Cloud BI: Future of Business Intelligence in the Cloud

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ABSTRACT

Cloud computing is gradually gaining popularity among businesses due to its distinct advantages over self-hosted IT infrastructures. Business Intelligence (BI) is a highly resource intensive system requiring large-scale parallel processing and significant storage capacities to host data warehouses. In self-hosted environments it was feared that BI will eventually face a resource crunch situation because it will not be feasible for companies to keep adding resources to host a never ending expansion of data warehouses and the online analytical processing (OLAP) demands on the underlying networking. Cloud computing has instigated a new hope for future prospects of BI. However, how will BI be implemented on Cloud and how will the traffic and demand profile look like? This research attempts to answer these key questions in regards to taking BI to the Cloud. The Cloud hosting of BI has been demonstrated with the help of a simulation on OPNET comprising a Cloud model with multiple OLAP application servers applying parallel query loads on an array of servers hosting relational databases. The simulation results reflected that true and extensible parallel processing of database servers on the Cloud can efficiently process OLAP application demands on Cloud computing. Hence, a BI designer needs to plan for a highly partitioned database running on massively parallel database servers in which each server hosts at least one partition of the underlying database serving the OLAP demands.

Keywords

Business intelligence, Online analytical processing, Cloud computing, software-as-a-service, database-as-a-service, massively parallel systems.

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1. Introduction

Cloud computing has become one of the revolutionary technologies over recent years. Cloud computing is conceptualized in three forms – software-as-a-service (SaaS), platform-as-a-service (PaaS) and infrastructure-as-a-service (IaaS). The SaaS providers interface with the end users by virtue of provisioning of business application services similar to the ones that have been traditionally self-hosted by the corporate houses [1]. Cloud computing paradigm has emerged to bring large-scale computing, storage resources and data service resources together to build a VCE (virtual computing environment) [2]. Cloud computing users can discard the hassles of large-scale investments in hardware and software platforms, in upgrading them regularly and in expensive licenses of application software used to run business processes, related transactions and decision-support systems [3].

The Cloud is generally a multi-tenant computing environment; the multi-tenant Cloud solutions can optimize resource sharing while providing isolation solution at different levels required to the tenant [4].

This model has ensured better affordability of the best possible application systems thus supporting an increase in efficiency of businesses [5]. Resources are allocated to end users against service requests made by their end terminals, and resources are allocated by a service provisioning engine that verifies the eligibility of users from a separate schema object that holds multi-tenancy data about all Cloud users and groups. Once the eligibility is verified, the resources are reserved for the user through session bindings until the computing processes are in

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progress by the user terminal. The terminal is normally a virtualized client presented through a virtual server farm. However, there can be direct loading of resources as well (example, for data backup). A separate layer monitors the session usage and utilization of resources such that the billing related information can be generated [6]. NIST (National Institute of Standards and Technology) is in the process of developing standard protocols for user connectivity to the Cloud through virtualization interface, terminal emulation interface, thin client interface and Internet browser interface. As of now, there is no standard protocol for users' connectivity to Cloud hosted resources [7].

As a data-centric approach to Business intelligence (BI), data acquisition is becoming easier to acquire and large data warehouses with 10s to 100s of terabytes of relational database management systems (RDBMS) are becoming increasingly common due to the popularity of interactive, web-based databases [33]. BI has been historically one of the most resource intensive applications. It comprises a number of data warehouses created by fetching decision-support data from organization wide databases. The data warehouses are updated at frequent intervals through appropriate queries executed on the business processing and transactional databases. Online analytical processing (OLAP) is the user-end interface of BI that is designed to present multi-dimensional graphical reports to the end users. OLAP employs a technique called multidimensional analysis is mainly used to enable flexible interactive analysis of multidimensional data [32]. Whereas a relational database stores all data in the form of rows and columns, OLAP also employs data cubes formed as a result of multidimensional queries run on an array of data warehouses. Furthermore, an OLAP application fetches data from the data warehouses, organises them in highly complex multidimensional data cubes, and presents to the users through user defined and configured GUI dashboards [8]. BI and OLAP framework has a high business utility, because it helps in locating and eliminating or solving business process deficiencies, inefficient process steps and waste process steps. A BI and OLAP framework is expected to provide timely, accurate, organized and integrated information to business decision makers [8, 9].

Despite of excellent business utility of BI and OLAP framework, many business owners were compelled to look for its alternative because of uncontrolled increase in computing and storage resource requirements in self hosted environments. At some stage, the cost of maintaining and upgrading the BI and OLAP framework becomes unjustified for a business [10]. However, the unique selling points of Cloud computing offer exactly what businesses need to successfully run BI and OLAP frameworks-unlimited resources, resource elasticity (resources on demand), moderate usage costs, high uptime and availability, high security, no hassles of upgrading and maintaining loads of servers and databases, and so on [1, 5]. Hence, it is hereby argued that Cloud computing has the potential to offer a new lease of life on BI and OLAP framework. Moreover, it is also argued that Cloud computing can extend the power of BI and OLAP to small- and medium-scale businesses, which could not have afforded the framework in self-hosted IT infrastructures. However, it is important to establish a framework for implementing BI and OLAP on a Cloud computing platform.

The rest of the paper is organized as follows. Section 2 is a literature review on how BI and OLAP framework can be implemented on the Clouds and presents key benefits of Cloud computing for BI. Section 3 shows an approach for taking BI to the Cloud as well as key challenges in hosting BI on Cloud. Section 4 describes and explains in detail how BI and OLAP framework can be modelled on a Cloud and how it should behave in order to extend maximum utility to the businesses by virtue of an OPNET based simulation experiment. Section 5 presents the summary of the research results and analysis. Finally, the conclusions of this work with future directions are discussed in Section 6.

2. Literature review

2.1. A review of Business Intelligence and OLAP and their porting on Cloud computing

Business intelligence (BI) is employed for monitoring the performance of business processes through accurate presentation and analysis of multidimensional data taken from distributed transaction processing systems across the enterprise [23]. The analysts using OLAP-enabled dashboards and reporting systems prefer to map financial data with performance data (of people and processes) to identify inefficiencies and reduce them through strategic restructuring of the business processes and workflows [23]. As per [24], a BI system is made of seven layers: IT and related infrastructure, data acquisition, data integration, data storage, data organising, data analytics and data presentation.

The OLAP cubes form the data storage (partially, in the form of views) and data organizing layers of a BI system. It sits over the data warehouse tables in the form of multidimensional views. A cube structure is made of a number of cross-referenced columns having data fetched from different processes and financial data tables over a period. The periods in a cube are shorter than the ones in the data warehouse that is tasked to store process related and financial data of longer periods (typically, five years or more). The OLAP queries are heavy duty search commands comprising data from multiple views at a time. The presentation layer makes the data sets visible in the form of multidimensional graphical screens [25, 26].

A number of OLAP query types are used to generate the views and present them in the dashboards/presentation screens. Some of the popular OLAP queries include: slice and dice, pivoting queries, merge/split queries, rolling-up queries, and drilling down queries [26]. The OLAP cube can be visualized as a stack of two-dimensional matrix planes, whereby each matrix plane represents a relationship between two different dimensions [26]. Figure 1 is a presentation of a multidimensional OLAP cube comprising two dimensional matrix planes.

It should be noted that these matrices are not independent of each other. All the attributes in these planes are nested with each other, and are linked with a primary key that controls all the relationships across multiple composite elements many-to-many relationships. For example, a product code can be viewed as a primary key that controls the relationships among all the attributes related to sales in a business [27].

Formation of OLAP cubes in an enterprise is not an easy task. A well planned architecture needs to be in place for content integration, modelling/mapping and presentation. The typical architecture should comprise of: components and connectivity for federated access to all the and DSS (decision support systems) across the enterprise, a data dictionary designed as per the OLAP cube formulations, a metadata mapping as per the data dictionary, a real data repository (warehousing), a virtual repository (data views serving as building blocks of the OLAP cubes) and the advanced data presentation services (dashboards and customised BI reporting interfaces) [28]. Accurate data modelling, metadata mapping and content integration helps in accurate formation of multidimensional cubes and finally resulting in accurate presentation of business issues [29]. The data presentation should be done in such a way that the human-computer interfacing is as friendly as possible (sorting, charting, colour coding and multidimensional interactive features) [30].

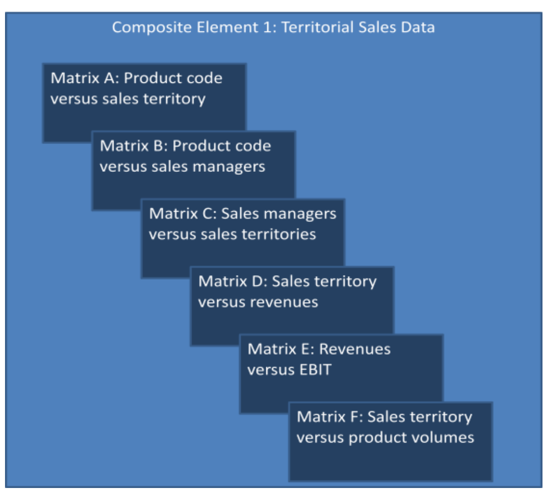

Fig. 1. A matrix view of a multidimensional OLAP cube

The Document Type Data (DTD) definition language for defining an XML schema is the primary enabler for taking BI to the Clouds. The multidimensional data views in the OLAP cubes can be formed by including DTD parsed XML data files. DTD parsed XML files in an OLAP cube results in the right structures to make use of web services oriented architecture of a Cloud. The dashboard/BI reporting interfaces and data analytics layers are built in applications that can be hosted as SaaS mode of Cloud hosting. The data warehouses and OLAP cubes can be formed employing multidimensional and hierarchical XML data files. The one-to-many DTD structures can be used to create the data warehouses and the many-to-many DTD structures can be used to create the OLAP cubes. The cubes and warehouses can be hosted on the PaaS mode of Cloud hosting. The underlying servers, databases, storage and networking infrastructure components can be hosted on the IaaS mode of Cloud hosting [22].

2.2. BI and OLAP

BI and OLAP framework comprises a highly complex multi-layer structure. Following are the key components of BI and OLAP framework [8]:

- A user interface layer comprising a large library of dashboards for graphical reporting.
- A layer for data analytics comprising what-if scenarios, reports, stored queries and data models.
- A layer for storing the OLAP cubes formed by multi-dimensional data extraction from the data layer (the data warehouses).
- A data integration layer for identification, cleaning, organizing and grouping of data extracted from the data warehouses before the cubes are formed.
- A data layer comprising of the data warehouses.
- A layer for acquiring data from the business processing, decision support and transactional databases used by various functions of the organization.
- The layer comprising the IT infrastructure components and related resources (data processing, storage and networking).

The key feature of a BI and OLAP framework is the OLAP cube, which is a multidimensional view formed in the structure of a matrix. The OLAP cube is a complex data view formed by running simultaneous queries on the tables of the underlying data warehouses that fetch at least three times more data compared with an ordinary database query. Each cube comprises a stack of multiple two dimensional reports (an ordinary planar graph showing a relationship between two variables). In typical OLAP applications, the queries fetch typically 10 to 12 times more data than an ordinary database query [11]. An OLAP application may comprise multiple OLAP cubes stored in the form of a complex hierarchy of matrices having data organized in the form of cross-tabulations. The cubes are normally stored in separate data marts or within predefined tables in the data warehouses [12]. The common OLAP functions employed for the formation of such cubes with a hierarchy of cross-tabulated data are drill-down, merge/split, roll-up, slice-and-dice and pivoting. Each matrix plane is identified by its own classification comprising different data mappings. The planes form a nest-like structure due to interrelationships. The resulting relationship looks like a tree with the roots comprising the primary variables and the branches comprising the secondary variables. For example, a product code is a primary variable and revenues generated in sales location is a secondary variable. The dashboard operator can modify or change the primary and secondary variables, which directs the query to fetch a different set of data to form different cross-tabulations in the next querying cycle on the underlying data warehouses. Hence, the OLAP cubes are flexible and can be changed dynamically as per the business needs [13].v Figure 2 shows the BI and OLAP framework.

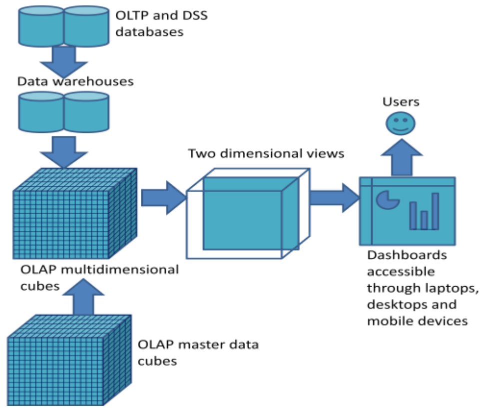

Fig. 2. The BI and OLAP framework

The figure shows two forms of cubes–the OLAP multidimensional data cubes and the OLAP master data cubes. The master data cubes control the relationship formation between the two-dimensional data planes within the multi-dimensional data cubes. Business users are offered a large range of variables that they can combine to form different views of two-dimensional reports needed in the dashboards. The data is pulled from OLTP (online transaction processing) and DSS databases into the data warehouse tables periodically, which in turn helps in periodic automatic updating of the data in the data cubes and finally in the dashboards. Hence, the business users can closely monitor business performance by virtue of updating dashboards continuously. Appropriate colour coding of reference points/thresholds helps in generating alerts and alarms. This could help the business strategic decision-makers to take appropriate steps [14, 5].

2.3. Benefits of Cloud BI

Nowadays, Cloud BI solutions are gradually gaining popularity among businesses, as many businesses are realizing the benefits of data analytics. Businesses need quality insights driven by accurate data more than ever. The SaaS providers are serving as the primary interfacing to the business user's community [22]. Cloud BI is the concept of delivering BI capabilities as a service. The following are key benefits of Cloud computing for business intelligence.

Cost efficiency

In the Cloud, companies do not need to budget for large, up-front purchases of software packages or carry out time-consuming updates on local servers to put the BI infrastructure up and running. They will treat it as a service, paying only for the computing resources they need and avoids costly asset acquisition and maintenance reducing the entry threshold barrier.

Flexibility and Scalability

Cloud BI solutions allow for greater flexibility to be altered quickly to give technical users access to new data sources, experimenting with analytical models. With the Cloud BI solutions, business users will be able to keep a better fiscal control over IT projects and have the flexibility to scale up or down usage as needs change. Moreover, in the Cloud, resources can automatically and rapidly scale in and scale out, and it can support large numbers of simultaneous users. This means that customers can easily increase their software usage without delay or the cost of having to deploy and install additional hardware and software.

Reliability

Reliability improves through the use of multiple redundant sites, which can provide reliability and secure locations for data storage and the resources can be spread across a large number of users, which makes Cloud computing suitable for disaster recovery and business continuity.

Enhanced data sharing capabilities

Cloud applications allow data access to be shared remotely and enable easy cross-location data sharing capabilities as they are deployed via the internet and outside a company's firewall.

No capital expenditure

Low TCO (total cost of ownership) is a key benefit of the Cloud model. With the Cloud, companies pay for a service they actually use. With this policy, Cloud computing allows companies better control the CAPEX (Capital Expenditure) and the OPEX (Operations Expenditure) associated with non-core activities. Hence, the benefits of BI can be rolled out faster to more users within the organization.

3. Taking BI to the Cloud

BI in the Cloud is a game changing phase of IT, as it makes BI finally affordable and accessible as compared to traditional BI. On the Cloud, the matrices in the OLAP cubes can be formed using the web data warehousing concept making use of XML data files using DTD (document type definition) described XML programming language. The data structures in the cubes are formed using the DTD parsed XML files [14]. The DTD format helps an XML file to exhibit relational properties of a conventional database. This is what enables the OLAP cubes stored on the Cloud making use of XML data files following DTD structures (called web cubes). This also helps the BI system make use of web services components thus ensuring better performance on the Cloud [17, 18]. The entire OLAP framework comprising the dashboards and the data analytics layer can be hosted as SaaS. The BI and OLAP framework software platforms available for Cloud hosting are SAP, IBM Cognos and Web-Sphere Dashboards dashboard, Oracle business objects and Salesforce.com. The integration of data warehouses (XML based) and OLTP/DSS databases can be hosted on PaaS. The underlying servers and databases can be hosted on IaaS mode of Cloud hosting. For optimum performance on the Cloud, the servers and database arrays should be implemented as a massively parallel system capable of processing large scale parallel queries [19].

A database optimized to work in a massively parallel processing environment. The databases on the Cloud need to be implemented in the form of a massively parallel system to support high demand elasticity of BI and OLAP framework. A centralized schema object may be designed to hold the details and privileges of all tenants on the Cloud. Each schema object holding the data files may be massively partitioned such that each partition can be held by a separate server on a large scale server array. The IaaS provider should be capable of rapid expansion of the server array making use of virtualized array expansion. In this way, it may be possible to serve one partition through more than one server that can enhance the performance of BI. The IaaS provider should keep a close watch on both load distribution and response time patterns and make effective network changes to ensure that the network load is also distributed evenly [21]. The OLAP application hosted on the Cloud may not be web services compatible. To make an OLAP application compatible to web services architecture, the SaaS provider may allow the creation of an intermediate layer to host a dependency graph that helps in dropping the attributes not needed in the finalized XML data cube [20, 21].

Hence, the following are key challenges in hosting BI on Cloud:

- Compliance of the BI application with web services architectural standards (and the standards defined by the SaaS or PaaS provider, like Google Apps standards)

- Deployment of massively parallel data-warehousing system with evenly distributed query load and even patterns of response times from all database servers. The IaaS provider should effectively use the virtualized server array management and expansion to meet the resources on demand.
- The network architecture should be designed in such a way that the query load can be evenly distributed among the servers in an array. This will ensure even query processing response times by the servers in an array. If the server array employs storage area networking for storing the XML data files and the OLAP cubes, the data fetching from various storage devices should again be evenly distributed by virtue of appropriate network connections.

In the next section, an OPNET model of a small scale BI and OLAP framework on the Cloud has been created. The network has been designed in such a way that the load can be evenly distributed to all the relational database management systems (RDBMS) servers. In addition, the application demands have been created in such a way that all RDBMS servers are evenly involved in receiving and processing the OLAP query load. The BI on the Cloud model is described in the next section and the simulation results are described in the subsequent section.

4. BI on the Cloud model

This section provides a brief description of the main interface of the OPNET model. The model comprises two large domains–the BI on the Cloud domain and the Extranet domain comprising six corporates having 500 OLAP users in each as shown in Figure 3. The Clouds shown in this interface are created using the IP network Cloud objects in OPNET. An IP network Cloud object can be expanded to enter another palette for carrying out detailed model comprising nodes and links.

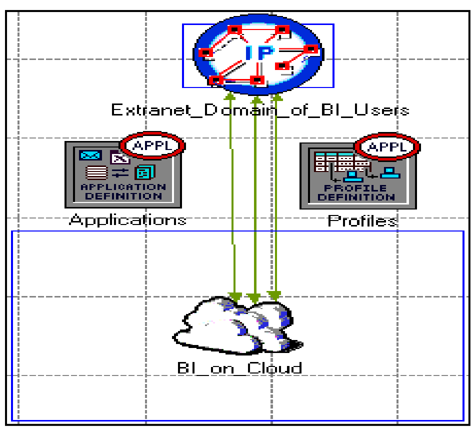

Fig. 3. The architecture of the model

The application Clouds are IP network Cloud objects comprising application server arrays and database server arrays, connected to a Cloud network. The profiles are required in an OPNET model to configure the behaviour of applications configured on the network and to apply on server systems, selectively, such that the role, traffic load, traffic patterns, initialization and termination, and inter-session delays can be clearly defined. The profiles also help in defining a traffic pattern initiated by a server or a client-end device, like – constant, linear, logarithmic, serial-random, serial-ordered, parallel (with overlapping times), concurrent, or exponential. If quality of service is implemented, the profiles also help in defining traffic prioritization.

BI expert will consider when making the move to Cloud-based BI will involve a massive implementation of relational databases on the Cloud hosted servers. Hence, the server arrays (both application and database) are implemented in the form of a massively parallel processing system with no physical object tied to any specific hardware [31]. The applications and databases on Cloud computing platforms should be web 2.0 compliant. Hence, all applications and databases should support XML and WML formats. These formats are supported by all modern database systems. Hence, the data stored in traditional schema objects can be exported into DTD formats to form XML data files. Parsing is a way of filtering data and forming a DTD structure identical to the structure prevalent in the schema objects. Parsing also helps in migrating the relational properties in the schema objects to the XML files. Given that OLAP cubes are multi-dimensional “extracts” from the schema tables of a data warehouse, they can be readily formed using the XML files after an organised DTD parsing. These XML files can be further queried to feed data into various dashboards, which essentially are self-updating two dimensional graphs/charts/meters.

The BI on the Cloud domain is expanded in Figure 4. The BI framework on the Cloud has been modelled using four numbers of Cisco 7609 series layer 3 high end routing switches connecting in such a way that the load can be evenly distributed. The Cloud switch 4 is dedicated to route all inbound traffic to the servers and send their responses back to the clients. The Cloud switches 1 and 3 are serving four RDBMS servers each and the Cloud switch 2 is serving all the OLAP application servers. An array of five numbers of OLAP application servers and an array of eight numbers of RDBMS servers. The blue dotted lines indicate the traffic flow distribution configured between the OLAP application servers and the RDBMS servers. The demands on RDBMS servers are equally distributed to invoke a massive parallel processing like environment.

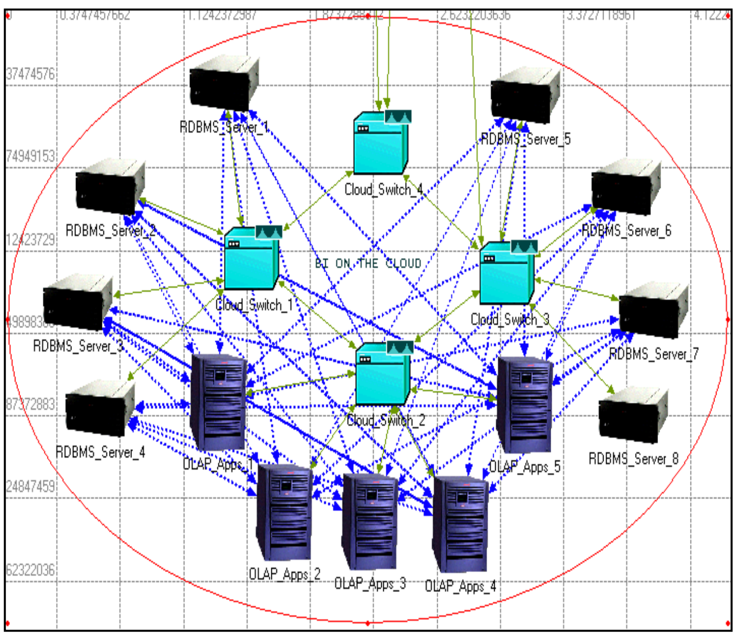

Fig. 4. The BI on the Cloud architecture

The blue dotted lines from each OLAP server are drawn to all the RDBMS servers indicating that each OLAP server will use the services of all the RDBMS servers available in the array to process a database query. The client load is routed to the OLAP application servers using destination preference settings on the client objects configured in the extranet domain, as shown in Figure 5.

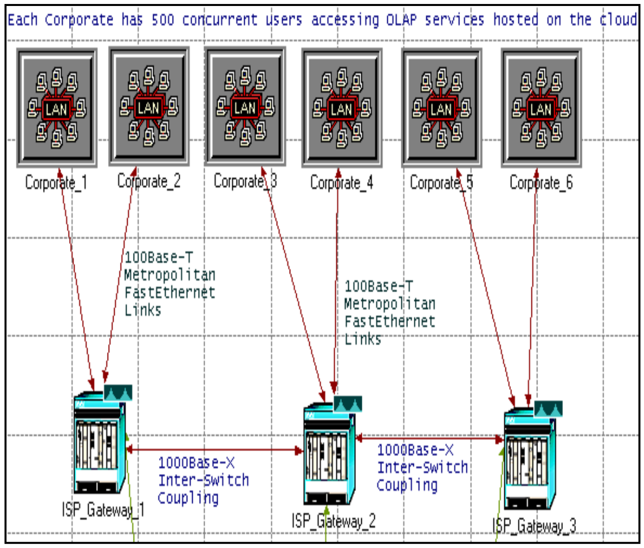

Fig. 5. The Extranet domain comprising six corporates having 500 OLAP users in each corporate

The extranet comprises of three ISP gateway switches serving six corporate LAN segments having 500 users each. A total of 3000 concurrent OLAP users have been modelled in the network. In real Clouds this number could be much higher (hundreds of thousands). The key idea is to analyse how the database servers are processing the parallel load applied by the OLAP application. Each LAN object has the four OLAP servers configured as destination preferences for the OLAP application profile. In this way, the OLAP requests from the clients are routed to the four OLAP servers and the RDBMS requests are routed from the four OLAP servers to the eight RDBMS servers (serving as a small scale server array in this model).

OLAP queries are 10 to 12 times heavier than normal database queries. This is because each query pulls multi-dimensional data from multiple schemas. Hence, the query load in OLAP transactions is very high. Given that OLAP service on a Cloud may be used by hundreds of thousands of users, the backend databases need to be massively partitioned with parallel processing of partitions to handle the OLAP query load. This fact has been demonstrated in the simulation results. A centralised schema object should be maintained with all details of the tenants, like – identification, users per tenant, user Ids, passwords, pre-shared secrets, access privileges, service level allocations and tenant schema details [31].

The OLAP queries have been configured with the following attributes:

- Transaction mix comprises 100% queries because all data warehouse tables are read-only.
- Transaction inter-arrival time is 1 second indicating a heavy query load.
- Each transaction transfers 10,240 bytes, which is 10 times more than the default size in OPNET. This is because an OLAP query is at least 10 times heavier than normal database query.

Table 1

The Database Query Settings to Emulate OLAP Query Load on the Databases

Attribute	Value
Transaction Mix (Queries/Total Transactions)	100%
Transaction Interarrival Time	constant (1)
Transaction Size (bytes)	constant (10240)
Symbolic Server Name	RDBMS Server
Type of Service	Excellent Effort (3)
RSVP Parameters	None
Back-End Custom Application	Not Used

The RDBMS queries are configured using the attributes shown in Table 1. The default configurations of heavy database load of OPNET has been chosen and then increased by 10 times in the table2. This is based on the literature review that OLAP query load on databases is at least 10 times heavier than the normal query load. Moreover, the inter-arrival time of query has been set at one second, and the type of service has been set at "excellent service". Finally, the transaction mix of queries versus total transactions has been set at 100%. This is because the BI and OLAP framework does not have any data entry load because the framework is used for strategic decision support.

The OLAP application has been configured as a heavy browsing HTTP application having varying 5,120 bytes to 10,240 bytes of object downloads per second (continuously updating dashboards), 7 to 10 objects per interface (dashboards, its description screens, legends, text boxes, and so on), one second object refresh time (because the transaction inter-arrival time on the databases is one second) and 10-second page refresh time (ensuring that the OLAP screen refreshes after every 10 cube refreshes such that the user gets noticeable data changes at every screen refresh).

Table 2
The OLAP Application Profiling

Attribute	Value
name	Profiles
model	Profile Config
Profile Configuration	(...)
rows	1
row 0	
Profile Name	OLAP_Requests
Applications	(...)
rows	2
row 0	
Name	OLAP
Start Time Offset (seconds)	uniform (5,10)
Duration (seconds)	End of Profile
Repeatability	(...)
Inter-repetition Time (sec...	exponential (300)
Number of Repetitions	Unlimited
Repetition Pattern	Concurrent
row 1	
Name	RDBMS_Services
Start Time Offset (seconds)	uniform (5,10)
Duration (seconds)	End of Profile
Repeatability	(...)
Inter-repetition Time (sec...	exponential (300)
Number of Repetitions	Unlimited
Repetition Pattern	Concurrent
Operation Mode	Simultaneous
Start Time (seconds)	uniform (50, 55)
Duration (seconds)	End of Simulation

Table 2 shows the application profiling of OLAP application (OLAP requests) and the RDBMS services. Both the profiles trigger concurrently with an offset of 5 to 10 seconds after the start time. The start time has been configured at 50 to 55 seconds to ensure that all routing updates are successfully completed on the network before the application services are triggered.

5. Research Results and Analysis

In this research, the results shown here are the ones captured from a simulation of 50 million events which is the maximum possible in the OPNET academic edition. The query load is not exactly the same on the RDBMS servers but the pattern indicates almost even distribution of query load. This is evident from the "database query requests per second" statistics collected from the eight RDBMS servers stacked one above another as shown in Figure 6.

The query requests experienced by each server are plotted in the form of "number of queries per second" on the Y-axis with respect to simulation time on the X-axis. In Figure 6, this statistic is reported for RDBMS server 1 through server 8 on the Cloud. This has been made possible in OPNET due to application demand configurations from each OLAP server to all the RDBMS servers.

This however will not be as straight forward in a real BI Cloud as appears here. Such a parallel distribution of query load will be achieved by implementing appropriate routing engines. In addition, the query load of each OLAP server will be different and hence, the routing engine should be an intelligent device that can sense the load from all OLAP servers and equally distribute them among the RDBMS servers. If an array of RDBMS servers is optimally loaded, the routing engine should ensure spilling over of load to additional arrays connected to the Cloud. It may be possible that the additional arrays are hosted by other IaaS providers.

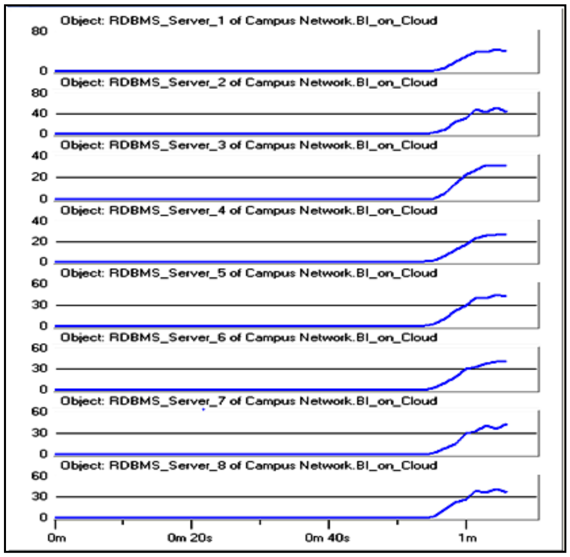

Fig. 6. Query load on the RDBMS servers

The query load is slightly above or below 40 requests per second on all the RDBMS servers. This reveals that the load distribution through appropriate network configuration and application demand profiling (traffic flow configurations indicated by blue dotted lines in Figure 4). These configurations have caused near even distribution of query load from the four OLAP servers on the RDBMS servers. Moreover, the query task processing times on the database servers are also nearly even as shown in Figure 7. This has been possible because the same hardware make, model and configurations have been chosen for all the eight RDBMS servers. The query response time by each server is plotted in the form of "number of queries processed per second" on the Y-axis with respect to simulation time on the X-axis. In the Figure 7, this statistic is reported for RDBMS server 1 through server 8 on the Cloud.

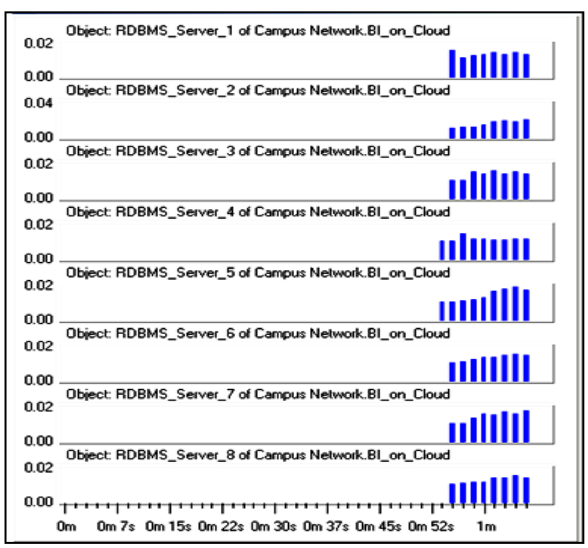

Fig. 7. Query task processing time by the RDBMS servers.

These results are a good demonstration of how a massively parallel RDBMS system can be deployed to form a BI and OLAP framework, and how the framework should perform in the Cloud environment. This is in line with the requirements stated by researchers as reviewed in the literature study. However, there are a few key points that should be kept in mind about this model as listed below:

First, the model has only eight servers in the RDBMS array serving only four numbers of OLAP application servers.

Second, the load distribution has been managed evenly through application demand flow modelling which is an excellent feature of OPNET and works very well.

Third, the servers chosen in this model are of the same make and model having identical hardware configuration.

Fourth, the load has been modelled as constant after an exponential increase at the start. The simulation of the load carried out in this model has lasted only for 50 million events with no load variations.

Finally, this model comprises only 3000 OLAP users connecting concurrently. A real BI environment on Cloud computing will have tens of thousands of end users applying concurrent BI load on the servers.

These are ideal scenarios that will not be possible on the real Clouds. However, these settings in OPNET have evolved into challenges that will be faced in moving BI to the Cloud as per the requirements stated by the researchers. A Cloud will have hundreds of servers in the arrays; hence, even distribution of network load will be a very challenging task.

The architects will have to watch for bottlenecks on the inter-switch connections, even if they are deployed using the fastest possible ATM connections or the 10G gigabit Ethernet. The load distribution will have to be managed by advanced provisioning engines and routers, which will not be as easy as configuring application demand flow patterns in OPNET as indicated by blue dotted lines in Figure 4. These provisioning engines and routers need to be optimized to ensure that the user load is evenly distributed among the servers in the array and spilled over to additional arrays if there is an overloading scenario. The partitioning of databases in the data warehouses should be achieved in such a way that the arrays can be quickly expanded and new servers can start contributing resources in serving the partitions without carrying out any structural changes of the databases. At some stage, it should be made possible to deploy both the data warehouses and OLAP cubes employing XML data files, thus completely eliminating the need for traditional RDBMS software systems in the BI and OLAP framework.

On the hardware side, it may not be possible for the IaaS provider to implement a Cloud with identical hardware make, model and configurations. Hence, the query processing response time of each server will be different on the Cloud due to differences in hardware configurations. Hence, a mere even distribution of load to the servers by the service provisioning engine and the router will not serve the purpose. There should be some intelligence to route the load based on the knowledge of query processing response times of the servers. The servers with slower response times should get lesser load compared with the servers with faster response times to eliminate wait states at the receiving end. The capabilities of RDBMS partitioning, RDBMS load balancing, web provisioning application services, services routing engines and query performance optimizing should be exploited effectively by the BI architects. This is to ensure that the massively parallel processing system of database server arrays works perfectly to effectively utilize the processing power of the servers and synchronize the query processing times to reduce or eliminate wait states at the application servers' end.

The above discussion presents one more challenge in taking BI to the Clouds. The SaaS, PaaS and IaaS providers may be different companies. Hence, to ensure the above requirements of BI hosting on Clouds, these providers need to carry out excellent coordination of architectural detailing for designing and deploying the services to enable the various layers of BI and OLAP framework. BI cannot be implemented in an ad-hoc way by the providers otherwise it will suffer from the same level of bottlenecks and resource crunch as it has been suffering in self-hosted environments. The providers need to carry out effective planning of every detail and implement the infrastructure components, platform components and application components to achieve a true massively parallel processing system with a highly elastic capacity enhancement framework using all available technologies efficiently.

6. Conclusions and Future Directions

Cloud is an important part of future BI and offers several advantages in terms of cost efficiency, flexibility and scalability of implementation, reliability, and enhanced data sharing capabilities. Cloud has the potential to offer a new lease of life to BI and OLAP framework. Cloud computing comprises three ways of provisioning services – software-as-a-service (SaaS), platform-as-a-service (PaaS) and infrastructure-as-a-service (IaaS). These services may be provided by the same or different providers depending upon the business arrangements. However, the SaaS provider needs the settings on the PaaS and IaaS Clouds to be defined as per the application services provisioned through the web services architecture components. Clouds comprise the service provisioning and routing engines that can effectively sense the loading pattern on the underlying resources.

BI and OLAP framework is highly resource intensive. It has a multilayer architecture comprising multidimensional OLAP cubes with multiplexed matrices representing relationships between various business variables. The cubes are formed by sending OLAP queries to the data warehouses stored in the RDBMS servers. The size of an OLAP query is typically 10 to 12 times larger than an ordinary database query. Hence, if BI and OLAP framework is taken to the Cloud for serving hundreds and thousands of end users, it is essential that the Cloud providers implement massively parallel processing RDBMS systems with even distribution of query load and query response times for the OLAP application servers. In this research, a BI and OLAP framework has been modelled using OPNET and the requirements of a massively parallel RDBMS server array has been modelled using the OPNET features. The results have reflected the ideal scenario for taking BI to the Cloud. However, the real Clouds will not have ideal configurations as made in this OPNET model. Hence, the real challenges on the Cloud need to be identified and addressed to ensure that the results can be brought closer to ideal scenarios as far as possible.

The details of challenges in implementing a massively parallel processing RDBMS server system to take BI to the Cloud have been discussed. Many settings that are possible in OPNET simulation environment may require significant architectural innovations to achieve what has been described in this paper to successfully take BI to the Clouds.

In the future, researchers may like to study modern technologies pertaining to service provisioning, service routing, schema partitioning, load balancing, and so on to implement an enterprise level RDBMS system to achieve a massively parallel processing RDBMS server system for taking BI to the Clouds. In this context, there is a significant opportunity to carry out multiple experimental studies to evolve the practical configuration solutions useful for the Cloud service providers targeting to host BI and OLAP framework on the Cloud.

Cloud computing also offers significant computing power and capacity. Hence, BI is expected to enter many complex domains (business and non-business related) which were impossible for it in a self-hosted environment. Applications like context-aware, location-aware automation, massive scale semantics, advanced science and technology databases, real time disaster and crisis management, city management, global finance and economy reporting, and global monitoring of industries and sectors are few such areas where BI or BI like systems possess tremendous potential on Cloud computing. The size, scale, dynamism, and scope of data marts and data warehouses on Clouds may exceed even the Petabytes scale (the emerging challenge of Big Data). Such data systems cannot be managed using traditional systems and tools. The security challenges at such massive scales will be different and much more complex. Hence, this research has significant openings for future contributions. This concept is a kind of a beginning of setting a stage for studies on such future challenges.

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