

A native enhanced elastic extension tables multi-tenant database

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ABSTRACT

Multi-tenancy is a cloud computing service that enables multiple customers to share the same software. The internet of things (IoT) is based on distributing devices and objects through the internet that needs an effective multi-tenant schema. Merging the multi-tenant structure with IoT systems becomes more challenging due to the different data types of IoT and workloads. There is a need to handle a massive amount of metadata by multi-tenant applications. This paper has two main aims to solve this problem. First, it proposes an enhanced elastic extension tables (E³T) schema to query the IoT database efficiently. Second, it proposes a Hybrid multi-tenant database (NXD-E³T) as a combination of the E³T and Native XML Database to reduce the response time and support a common query language. The proposed schema was implemented on an IoT benchmark. The simulation results show that the proposed NXD-E³T outperforms the other multi-tenant databases in terms of the query speed.

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1. INTRODUCTION

Due to increasing the user's requests to millions of online users, organizations often spend large amounts of their time, resources and cost in their database stored, to ensure that the correct information is available when it is required. Cloud computing relies on sharing of various resources such as networks, servers, storage, applications, and services to acquire coherence and economies of scale [1]. These services can accomplish in many forms such as outsourcing, on-demand resource provision, the economics of scale, and pay-as-you-go. This cloud software approached is called software as a service (SaaS). SaaS is capable of presenting a single configurable software and computing environment for multiple tenants [2, 3]. SaaS applications are deployed as hosted services and accessed from everywhere over the web. The idea of outsourcing software through several experiences as in [4].

Many companies desire to outsource their data to a third party which hosts a multi-tenant database system to provide the data management service with much fewer resources, through the same server instance. The main benefit of multi-tenancy is to minimize the operating costs of running software from the provider's perspective [5]. Many problems appeared while achieving this target such as lacking the tenant privileges and the long time required to perform a single query.

Therefore, this paper proposed a native enhanced elastic extension tables database (NXD-E³T) as a combination of the proposed E³T schema and the Native XML data model to increase the performance by computing the response times of the preformed query. Applying this Schema to the IoT System is considered an additional contribution in this paper. The remainder of this paper is structured as follows. Section 2 reviews the background for multi-tenancy main approaches and the related work of multi-tenancy database techniques, section 3 describes the proposed Schema for NXD-E³T Multi-Tenant Database, section 4

proposes the results for the performance of our proposed method. Finally, section 5 concludes this paper and describes future work.

2. BACKGROUND AND RELATED WORKS

2.1. Background and basics concept

Since IoT has become more significant, additional designs must be presented each day to adapt the specificities introduced by these systems of the physical world and the public networks [6-8]. Some of these solutions based on SaaS and Multi-tenancy [9]. Paying the multi-tenancy models based on the way how data is isolated for individual tenants, there are three main approaches of multi-tenancy databases as shown in Figure and in [10]. Multi-tenancy is based on Shared DB–Shared Schema [11]. Multi-tenancy is capable of serving a large number of tenants with a minimum general cost [12].

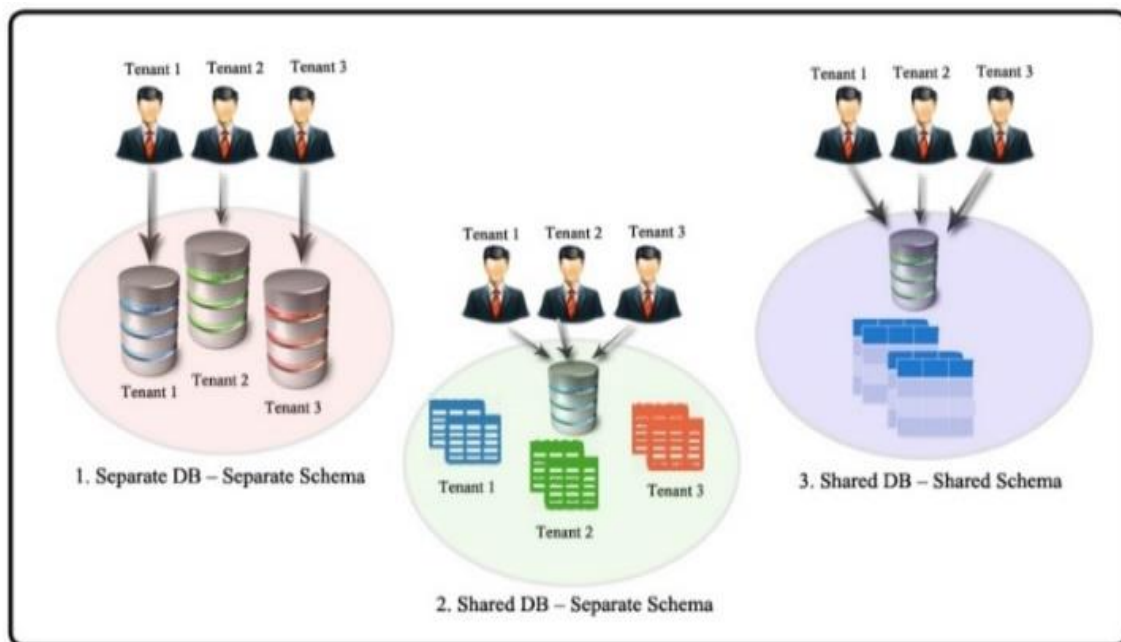


Figure 1. Approaches to managing multi-tenancy

2.2. Related works

There are many techniques submitted for demonstrating data in multi-tenant databases. These techniques accomplish some features, at the expense of other features. These techniques are still not enough, and not exceeding multi-tenant database challenges. Some of these techniques are examined in the following paragraphs.

Private Tables [13] technique permits each tenant to possess his private tables which can be different and expanded. The query is processed by database without using extra columns like “tenant_id” to distinguish and isolate tenant’s data, as submitted in this paper for the rest of the multi-tenant database schema mapping techniques [14].

The extension tables are simulated due to the development of the decomposed storage model that had been required described in [15]. This technique consists of creating segments of a table of n- columns into n 2-column tables. This technique of using Extension Tables is considered outstanding to the Private Tables approach described above. Multiple tenants can use the base tables also the extension tables.

The Universal Table as presented in [16] a sparse dataset consists of a huge number of columns. The Universal Table is a table that contains extra columns of the basics application schema columns, which permits tenants to store their needed columns side by side. Storing such a dataset can potentially lower its performance due to the high number of NULL values it may contain.

In Pivot Tables, each column of each row in a logical source table is converted to its record in the Pivot Table [3, 16]. The rows in the Pivot Table represented by four columns: ‘tenant_id’, ‘table_id’, ‘col’, and ‘row’ which are used to identify each row in the logical source table. The selected data types are

elastic data types such as VARCHAR to increase the possibility of other different data types that can be cast to. For example, the “pivot_str” table can be used to store non-numerical data types. And “pivot_int” table which is used to store the numerical data type values.

The Chunk Table is another structure technique that is closest to the Pivot Table technique [4]. Except, it contains a group of data columns with a mixture of data types that are placed the column ‘col’ in the Pivot Table with the ‘chunk’ column in the Chunk Table. This technique splits the logical source table into groups of columns. Each group appointed to a unique Chunk-ID and converted into a suitable Chunk Table [17].

The Chunk Folding technique is derived from the Chunk Table technique and the Extension Tables as presented in [1, 13]. This schema vertically segmented virtual tables into chunks. Each segment has a ‘chunk_id’ where a chunk of columns is partitioned into segments of columns. The remaining parts are mapped into the extensions. But it can be implemented in open-source relational database products such as PostgreSQL.

The XML Table database extension technique is constructed by extensible markup language (XML) [18, 19]. This is accomplished by providing an XML data type or by adding the XML document into the database as a Large Object. Nevertheless, this technique reduces the overall performance using XML files due to it consumes large space of the RAM.

The Elastic Extension Tables database technique which is the most recent technique of designing and structuring a multitenant database [13, 14]. EET is a database technique that uses the Shared DB–Shared Schema model. EET is consists of three main classes: common tenant tables (CTT), virtual extension tables (VET), and elastic extension tables (EET). The first class is the CTT that can be performed on any business domain database. The second class is the VET that grants tenants the ability to extend the existing business database. The third class is elastic extension tables (EET), which consists of eight tables that are used to construct VETs tables as presented in Table 1. EET exhibits a flexible method for constructing the tenants’ database schema. With all the EET features and advantages, it has some drawbacks such as the access time to large numbers of records there will be a noticeable delay due to the usage only of the relational data system. The EET is lacking the tenant privileges to cooperating with all database programming features required nowadays such as triggers, routines, and procedures.

Table 1. Elastic extension tables

No.	Table Name	Table Features
1	“db_table”	Enable tenants to create virtual tables, give them unique names and determine the number of columns of each tenant table.
2	“table_column”	Allow tenants to create virtual columns of the previously created “db_table” tables.
3	“table_row”	The Row Elastic Extension Tables store records of the Virtual Extension Columns which tenant created in three separate distinguish tables. These tables are separated based on the data type of values.
4	“table_row_blob”	- “table_row” table is utilized for storing values like INT, FLOAT, DATE, TIMESTAMP, TIME, CHAR, VARCHAR and BOOLEAN.
5	“table_row_clob”	- “table_row_blob” table is utilized for storing large data values such as the BLOB values for virtual columns with the BLOB data type. - “table_row_clob” table is utilized for storing all CLOB values for virtual columns.
6	“table_relationship”	Utilizes tenants to create virtual relationships for their virtual tables.
7	“table_index”	Applied to add and create virtual indexes to virtual columns to improve the speed and the performance.
8	“table_primary_key_column”	Enable tenants to create virtual primary keys for the virtual extension columns which are stored in the “table_column” table.

All the previous techniques did not consider the heterogeneity of data. One of the major challenges is how to handle an increasing amount of heterogeneous IoT data with a variety of data types and data sources. Despite the popularity of relational databases, the scalability of the NoSQL database model and the document-centric data structure of NXD databases appear to be promising features for an efficient IoT system [20]. The results in [21] show that the NoSQL database is the best choice for query speed, whereas NXD is advantageous in terms of flexibility and extensibility, which are essential to cooperate with the characteristics of IoT data. The characteristics and limitations of the previously described techniques are explained in Table 2. In this paper, a new multi-tenant database schema NXD-E³T is proposed that combines a new proposed E³T schema and the Native XML Database to implement the database query more efficiently and reduce the query response time [22].

Table 2. Multi-tenancy techniques characteristics

No.	Multi-tenancy Database Design	Extra Columns	Large No. of Tenants	Divide Tables	NULL values	Overhead	Complexity Query	Schema Known in Advance	Large Space of the RAM	Noticeable delay	Programming Features	IoT Benchmark
1	Private Tables	X	X	X	X	X	X	X	X	✓	X	X
2	The extension tables	✓	X	✓	X	X	X	X	X	✓	X	X
3	The Universal Table	✓	✓	X	✓	X	X	X	✓	X	X	X
4	Pivot Tables	✓	✓	✓	X	✓	✓	X	X	✓	X	X
5	The Chunk Table	✓	X	✓	X	✓	✓	X	X	✓	X	X
6	Chunk Folding	✓	X	✓	X	✓	✓	✓	X	✓	X	X
7	The XML Table	✓	✓	X	X	X	X	X	✓	✓	X	X
8	The EET Technique	✓	✓	✓	X	X	X	X	X	✓	X	X

3. THE PROPOSED NATIVE ENHANCED ELASTIC EXTENSION TABLES DATABASE (NXD-E³T)

This paper proposes a multi-tenant database NXD-E³T schema to reduce the query response time included programming features with a simple and fixed number of basic tables. The contribution of this paper consists of two main partitions: First, allowing tenants to establish their full databases using the proposed enhanced elastic extension tables (E³T) and even providing all programming features required. These features started from insert, update, and delete data to add triggers, routines, and procedures. Performing the E³T schema provides availability as this design serves multiple tenants with their sub-users. Then, applying this new structure of database on IoT benchmark [23]. Second, it proposes the NXD-E³T schema that structures data for sharing and support in relational databases, demonstrates the idea of executing as multi-tenant storage. These objectives are the motivation to propose an improved database design E³T schema to support multiple levels of data isolation and performance for all tenants in the multi-tenant database.

3.1. The proposed enhanced elastic extension tables (E³T) schema

The E³T database schema proposes an enhanced design of multi-tenant database schema to eliminate the miss selecting of a large scale of heterogeneous IoT data from the database and permits any tenant to handle the database queries (insert, update, delete) correctly [24]. The E³T schema handles the data as follows:

3.1.1. Storing the data based on tenant action

The proposed design adds three tables to the Elastic Extension Tables to ensure that the tenant has full programming control to their database. It provides three tables to solve three different cases for IoT systems [14].

- “table_trigger” table, this table allows tenants to add triggers, it is associated with a specific table that activates when a specific event occurs for that table. This is needed if a tenant requires to trigger an action that activates when a specific event occurs [25].
- “table_procedure” table, this table is used when it is required to perform in a single call to a procedure a repetitive task that requires checking, looping, multiple statements on the server with a return value that can be stored to start many another actions. This is needed if a tenant intends to perform a procedure as a result of specific data.
- “table_routine” table, this table permits tenants to create routines for preventing the need to keep reissuing the individual statements but can refer to the stored routine instead while accessing the VET or CTT [26]. This is needed when a tenant attends to create a routine which essentially used to gather parameters and compare values following by single return value.

3.1.2. Storing the data based on data size and format

Data in IoT systems can be in several different formats, ranging from text and numbers to audio, pictures, and videos. The proposed E³T database allows the user to store different data types in three different separated tables [27].

- “table_row” table, for storing small data types values such as (CHAR, VARCHAR, INT, FLOAT, DATE, TIME).

- b. "table_row_blob" table, for storing multimedia files. It stores the data in the form of a binary large object (BLOB) data type.
- c. "table_row_clob" table, for storing image files. It stores the data in the form of a character large object (CLOB) data type.

3.1.3. Storing the data based on the query type

In the E³T schema, the database tables are partitioned into two main parts: CTT, and E³T tables.

- a. The CTT tables that store metadata (i.e. data about database structure) are the physical tables that existed and shared between all tenants. These tables are created by each tenant administrators and the number of these tables is unlimited. The query that is based on data definition language (DDL) deals with the CTT tables.
- b. The E³T tables that store the tenant's data. These tables are responsible for the creation of the VET tables to establish the virtual data structure that each tenant has, which can be created to be convenient for each tenant requirements as shown in Figure 2. These tables are added to the previously EET tables to ensure that this schema is compatible with any tenant needs. The query that is based on data manipulation language (DML) deals with the E³T tables.

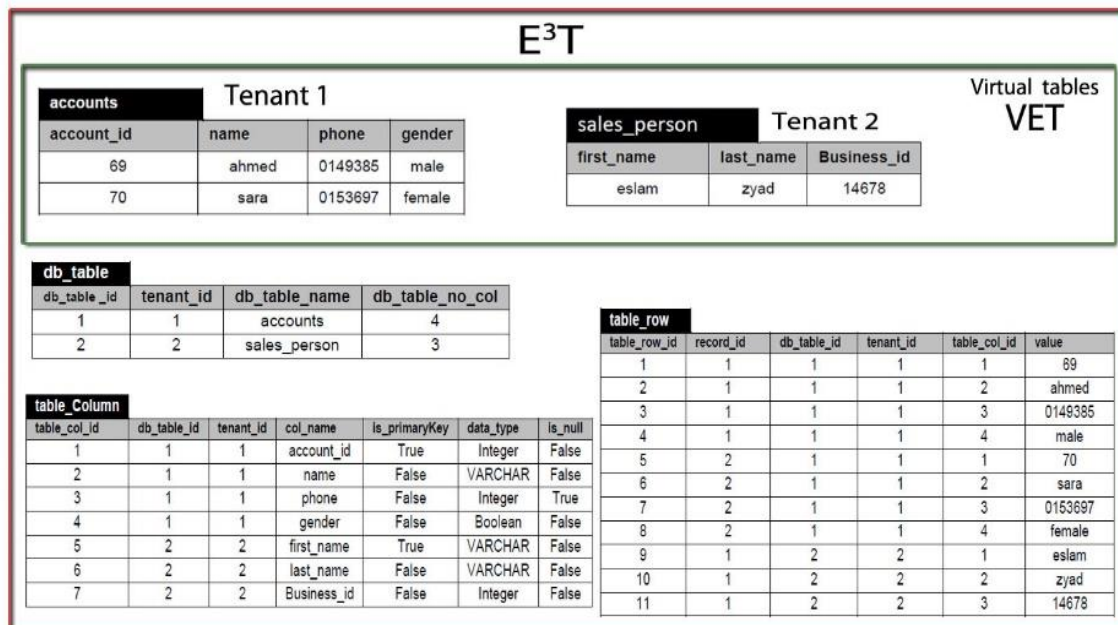
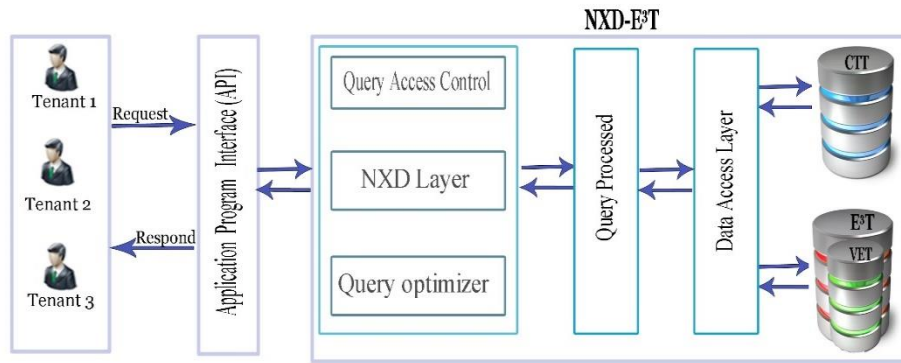


Figure 2. Enhanced elastic extension tables

The E³T tables provide high scalability, low space overhead, and flexibility for the following reasons: The total number of tables from multiple tenants is a fixed number and not too large. Then the number of tables does not grow linearly with the number of tenants. Eliminate the existence of NULL values comparing other multitenancy techniques such as universal table technique as discussed before. Low storage needed as all the tenants are put into the same tables considering importance. It is more flexible because the cost of adding new or deleting old attributes is much smaller than other approaches.

3.2. The NXD-E³T Database

In this section, the NXD-E³T schema is proposed as a combination of the E³T and Native XML databases. The Native XML database is used to minimize the amount of data placed in the memory and improve the performance of the E³T by reducing the access time. In the beginning, the application program interface (API) gather the information data from the different interfaces and devices. The query access control checks the privilege of the tenant's query to access either CTT or VET. Then the NXD targets the selected tables to load it. and then, the queries are pushed to the Query optimizer which carries out the required function. Finally, the queries are passed to be access data and processed as shown in Figure 3.

Figure 3. NXD-E³T schema

When NXD data is loaded into relational databases, NXD recognizes and understands the queries need to be transformed into SQL queries in the relational data. The advantage of this technique is that it does not demand many modifications of the existing database engine. Merging the E³T database with the NXD will provide the multi-tenancy databases to be relational with the virtual tables to each tenant as well as will increase the speed and decrease the response execution time of the multi-tenant database. Considering the NXD is a middle layer between the tenant requests and the query result, and the actual tables either CTT or VET, this layer consumes less memory. Then all query processing is passed into a relational query optimizer without any extra processing work. Using NXD-E³T has two main objectives. First, query the database using a common query language. Second, support multiple tenants and sub-users roles.

4. RESULTS AND DISCUSSIONS

In this section, the performance of the proposed NXD-E³T schema is evaluated. The proposed schema is compared against EET and E³T on a heterogeneous IoT database [28]. Moreover, the proposed schema is compared against variant multi-tenant techniques; Private tables, Extension tables, Universal tables, Pivot tables, Chunk tables, Chunk folding, XML tables, EET, and E³T, where this evaluation is implemented on a traditionally structured database [13, 14]. The proposed schema simulates a real multi-tenant scenario by passing query requests from many tenants concurrently and by affecting many numbers of rows and then evaluate the solutions by analyzing the execution time data captured during executing those experiments. The experiments were completed on four different query types which are select, insert, update, and delete to verify the E³T performance.

4.1. Experimental data set

The experiment was implemented with Apache Version 2.4.18, PHP Version 7.4, and MySQL Version 8.0.4. This paper database structure is deployed in a server platform HP ProLiant ML350 Gen10 Server Tower. Table 3 shows the specifications of the used platform.

Table 3. Specifications of the used platform

Operating system	Windows Server 2019
Processor	Intel® Xeon® Scalable 4210 (10 core, 2.2 GHz, 13.75 MB, 85W)
Memory	32 GB RDIMM DR
Storage capacity per disk	4 x 8 TB

4.2. The NXD-E³T implementation on unstructured IoT database

In this comparison, the proposed schema is compared against EET and E³T on a heterogeneous IoT database in terms of the execution time. The results of this experiment are executed and calculated on 1, 10, 50, 100, and 1000 rows [24]. Figure 4 shows the effect of increasing the number of records on the insertion operation. It shows that the average execution time of the NXD-E³T is approximately 45% faster than the average execution time of the E³T. Figure 5 shows the effect of this increase on the update operation. The result shows that the average of the execution time of the NXD-E³T is 30% faster than the average execution time of E³T. Another noticeable feature that this performance is taking a line function with the increase of the rows.

The Delete operation is shown in Figure 6. The result shows that the average of the execution time of the NXD-E³T is almost the same as the average of the execution time of E³T with small numbers of rows or even a little faster. But as the number of rows increases the execution time of NXD-E³T becomes faster. The Selection operation is shown in Figure 7. The result shows that the execution time of the of NXD-E³T is approximately the same as the average of the execution time E³T even after the number of records increases the same time is taken in each method.

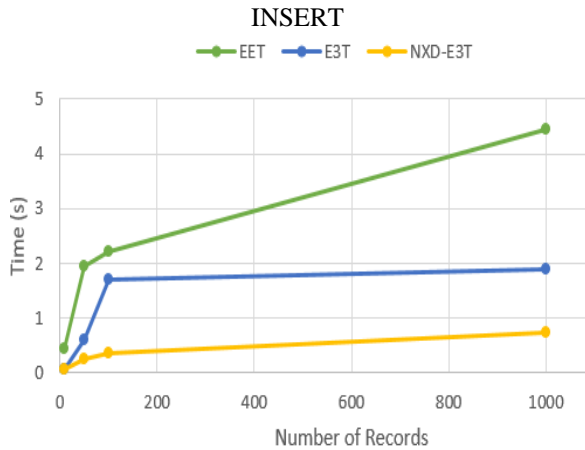


Figure 4. The execution time of INSERT query

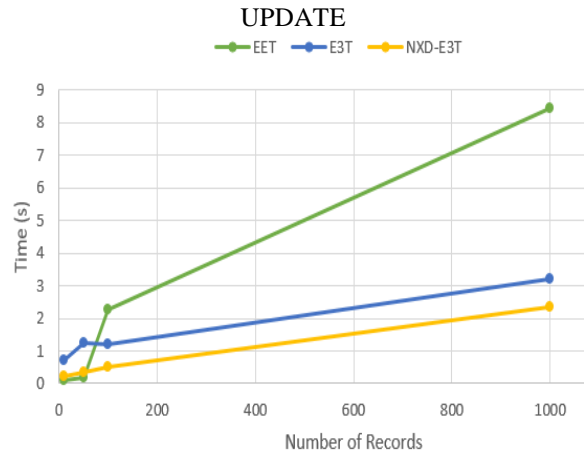


Figure 5. The execution time of UPDATE query

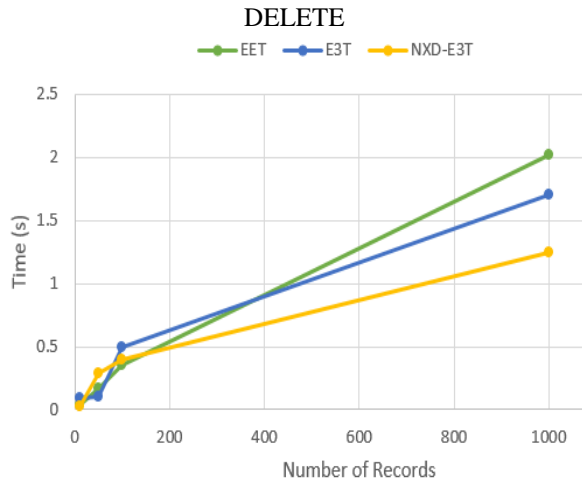


Figure 6. The execution time of DELETE query

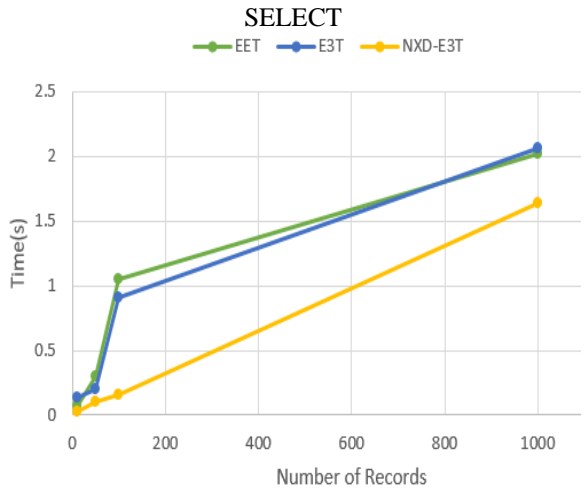


Figure 7. The execution time of SELECT query

4.3. The NXD-E³T implementation on structured database

In this sub-section the comparison is implemented on a traditionally structured database, the proposed schema is compared against different multi-tenant techniques such as Private Tables, Extension Tables, Universal Table, PivotTables, Chunk Table, Chunk Folding, XML, and EET. The results of this experiment are executed and calculated when operating 1, 50, or 100 rows.

Inserting Query Experimental Result. This experiment is showing that the average execution time of the NXD-E³T is approximately 29% faster than the average execution time of the EET Schema as presented in Figure 8. NXD-E³T Schema is considered the fastest average execution time from all multi-tenant techniques in the insert query. Updating query experimental result. This experiment is showing that the average execution time of the NXD-E³T 9% faster than the average execution time of the EET Schema in Figure 9. NXD-E³T Schema is considered the fastest average execution time from all multi-tenant techniques in the update query.

Deleting query experimental result. This experiment is showing that the average execution time of the NXD-E³T, is approximately 24% faster than the average execution time of the EET as presented in Figure 10. The delete and the insert query approximately have the same average as both having almost the same processing methods. The number executing the query is in ascending relationship with the number of rows affected.

Selecting Query Experimental Result. This experiment is showing that the average execution time of the NXD-E³T is nearly 8% faster than the average execution time of the EET as in Figure 11. The SELECT query is the more complicated query in any multi-tenant technique as it requires more processing in JOIN operation and more understanding of the technique. The time of the query executing is in a linear relationship with the number of rows affected. With all these challenges the NXD-E³T Schema has managed to perform this query with minimum response execution time in comparison to the multi-tenant techniques.

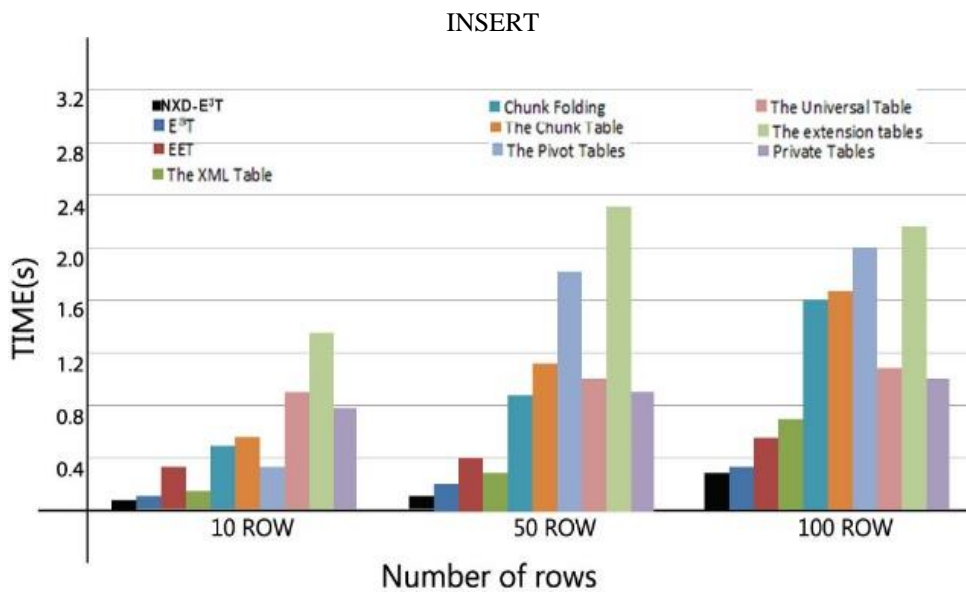


Figure 8. The execution time of INSERT query

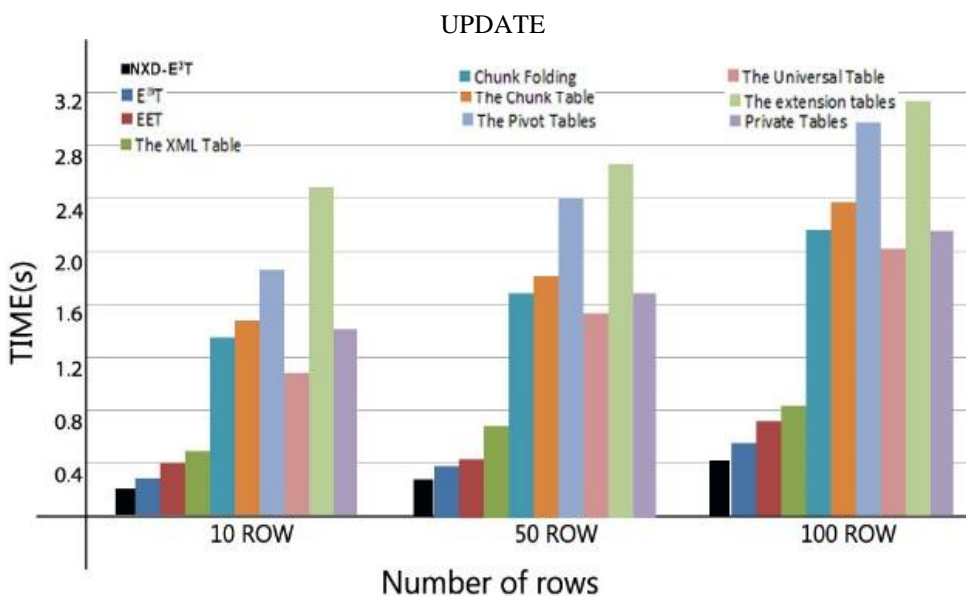


Figure 9. The execution time of UPDATE query

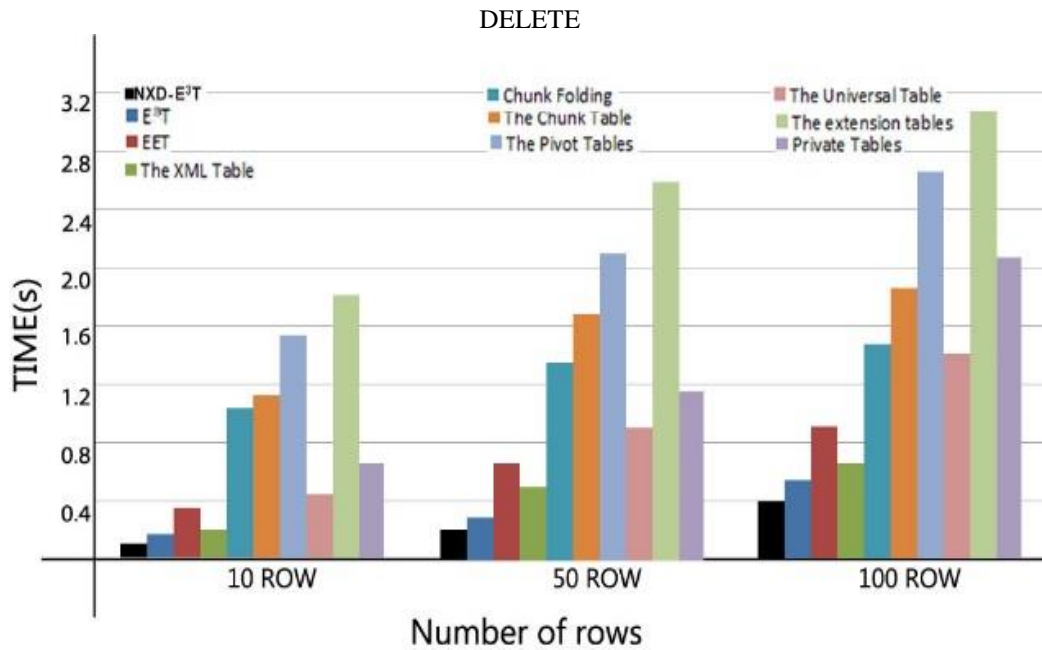


Figure 10. The execution time of DELETE query

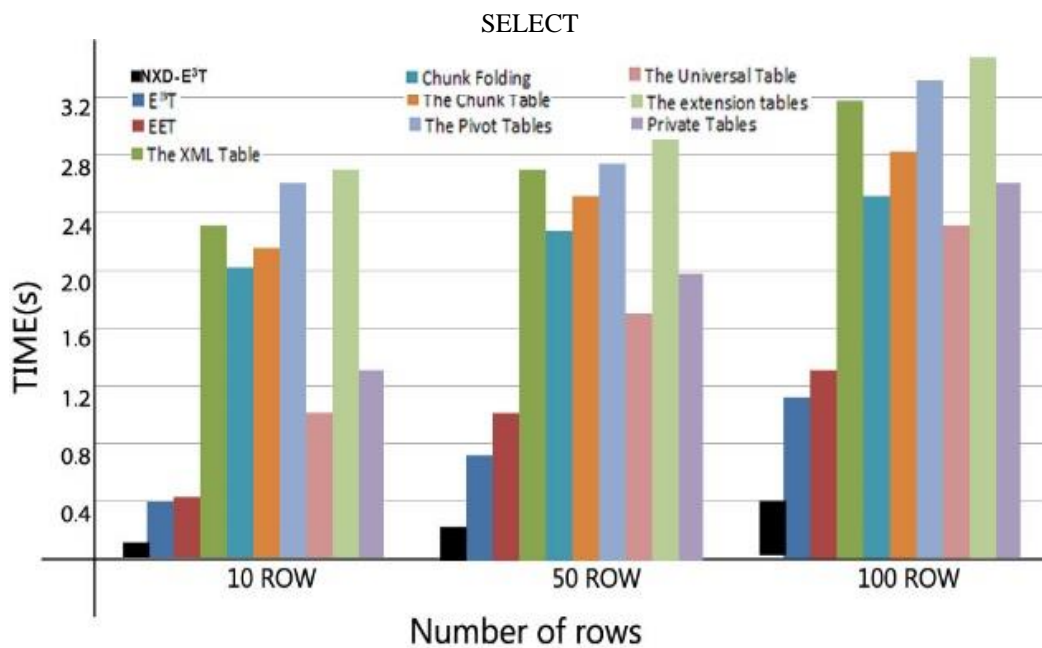


Figure 11. The execution time of SELECT query

5. CONCLUSION

In this paper, a native enhanced elastic extension tables (NXD-E³T) database is introduced as a multi-tenancy database system. The NXD-E³T Schema permits tenants to create databases with different requirements needed for any business which achieve high scalability and all needed programming features with a high average response time. The NXD-E³T Schema enables tenants to own their elastic relational database schema. It can be implemented in the IoT systems efficiently. Future publications will focus on merging the NoSQL to the E³T as the NoSQL data storage aims to handle data in the IoT systems more accurately.

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