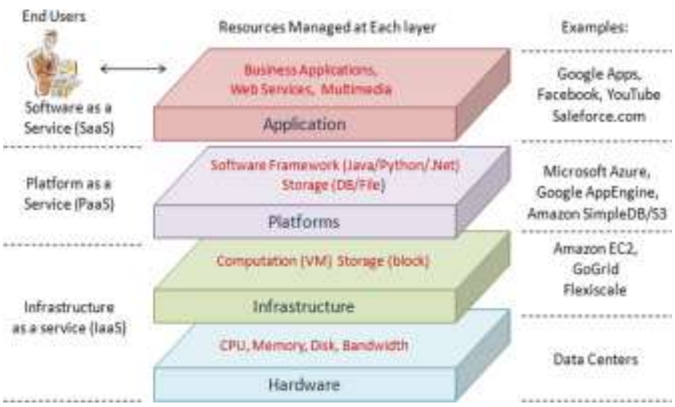

Fig -9: Cloud Service Models

Advantages of Cloud Computing include[11,12]:

- To meet the demands of Data velocity, variety, and volume (3Vs)
- The user has to pay only for the actual consumption (pay-per-use).
- Reduced cost of acquiring and maintaining computing power.
- Universal access to high power computing and storage.
- Resources of the cloud is always on with dynamic provisioning
- Less number of qualified IT professionals required.
- Greater collaboration and information sharing.
- Applications like Zomato, OLA, MakeMyTrip etc.

3.2 Cloud Research Issues

Various issues in cloud computing involve [2,14]

- Energy efficiency
- Software framework for data intensive applications (e.g. Map reduce framework using Hadoop)
- Performance Issues: Virtual Machine Migration, Server consolidation, scalability of storage, latency
- Elasticity, scalability and reliability
- Quality-of-Service (QoS) and Service Level Agreement (SLA) issues
- Cloud data security
- Interoperability and portability across multiple cloud environments
- Cloud Federation: Interconnecting cloud environment.

4. Internet-of-Things (IoT) & New Computing Paradigms

Cloud data centres are locates thousands of kilometer away from the source (Sensors, devices). The new computing models like fog computing, roof computing and Interne-of-Things (IoT) can help the bringing data processing and storage closer to the sources. This will lead in substantial reduction in latency problem and improve the performance. Based on the distance from source, we can classify various emerging computing techniques as follows:

- Cloud Computing: Hundreds of Computers upto thousands of KM away from source. The computing infrastructure inform of servers and nodes, Storage and network bandwidth are organized in form of data centres [8] which are centralized. With cloud computing, the users are able to receive services in various forms on pay-per-use basis without maintaining the expensive infrastructure in their premises and any upfront cost. However, as the data centres are located far away from users, the time to transmit messages between user and data centres increases network latency[9,10].
  - Fog Computing comprises of Tens of Thousands of Computers few KM away. Fog computing extends the services provided by the cloud from the core to the edge of the network. Fog computing Process data locally, resulting in reducing latency problem considerably[13].
- Roof Computing contains Millions to Billions few meters/one hop away for better IOT. Roof is an protected environment where they can operate, build trust, collaborate

Fog computing extends the services provided by the cloud from the core to the edge of the network. Fog computing Process data locally.

IoT: Billions to trillions roofs . It is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people with unique ids (UIDs) with ability to transfer data over a network without requiring interaction. Thing is an entity or physical object with unique identifier, embedded systems and ability to transfer data over network.

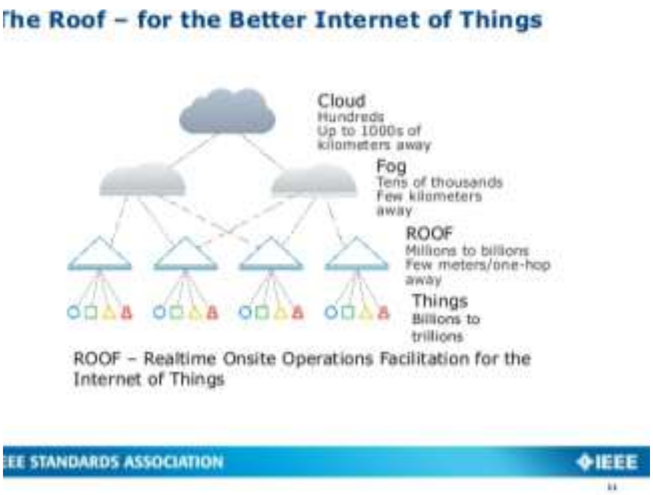

Fig. – 10: New Compuing paradigms and their interrelation ship among the models.

5. CONCLUSIONS

This paper discussed the evolution of the high performance computing techniques which are continuously growing. Cloud computing technology has not only made the availability of computing resources convenient, but also enabled the growth of new technology based online businesses like zomato, Ola, Makemytrip. Cloud computing has completely redefined the manner in which businesses are now operating. However, cloud computing also suffers from some drawbacks like latency and new technologies like IoT, fog computing and edge computing are attempting o address the issue of reducing the latency problem substantially while retaining the basic application of cloud computing.

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