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Enhancing Mobile Network Infrastructure Through Spatio-Temporal Analysis and Decision Support Systems by Geo-Decisional Prototype

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***Abstract* – The telecommunications industry generates copious amounts of data, including geographic information vital for robust business forecasting. This study endeavours to develop a prototype Spatial Online Analytical Processing (SOLAP) system aimed at conducting multidimensional statistics and predicting the expansion of radio antenna parks. Six fundamental concepts underpin our approach: (1) Big Data management for chronological storage of business data, (2) Multidimensional modelling to structure data around 'facts' and 'dimensions', (3) OLAP for navigating Big Data and conducting multidimensional statistics, (4) GIS for representing spatial data on satellite and topographical backgrounds, (5) SOLAP, which merges GIS and OLAP properties for statistical analysis and forecast scenarios, and (6) Open Source tools for crafting an operational SOLAP prototype using available software. The prototype's design encompasses four pivotal steps: (1) Multidimensional spatial database modelling, (2) Establishment of a data warehouse space dubbed 'GouvData' using PostgreSQL, (3) Development of the SOLAP system 'GouvRes' by integrating a GIS platform (QGIS) and an OLAP 'cube' developed in Python, and (4) Creation of a user interface to formulate statistical queries and urban planning scenarios. This study presents a holistic framework for leveraging spatial intelligence in mobile operator forecasting, with due consideration given to urban planning, thus contributing to strategic decision-making and fostering business development. As a result of this study, the capability to depict the magnitude of traffic across a region using interactive maps and satellite imagery has been developed. This capability allows for the effective monitoring and management of the extension of mobile network infrastructure.**

Key Word: BI, Datawarehouse, DataMart, OLAP, Open Source. SIG, SOLAP,

I. INTRODUCTION

A mobile phone system comprises three essential components: a cellular-based access network consisting of relay radio antennas, which are connected to the system's core through a supply network or backhaul. Analysing traffic fluctuations within the access network, both spatially and temporally, is crucial for effective operational maintenance and informed decision-making regarding the long-term expansion of infrastructure. Since the early 1970s, the field of Information Technology (IT) has provided businesses and researchers with a variety of applications aimed at facilitating decision support. [1].

Among these technologies, three distinct groups stand out: Geographic Information Systems (GIS): Designed to collect, store, process, analyse, manage, and display various types of spatially related data, GIS systems play a crucial role in managing infrastructure data.

Online Analytical Processing (OLAP): OLAP facilitates online analysis of data by generating summary reports that offer a comprehensive view of the company's activities, allowing for in-depth analysis and decision-making.

The SOLAP system emerges from the integration of functionalities inherent to both GIS and OLAP tools [2]. In today's competitive landscape, Big Data has become a pivotal asset for numerous organisations [3]. Within the company of mobile telephony, entrepreneurs amass a significant volume of georeferenced or geotagged numerical and alphanumeric data at the core of their systems and across various operational databases such as Excel, Access, Oracle, and others. Despite the abundance of this data, much of its latent potential remains untapped within transactional systems.

This article aims to introduce a geo-decisional prototype, known as SOLAP, designed to extract and store large volumes of big data. The objective is to unlock hidden insights within this data by presenting it on interactive maps that are readily accessible and comprehensible to decision makers. The functional capabilities of this prototype will be thoroughly tested, validated, and demonstrated using data pertaining to the transmitting-receiving antennas of a mobile network within the city of Rabat. Through this initiative, we seek to showcase the potential of SOLAP in harnessing spatial intelligence for informed decision-making in the telecommunications sector

A. Generic Structure of a Mobile Phone Network.

A mobile network is typically divided into three distinct parts, as illustrated in Figure 1:

The network access component is responsible for modulating the traffic within the system.

The access network is responsible for providing coverage to geographical areas known as cells, typically with a hexagonal shape. The size of these cells can range from thirty kilometres to just a few metres, depending on factors such as traffic intensity and the type of antenna deployed. Importantly, cell size is not fixed; it dynamically adjusts based on variables like weather conditions, obstacles present, and traffic intensity. Within each cell, hardware and software are deployed to facilitate communication with mobile stations. [3]

The mobility network ensures seamless user mobility throughout the network.

The backhaul, also known as the feeder network, serves as the link connecting the access network to the core network. The links comprising the supply network can vary and may include optical fibre, copper, or radio-relay systems to facilitate data transmission and communication within the network.

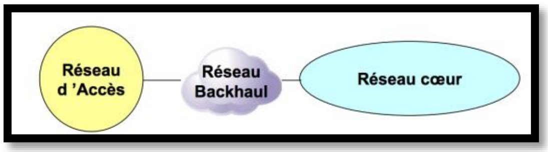


Fig. 1: essential Components of mobile networks

B. Decision Support Systems

In a Data Warehouse, information represents intangible capital, where effective management is a critical factor for the success of any organisation. Decision support systems, or BI (Business Intelligence), aim to support the operational activities of an organisation. They are constructed based on business requirements and company-defined processes to store, process, and communicate information.

Information Systems (IS) within companies accumulate a vast amount of data over time, stored across various internal sites or obtained from external sources such as partners or the web. The challenge for companies lies in effectively utilising this data to enable decision makers to optimise and anticipate their choices. Consequently, the necessity for efficient data utilisation in a decision-making context has led to the development of new systems known as Decision Support Systems (DSS), which facilitate the storage and synthetic processing of large volumes of data.

These DSS enable the selection of operational information relevant to the company and, notably, to decision makers. They integrate information and tools to effectively support decision-making processes. DSS consolidate, standardise, and coordinate databases, analysis models, and visualisation techniques.

Decision support systems find applications in various domains where decision-making is essential, including areas such as commerce (marketing, sales), logistics, healthcare (medical decision support), science (e.g. bioinformatics), telecommunications, and transportation (e.g. motorway traffic management).

To provide a comprehensive overview of the company’s operations, decision support systems gather and store data from databases across different business units as well as from external sources such as websites and emails. The architecture of these decision support systems comprises four levels: two storage levels and two operational levels, as illustrated in Figure 2.

C. The SOLAP or OLAP Spatial Concept

An efficient solution for spatial-multidimensional spatial data analysis, Spatial Data Warehouses allow the integration, multidimensional organisation, storage of very large volumes of spatial and non-spatial data from multiple data sources to support the decision-making process within an organisation.

SOLAP systems represent a specialised category of software tools that facilitate interactive exploration through multi-level spatial-multidimensional approaches to Decision Support Systems (DSS). These systems augment the analysis and representation capabilities of traditional OLAP systems by incorporating new concepts and operators known as SOLAP concepts and operators. These enhancements enable OLAP analysis to be enriched with spatial analysis capabilities.

In addition to enabling spatial-multidimensional navigation through SOLAP-specific operators like spatial drill-down, these systems also allow decision-making results to be visualised through interactive maps. This visualisation capability enhances comprehension of the analysed phenomenon.

Both DSS and SOLAP systems are built upon the spatial-multidimensional model, which extends the classical multidimensional model by incorporating additional concepts such as measurement and spatial dimension. This integration of spatial information into multidimensional analysis enables a more comprehensive understanding of data patterns and relationships [5].

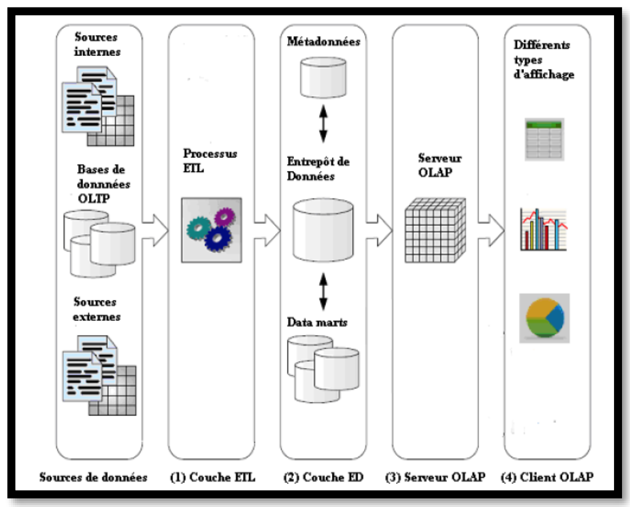


Fig. 2: The typical architecture of an OLAP system

(1) Utilising Extract, Transform, Load (ETL) tools to facilitate the extraction, transformation, and loading of data from various sources into warehouses and data marts. (2) The data warehouse serves as the repository for all decisional information, housing an extract of data from diverse sources. Its organisation is pivotal, designed to streamline data integration and preserve their evolutionary trends. Meanwhile, the data mart represents a subset of the data warehouse, organised according to a specific model tailored to facilitate decision analysis. (3) OnLine Analytical Processing (OLAP) tools empower decision makers to query and analyse data in formats conducive to their needs [2]. (4) The OLAP Client is utilised for managing different types of display options and reporting functionalities.

D. Spatial Dimensions

The spatial dimension allows for the representation of spatial information related to both geographical and non-geographical locations along the axis of analysis. Put simply, it involves incorporating spatial information as a dimension within a decision-making application. This concept encompasses three main types of spatial dimensions:

descriptive, geometric, and mixed, alongside non-spatial dimensions. Various definitions have been proposed to articulate this notion [6] and [7].

The 'descriptive' dimension solely relies on nominal spatial references, such as place names, without any accompanying map representation associated with its members. This type of spatial dimension is frequently utilised in traditional OLAP tools.

The 'geometric' dimension entails each hierarchical level containing a collection of geometric shapes, such as polygons, points, or lines, corresponding to spatial elements.

The 'mixed' dimension combines spatial component levels with purely textual levels.

An illustrative example demonstrating the descriptive, geometric, and mixed spatial dimensions is provided in Figure 3.

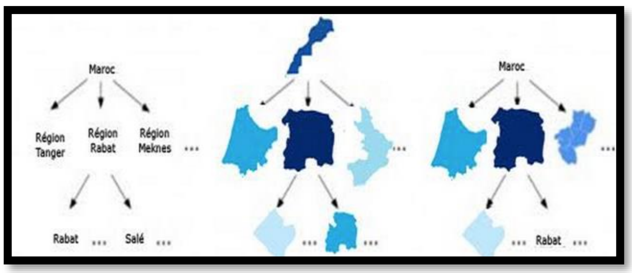


Fig. 3: The three modes of representing spatial dimensions supported by SOLAP

II. Related Work

The utilisation of On-Line Analytical Processing (OLAP) systems augmented by spatial data warehousing has become omnipresent across decision-making domains, including commerce (e.g. marketing, sales), logistics, healthcare (e.g. medical decision support), scientific research (e.g. bioinformatics), telecommunications, transportation, and agriculture [6]. Geospatial technologies, reinforced by Geographic Information Systems (GIS), have emerged as pivotal tools in real-time field application management, particularly accentuated in the aftermath of the COVID-19 pandemic [7], [8].

Spatial OLAP (SOLAP) systems constitute a category of software tools facilitating interactive exploration predicated on a spatial-multidimensional framework [9]. These systems enable nuanced analysis across varying levels of detail. Furthermore, the foundational architecture of OLAP servers is delineated, serving as intermediaries between report generation software and diverse data sources, thereby facilitating systematic multidimensional data analysis.

Three principal avenues for implementing OLAP [10] systems are defined: ROLAP, MOLAP, and OLAP clients. ROLAP employs relational databases for data and aggregation storage, offering flexibility but potentially encountering performance constrictions. In contrast, MOLAP stores data in a multidimensional format, optimising access speeds although necessitating operational redefinition for multidimensional structure manipulation [11]. The OLAP client provides a user interface replete with reporting tools, interactive analysis functionalities, and, at times, data mining capabilities to render multidimensional information accessible.

Despite the competence of OLAP systems in traditional data analytics, their native incapacity to manage spatial information necessitates the development of novel paradigms for spatial integration within OLAP frameworks. Thus, following article will illustrate upon the imperative for integrating spatial information systems, commencing with a comprehensive exposition on geographic information systems (GIS). This last will describe methodologies and frameworks aimed at augmenting OLAP systems with spatial capabilities, thereby enhancing decision-making efficacy across diverse sectors especially in mobile networks.

III. MATERIEL AND METHODS

A. Methodology

The methodology employed in this study involves the creation of an open-source spatial data warehouse termed 'GouvData' using PostgresSQL. This warehouse is designed to organise mobile telephony network data and access network data in a multidimensional structure.

Additionally, an open-source S-OLAP tool named 'GouvRes' is developed by integrating the functionalities of a GIS tool, specifically QGIS, with an OLAP library under Python. This tool is constructed following the hybrid GIS mode, as detailed. The hybrid GIS mode combines GIS functionality with a subset of OLAP services, offering users a comprehensive set of capabilities.

Furthermore, the implementation of the 'Geodecision Prototype' is executed to visualise multidimensional analysis results on interactive maps or satellite images. This prototype enables users to interactively explore and analyse spatial data, facilitating informed decision-making processes.

B. OPEN-SOURCE SOFTWARE

Much more than a mere copyright, Open-Source terminology (also referred to as free software) embodies a particular philosophy. Richard Stallman, the founding father of the Free Software Foundation, succinctly encapsulates the essence of Free Software as 'Freedom, Equality, Fraternity.'

The license of an 'Open-Source' program must adhere to the following criteria:

The license should not inhibit the sale or distribution of the software as a component of a package containing programs from various sources. It should not impose royalties on the sale.

The program must provide access to its source code, and distribution in both source code and compiled form should be permitted. If a product is distributed without its corresponding source code, there must be a clear means to obtain the source code from the Internet without incurring any additional charges. The source code represents the most suitable form for programmers to modify the program. It is prohibited to offer intentionally incomprehensible source code or intermediate forms, such as those generated by preprocessors or automatic translators.

C. Rationale for choosing Open Source

Audaxis based its development strategy on the integration of Open Source solutions, for the following reasons:

Licenses being free, the risk of software investment, which generally represents 20% of the project budget, is ruled out.

One hundred percent of the investment is allocated to the services (personalisation, training, support) which makes it possible to maximise the chances of success of the project.

The free access to the sources makes it possible to freely personalise the application to the business of the company and increases the adequacy of the solutions to the needs of the users.

The Research and Development culture of free software publishers and the collaborative development model allow a fast and reliable evolution of Open-Source software.

Open-Source solutions are based on interoperable object components.

Customers are masters of the evolution of their information system since there is no dependence regarding a publisher or obligation to migrate to new versions.

The logic of open-source means that the durability of the software is ensured by the attractiveness of the community concerning the tool and not by economic laws.

The logic of free use of software brings transparency and allows them to reach maturity more quickly than with a publisher owner.

Audaxis has formulated its development strategy around the integration of Open-Source solutions for the following reasons:

Cost-Efficiency: Open-Source licenses are free, mitigating the risk associated with software investment, which typically accounts for 20% of the project budget.

Maximised Investment Allocation: By eliminating licensing costs, 100% of the investment can be directed towards services such as customisation, training, and support, thereby enhancing the project’s likelihood of success.

Flexibility and adaptability: Free access to the source code enables unrestricted customisation of applications to align with the company’s business requirements, thereby enhancing user satisfaction and solution effectiveness.

Rapid Evolution: The Research and Development ethos prevalent among free software publishers, coupled with the collaborative development model, facilitates swift and reliable evolution of Open-Source software.

Interoperability: Open-Source solutions are built on interoperable object components, fostering seamless integration with existing systems and technologies.

Client Empowerment: Clients retain control over the evolution of their information systems as there is no reliance on a specific publisher or obligation to migrate to new versions.

Community-Driven Durability: The Longevity of Open-Source software is sustained by the vibrancy of the community surrounding the tool, rather than by economic factors.

Transparency and Accelerated Maturation: The ethos of freely using software promotes transparency and accelerates the maturity of Open-Source solutions compared to proprietary alternatives.

D. Structure of the proposed data warehouse

Our data warehouse model was specifically crafted to incorporate interactive cartographic representations, thereby enhancing the traditional geographic information typically highlighted by Geographic Information Systems (GIS) with additional geometric information and measurements displayed on cards (refer to Figure 4). To achieve this, our proposed model integrates spatial data through the ‘Urban Planning’ dimension, which holds significant importance for subsequent analyses [8].

Conceptually, our spatial data warehouse adheres to the principles of multidimensional modelling, which underpin the concepts of facts and dimensions. In this framework, the subject under analysis is conceptualised as a point within a space characterised by multiple dimensions. This perspective entails structuring data along various axes of analysis (or dimensions), which may encompass diverse concepts such as time, geographical location, urban planning, and more [9] [10].

The storage architecture relies on the relational model, with the warehouse structured following the flake diagram derived from the star schema. In this schema, the fact table remains central while dimensions are segmented into multiple tables based on their hierarchies. The flake model is particularly recommended when dimension tables contain a substantial volume of data [11].

E. Technical Data mart

The Data Mart depicted in Figure 4 is organised hierarchically based on the following dimensions:

BTS Dimension (Base Transceiver System): This dimension serves as the core of the spatial Data Mart, representing the fundamental element for decision-making. It encompasses information pertaining to a BTS, including its name, Agency, Maximum Traffic, as well as its X, Y, Z coordinates. Additionally, it features a BTS geometry field of point nature, encapsulating the spatial aspect of the BTS.

Cell Dimension: Cells are comprised of a collection of BTS(s), forming an integral part of the hierarchical structure within the Data Mart.

BSC Dimension (Base Station Controller): The BSC dimension orchestrates a multitude of BTS, potentially numbering in the hundreds. It encompasses information such as the Name and Commissioning Date of the BSC.

BSS Dimension (Base Station Subsystem): This dimension provides a comprehensive description of the Base Station Subsystem.

OS Dimension (Operating System): The OS dimension contains all relevant information regarding the operating system utilised within the Data Mart environment.

F. Urban Planning Data Mart

The Data Mart illustrated in Figure 4 incorporates the spatial dimension provided by Urban Development Plans (PDUs) or Rural Development Plans (PDAR), along with their respective approval and expiry dates. These plans delineate various existing or projected urban entities. For improved clarity and readability, this data mart has been structured hierarchically across five dimensions:

Ilot Dimension: This dimension encompasses population clusters or islands, including details such as the number of households and descriptions of the urban regulations applicable to each block. Its spatial component is represented as polygons.

Equipment Dimension: Within this dimension, information about administrations, agencies, and existing or planned equipment is stored.

Grid Dimension: The spatial aspect of this dimension, depicted as polylines, represents entities within the High Voltage (HV), Medium Voltage (MV), and Low Voltage (LV) electrical networks.

Hydrography Dimension: This dimension deals with the size of hydrographic features, including watersheds and the courses of various rivers.

Road Fabrics Dimension: This dimension focuses on road networks and their different classifications (e.g. national road, secondary road, railway, highway), with the spatial aspect represented as polylines.

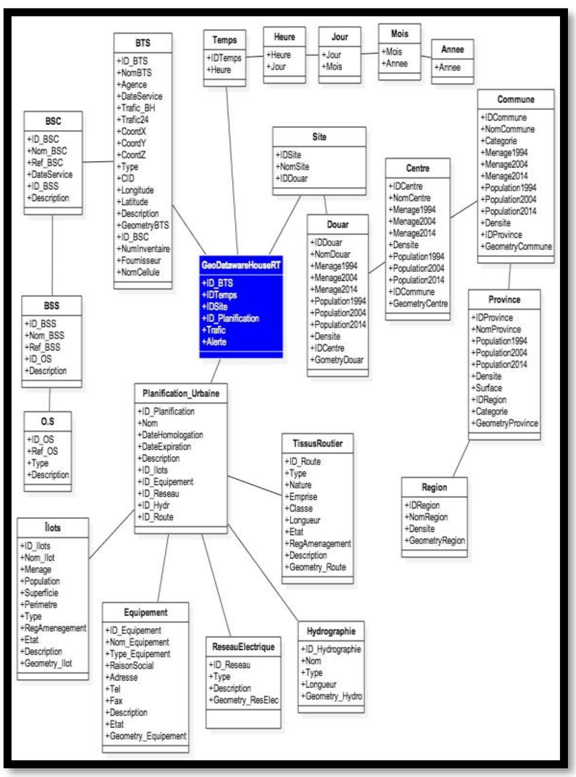


Fig. 4: The Model of Data warehouse

(Figure 4) is represented by the fact table (blue table) which contains the necessary information (Measure) in the description of a mobile network such as traffic.

The model has 4 Data Marts each **one** represents a specific subject:

Time Data mart

This data mart (Figure 4) contains time information. It represents the division of time following the hierarchy:

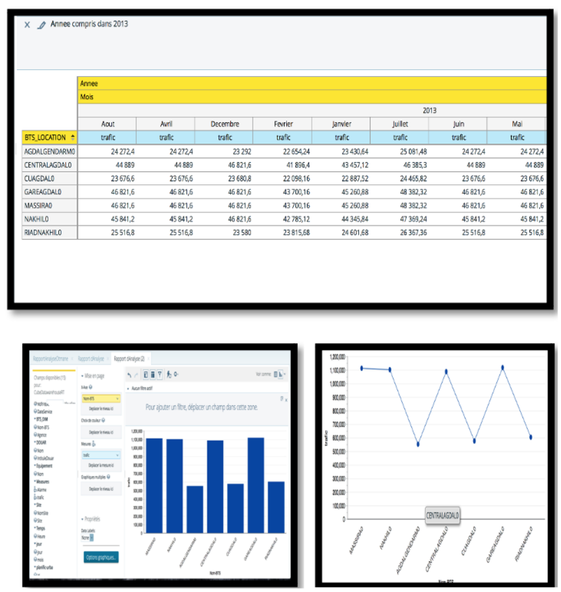
- Year dimension, Month Dimension, Day Dimension, Hour Dimension

IV. RESULTS

To showcase the resilience, speed, and flexibility of our data warehouse performance, we can highlight the various types of displays it can achieve:

A. Displaying Data

spatial data warehouse 'GouvData' (Figure 5) shows that our Spatial Datawarehouse is fully operational and allows flexible navigation within the data using of Pantaho whose graphical power allows a display of the results under different types of graphs (Figure 5). In addition, Pantaho allows a projection on some satellite or cartographic databases at different scales, of the results of the analyses carried out for each BTS (Figure 5). These results illustrate the graphical and spatial power of Pantaho. But Pantaho requires deep knowledge of computer science and data cube modelling with the WorkBensh tool. That's why we chose to develop a SOLAP tool in the form of a plug-in. This tool has been designed to be adapted to the needs of users who are new to computer science. In other words, this tool aims to display results identical to those obtained using Pantaho without the user has any knowledge in computer science.



Annee compris dans 2013

	Annee							
	Mois							
	2013							
	Aout	Avril	Decembre	Fevrier	Janvier	Juillet	Juin	Mai
BTS_LOCATION	trafic	trafic	trafic	trafic	trafic	trafic	trafic	trafic
AGDALGENDARM0	24 272,4	24 272,4	23 292	22 654,24	23 430,64	25 081,48	24 272,4	24 272,4
CENTRALAGDAL0	44 889	44 889	46 821,6	41 896,4	43 457,12	46 385,3	44 889	44 889
CUAGDAL0	23 676,6	23 676,6	23 680,8	22 098,16	22 887,52	24 465,82	23 676,6	23 676,6
GAREAGDAL0	46 821,6	46 821,6	46 821,6	43 700,16	45 260,88	48 382,32	46 821,6	46 821,6
MASSIRA0	46 821,6	46 821,6	46 821,6	43 700,16	45 260,88	48 382,32	46 821,6	46 821,6
NAKHIL0	45 841,2	45 841,2	46 821,6	42 785,12	44 345,84	47 369,24	45 841,2	45 841,2
RIADNAKHIL0	25 516,8	25 516,8	23 580	23 815,68	24 601,68	26 367,36	25 516,8	25 516,8

Fig. 5:Data Display in Graph and cross-Table Format

B. Displaying Data on a Satellite Image

The primary advantage of Spatial OLAP (SOLAP) lies in its capability to present data overlaid on a geographical backdrop, providing a comprehensive regional perspective. In Figure 6, we observe a recent satellite image of the Rabat region, where the size of the red dots corresponds to the annual traffic intensity recorded for each Base Transceiver Station (BTS). This visualisation approach offers a succinct and intuitive representation of the distribution and magnitude of traffic across the region. By integrating spatial and analytical data, SOLAP facilitates a deeper understanding of patterns and trends within the geographic context. Users can discern areas of high traffic concentration, identify potential areas for infrastructure optimisation or expansion, and make informed decisions to enhance network performance and efficiency.

In essence, SOLAP leverages the power of spatial analysis to transform raw data into actionable insights, empowering decision makers with a holistic view of regional dynamics and enabling strategic planning and resource allocation.

Fig. 6: Image Satellite Displaying Data

Area of the red dots representing each BTS is proportional to the annual traffic intensity recorder for each of BTS

V. DISCUSSION

The research presented in this paper introduces a prototype of an operational spatial data warehouse designed to support a multidimensional analysis system tailored for governing mobile networks. Specifically, it focuses on prospective analysis of access networks. The aim of this prototype is to analyse and forecast infrastructure development at various scales, ranging from neighbourhoods to cities, regions, and entire countries.

The significance of predictive modelling for the evolution of such intricate networks lies not only in the multitude of parameters to be considered but also in understanding their interactions. Multidimensional analysis plays a pivotal role in identifying and examining these interactions, thereby enhancing the ability to make informed predictions regarding network development.

A. Data Availability

Mobile operators diligently collect a vast amount of data, albeit within a context that isn’t inherently conducive to multidimensional analysis. Furthermore, these datasets often overlook the spatial dimension, despite a significant portion of the data being directly influenced by it. Addressing this challenge requires the implementation of specialised tools to carefully select and standardise the data supplied to spatial data warehouses. These tools play a crucial role in ensuring that spatial factors are properly integrated into the analysis, thereby enhancing the accuracy and relevance of insights derived from the data.

B. Medium – And Long-term Management of BTS

Ensuring seamless service delivery stands as a key strategic objective for mobile operators. The proposed prototype facilitates the identification of Base Transceiver Stations (BTS) that have reached saturation thresholds, rendering them incapable of supporting consistent and reliable traffic. Consequently, this enables the prediction of:

Capacity Expansion for Defective Equipment: Predicting the need to enhance the capacities of existing equipment that has reached its limits, ensuring it can adequately accommodate the demand.

Territorial Relocation Considerations: Envisaging potential adjustments to the geographical placement of BTSs to better align with changing traffic patterns and user demand, thereby optimising network performance.

Installation Planning for New BTSs: Planning for the deployment of new BTSs, taking into account both the geographical landscape and the socio-economic context of the areas they serve. This ensures that new installations are strategically positioned to effectively meet evolving communication needs while considering environmental and socio-economic factors.

By leveraging insights derived from the prototype, mobile operators can proactively address network congestion issues, enhance service reliability, and strategically plan for future infrastructure development to maintain seamless service delivery for their customers.

C. Impact of the open-source use

This work serves as a compelling demonstration of the capabilities of open-source tools. These tools offer comparable power to proprietary counterparts across various aspects, including creating, population, and querying data warehouses. Additionally, open-source tools provide a cost-effective alternative, as they are freely available, unlike proprietary tools that can be prohibitively expensive. From this perspective, leveraging open-source tools for this prototype enable significant cost savings, making it particularly appealing for newly established operators. These operators, especially those expanding their networks in regions with emerging markets and underdeveloped infrastructure, can benefit greatly from the affordability and scalability offered by open-source solutions. This prototype thus presents an attractive option for such operators looking to efficiently manage their network development while minimising costs.

VI. CONCLUSION

This paper serves as a comprehensive guide for leveraging Big Data Analysis to create Strategic Business Value, particularly within the context of mobile operator networks.

One of the key challenges faced by mobile operators is maintaining consistent radio traffic across vast spatial and temporal dimensions to cater to millions of users simultaneously traversing expansive areas. The mobile phone network comprises a complex array of structures, notably the access network consisting of transceiver antennas (BTS, NoteB, eNoteB), which must efficiently distribute a single radio spectrum among these millions of users. Hence, it is imperative for operators to establish expansion forecasts for the access network to uphold operational capacity at existing sites and extend territorial coverage.

The primary objective of this paper was to design and implement a geo-decisional prototype capable of conducting statistical analysis on radio traffic fluctuations in both space and time. Additionally, it aimed to characterise, based on these statistics and territorial plans, the optimal locations for new network deployment sites.

Data pertaining to the mobile access network is inherently georeferenced and possesses spatial characteristics. Consequently, SOLAP-based geo-decision analysis systems prove particularly adept at supporting extension forecasts for this network.

To this end, a Geo-Decisional Prototype was designed and developed, featuring an architecture comprising a Spatial Data Warehouse (SDW) and an integrated SOLAP-GIS system. This SOLAP integrates the capabilities of the GIS tool 'QGIS' with those of the 'Cube' OLAP, developed on a 'Python' platform. This integration facilitates seamless analysis and decision-making by combining spatial and multidimensional data analysis functionalities.

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