Real-Time Big Data Analytics: Applications and Challenges

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***Abstract*—Timely analytics over big data is a key factor for success in many business and service domains. Some examples of these domains include finance, transportation, energy, security, military, and emergency response. Several big data applications in these domains rely on fast and timely analytics based on available data to make quality decisions. This paper surveys real-time big data analytics applications and their technical challenges.**

Keywords: Real-Time processing, Big data, Data analytics

I. INTRODUCTION

Big Data refers to the huge data sets obtained from various sources such as science experiments, sensor systems, social network activities, telecomunications data, cameras and surveillance systems, and daily business and financial transactions. Companies collect huge volumes of data about their customers, suppliers, operations, and business transactions. Sensors that are embedded in roads, buildings, mobile phones and devices, vehicles, and smart energy meters generate trillions of bytes of real-time information. In addition, billions of individuals around the world contribute on a daily basis to the increasing size and availability of big data through social media sites and applications. Such huge data offer a great opportunity to understand and use it in beneficial applications. However, the sheer size of such data sets pause new technological challenges in terms of storage capacity and management, organization, processing and analysis.

With big data, businesses and organizations can learn more about their businesses and operations and they can translate that knowledge into improved decision making processes and better performance [11]. The availability of big data can be utilized to enhance performance in different application domains such as healthcare, finance, transportation, education, security, and governmental planning. Some special types of big data applications need to make real-time decisions to enhance the performance of their operations or services or to increase profits. Examples of these applications are intelligent transportation, financial market trading and surveillance, military operations decision making, smart grids, and emergency response. These applications need to deal with current and historical massive data to perform fast analysis aiding in instantaneous decision making. Slow or untimely data collection and analysis leading to delayed decisions can significantly reduce the performance of the big data applications. Such applications have a number of technical challenges to provide real-time processing due to the massive data available for optimal or near optimal decision making.

This paper surveys real-time big data analytics applications. The paper then discusses some of the technical challenges facing these real-time applications. In addition, it provides some analysis of the performance and requirements of real-time big data applications. Thus in the rest of this paper Section II provides an overview of big data. Different real-time big data applications are discussed in Section III. Section IV discusses the common technical challenges. Section V provides some discussion and analysis, while Section VI concludes the paper.

II. BACKGROUND

The term “Big data” refers to data sets that typical database management systems cannot store, manage, and analyze due their massive sizes [10]. Big data sizes range from a few dozen terabytes to multiple petabytes. Big data applications generally seek new knowledge and gather intelligence from the data and convert that into business advantages [11] in terms of enhancing operations and profitability and reducing risks and overheads. In addition, utilizing big data can provide a number of new types of advanced services that have just recently been introduced or will be introduced in the near future. These services enhance the quality of life and help reduce risks and threats. Big data differs from regular data in three characteristics: volume, velocity, and variety.

Volume: It was estimated that around 2.5 exabytes (one billion gigabytes) of data are created from different sources each day in 2012. This number is doubling every 40 months. The expanding use of the Internet, mobile devices and Smartphones contributes significantly in generating this huge data. Another source of this data is sensors and sensor systems that are embedded in our life. Different types of sensors are available in roads, building, cars, different environments, and factories. These sensors collect massive amounts of collected information. Some of these sensors are fixed such as road and environmental sensors while others are mobile such as sensors installed in smartphones and vehicles such as cars and unmanned aerial vehicles (UAVs).

Velocity: huge amounts of new data are created every second and added to existing big data sets. In most big data applications, this new data needs to be included in the analysis and real-time decision making. Organizing, accessing and processing the data as it is collected to be included in the decision making in real-time applications is usually considered a complex technical challenge.

Variety: data is usually collected from different sources and in different formats. These sources can be messages, images and videos posted to social networks, readings from sensors, business transactions, and economic and political news. Most of the sources of big data are relatively new due to the recent introduction of online social networks and smartphones. The collected data can be structured or unstructured data. It can also have different formats. Some of the data is produced in a random fashion while some is frequently or periodically produced. In the latter case, the data can also differ in the production frequencies.

III. Applications

Real-time applications differ from regular applications in one major attribute. Real-time applications rely on instantaneous input and fast analysis to arrive to a decision or action within a short and very specific time line. In many cases, if a decision cannot be made within that timeline, it becomes useless. As a result, it is important to make all data necessary for such decision available in a timely fashion and that the analysis is done in a fast and reliable way. There are different real-time big data analytics applications and we discuss examples of these applications in this section.

A. Intelligent Transportation

One of the most important applications of real-time big data analytics is to enable intelligent transportation systems. These days, different sensing technologies are available to monitor traffic conditions in big cities and crowded streets. These sensing technologies are divided into two groups: road sensors and vehicle sensors. Examples of road sensors are road monitoring cameras, road tube axie sensors, vehicle inductive loop sensors, capacitance mats, and piezoelectric axie sensors [1]. Vehicle sensors include on-board cameras, GPS systems, proximity sensors, and speedometers [2]. These sensors can be associated with communication capabilities such as GSM, satellite communications, WiFi, and Bluetooth to provide real-time monitoring for different conditions such as vehicle locations, average speeds, and driving behaviors of drivers as well as road conditions.

The roads and vehicular sensors can generate big data that can be utilized to provide advanced intelligent transportation services in big cities. One example of such services for end users is a real-time service that provides information about shortest-time routes to any destination from the current location based on the current traffic conditions [3]. Such a service cannot be provided without having a full picture of all roads and traffic conditions in the city where the service is provided. While this service is very useful for regular user vehicles, it is extremely important for emergency vehicles such as fire engines, ambulances, police cars, and public utility emergency cars. Current GPS systems offer drivers best route information; however, many cannot respond quickly enough to sudden changes in traffic conditions such as accidents or roadblocks. In addition it may not be possible to provide on-time information to vehicles to clear the road efficiently for emergency vehicles.

Within the same line other more advanced intelligent transportation services can be provided such as a service that provides end users with information about most energy-efficient routes from any current vehicle location to any defined destination point. These best energy-efficient routes cannot be defined with only observing the current traffic conditions but also the previous traffic experiences, the characteristics of energy consumptions in the vehicles, and the drivers' driving behaviors. All this information is needed to find the most energy-efficient route to a destination. Another advanced service that can be provided for goods delivery drivers is a real-time and dynamic solution of the traveling salesman problem for defining the order and routes of the delivery points such that delivery time is minimized. This delivery order and routes can be dynamically changed during the trip due to the current traffic conditions to meet with the objective of minimizing the total delivery time.

B. Financial Market Trading and Surveillance

Huge amounts of financial data are generated every second for stock and option trades from multiple markets, currency exchange rates, interest rates, and commodity prices. This data is not only big but also very dynamic. Companies and organizations can use this dynamic big data to detect opportunities and threats and to quickly react to them. Examples of these opportunities are: predicting increases or decreases in prices of some securities before a change actually occurs. The timely reaction to such opportunities can be buying securities before their prices increase or selling some before the prices drop. Many sold securities can be re-purchased at lower prices later to increase profits. The earlier such decisions are made the higher the chances of making more profit. This type of opportunities needs good forecast models that rely on both current and historical information. In terms of financial threats, examples include fraud and illegal activities. The timely detection of stock market exchanges' fraudulent and illegal activities such as market manipulation, price rigging, and uninformed insider trading helps stop such activities quickly thus it improves market performance and secures investors transactions. The financial opportunities cannot be utilized and the threats cannot be prevented unless the detection process is very fast. These financial opportunities and threats can be discovered by humans; however, they usually need a long time and the opportunities will not be available any more and the threats will take effect before they can prevent them. There are some automated trading systems developed recently to discover and react to financial opportunities. In addition, there are some real-time fraud detection systems developed recently to detect and prevent financial threats in a timely manner. Such systems currently rely on smaller and limited data sets to achieve real-time performance. However, for these systems to be more effective, they need to deal with all available data. This financial data is usually huge and changes dynamically, which introduces several technical challenges for such applications.

Traditionally, Data Mining and Business Intelligence Techniques are mainly used in the financial sector to discover some opportunities and threats. These types of techniques only work on historical data and need high involvement from the business users [5]. Although, these techniques are proven to provide useful information for long and middle level business planning for the financial sector, these techniques have very large latencies with respect to detection and response. Therefore, they cannot be effectively used for timely detection and prevention processes for some financial systems such as automated trading and fraud detection systems. These systems need to deal with huge data streams and must deploy very fast detection and reaction processes.

C. *Crowd Control*

Crowd control is important for police and emergency response teams when large events take place. Examples of such events are major sports games, concerts, parades and outdoor celebrations like New Year's Eve or the 4th of July festivities. Being able to watch and predict crowd movements and make immediate decisions such as opening more parking lots, closing some streets to facilitate pedestrian movement, or increasing police presence in some areas becomes important. This can be done using two types of sensing and tracking technologies. Traffic monitoring through traffic sensors and vehicle tracking allows for better information about incoming traffic into the event's area thus allowing for better control on where traffic is directed. In addition using GPS and location tracking apps on the peoples' mobile devices allows for tracking and learning about the people and their movement and concentration patterns in the area. Using the tracking applications in real time can provide an accurate view of where everyone is and identify overcrowded areas. Using this information, police forces can be better distributed to have optimal control over the area and best possible locations to provide their services. Given the huge number of people that can be present in one location for an event, the amount of data collected is huge and has to be organized and analyzed on the spot to make decisions immediately.

Furthermore, in such events the probabilities of accidents and catastrophic incidents also increase. With proper tracking and analysis systems the authorities become more capable in identifying the location of an accident and immediately planning response strategies such as clearing routes for emergency response vehicles, evacuating the people in the area and providing the necessary support services in a timely fashion. However, to handle this type of decision making, it is important to handle huge amounts of data must be analyzed which is not an easy task given the current technology.

D. *Military Decision Making*

Wars are very dynamic and complex. The key to winning a war is not only strength but also the ability to collect correct information about the current situation and make the right and decisions quickly [9]. In wars hundreds of different equipment, vehicles, structures and communication systems are used. Military vehicles can be tanks, armored vehicles, transportation and logistics vehicles, manned and unmanned aircrafts, military boats and ships, and underwater vehicles. This equipment, vehicles, and other resources in addition to thousands of soldiers can be in different locations. On top of that, information about the enemy resources and movement need to be collected and analyzed as well. Keeping all that in perspective, fast decisions for actions or reactions to attacks or enemy maneuvers must be taken. It is possible to monitor in real-time the location of these resources through GPS technologies, satellites, aircraft remote sensors, and other detection technologies. In a battlefield moving in fast pace, the data collected is huge and highly dynamic. This data must be used along with other static information such as road maps and risk information to plan for the right decisions. The more data collected and analyzed, the more accurate the decisions can be, as a result new technologies to handle such big data in real-time are important.

E. *Large-Scale Emergency Response*

In disasters such as earthquakes, volcanoes, floods, wars, and large-scale terrorist attacks correct and fast actions should be taken within a few minutes to respond and help those affected. In such scenarios huge information will flow to an emergency control center from different officials and regular people about their findings. More information will also flow in from deployed UAVs, robots, sensors, and satellites. The emergency control center needs to use the available human and equipment resources to relieve the injured as quickly and efficiently as possible. Human resources include doctors, firefighters, emergency staff, policemen, soldiers, workers, drivers and volunteers. Equipment can be emergency vehicles such as fire engines, ambulances, police cars, UAVs, boats, and public utility emergency cars or other special equipment such as concrete demolition or temporary communication infrastructure devices. The use of technology that can collect and process the available information can facilitate the goal of achieving optimal, or close to optimal resource management and allocation in such scenarios to run an efficient rescue operation. The main component of this technology is a real-time decision support system that can collect as much data as possible about the situation and the current available resources. Then use this data to quickly propose emergency actions that can be changed based on the availability of new information, resources, or the progress of the situation.

F. *Smart Grid*

A smart grid is a renovated electrical grid system that uses information and communication technology to collect and act on available data, such as information about the behaviors of suppliers and consumers, in an automated fashion to add some values [4]. It improves the efficiency, reliability, economics, and sustainability of the production and distribution of electric power. A smart grid uses computer-based remote control with two-way communication technology between power producers and consumers to increase grid efficiency and reliability through system self-monitoring and feedback. This involves placing smart sensors and meters on production, transmission, and distribution systems in addition to consumers to get granular near real-time data about the current power production, consumption, and faults. It implements dynamic pricing models for power usage to smooth out peaks by applying high charges during peak times and lower charges during other periods. This helps avoid potential power outages due to high consumer demands. It can provide consumers with near real-time information about their energy use and allow them to manage their usage based on both their needs and their affordable prices. Consumer devices such as washing machines and water heaters can be more cost-effective by controlling them automatically to operate during lower prices. Although the smart grid has many potential benefits, it requires the collection of huge amount of data from power procedures, transmissions, distributors, and consumers. In addition, it requires processing the collected data, which is considered big data, in real-time to send back some control information to improve overall the efficiency, reliability, economics, and sustainability of the whole electric power system. Important applications in smart grids such as power load forecasting, power usage analysis, grid failure detection involve large scale data and require fast processing and communication mechanisms that cannot be handled by the current commercial processing and communication platforms created for general business usage.

G. Early Warning for Natural Disasters

Early warnings of natural disasters can save the lives of thousands of people. Early warning systems involve time-critical processing of huge distributed data collected in real-time from ground sensors, underwater sensors, remote sensors such as those installed in unmanned aircraft vehicles and satellites with other data such as weather information, geographic or area maps to predict where the natural disaster will happen [6]. One example of such systems is the Indian Tsunami Early Warning System [7] which involves sensors for earthquake detection, ocean-based sensors to detect tsunamis, satellites to associate weather information, and geographic area maps to identify where the tsunami will strike. Another example is the global early warning system for wild land fire that can predict the expansion patterns of forest fires [8]. Wild land fires burn several hundred million hectares of vegetation every year. They have serious negative impact on human safety, health, and regional economies. The aim is to use the advent of technology in computing, communications, and sensor systems to build advanced solutions to limit the impact of these fires. In addition, the same technology can be used to provide some real-time predictions of flood and volcanic eruptions expansion areas. This helps in issuing early warnings for people living in the expected target areas. The warning can include information about safe areas so people will know where to go. In addition, with advanced location-based technology, it is possible to direct each individual to the closest safe area using a safe path of roads. This type of application will need to handle thousands of people at the same time and must provide accurate safety and routes information immediately. This can be achieved by having a system that is capable of dealing with big data of the flood or volcano information, road maps and current conditions, expected target areas, and the locations of the people to send thousands of customized direction messages to direct them to the identified safe areas. One simple example is how exit roads of an evacuation area can easily become congested by people trying to leave in an unorganized manner. With a real-time system monitoring movements and road conditions, it may be possible to redirect traffic by providing customized route information to individuals such that congestion areas are avoided and better traffic flow is achieved.

IV. CHALLENEGES

There are a number of challenges facing the design, implementation and operations of real-time big data applications. Most regular big data applications are implemented using an open-loop approach. In this approach big data for a specific domain is analyzed to obtain some new information and knowledge that can be used to enhance the operations or profitability of that domain. The time needed to analyze the big data and make decisions is generally very long and could significantly reduce the benefits and effectiveness of the applications. Unlike regular big data applications, real-time applications must initiate fast actions that are usually bounded by specific time frames dictated by the targeted domain. Real-time big data applications are usually implemented using a closed-loop approach in which actions are usually based on the current and previous situations. To understand the challenges of designing, implementing, and operating real-time big data applications, we need to first understand their common action steps which can significantly impact the action completion times. Action times in real-time big data applications can be divided into five steps.

A. Real-time event transfer

All current distributed application events should be transferred in real-time to where they can be processed. These events can be transferred from their distributed sources as raw events or as filtered or aggregated events. All generated current row, filtered, and aggregated events can be transferred to a centralized processing point or to distributed intermediate processing points for pre-processing or for further filtering and aggregation before being transferred to the main decision making unit. The centralized approach is good if the current generated events are not huge and there are no limitations on the network resources used to transfer these events. The distributed approach is good if there are huge events such that it is impossible to transfer all the generated events to a single location. Filtering and aggregation will become important in this case. This can be done at the event sources and the intermediate points using an open-loop or a closed-loop approach. In open-loop approach filtering and aggregation policies are pre-defined while in closed-loop approach filtering and aggregation policies are interactively defined based on the current events and decisions, current system and network resources, or external business policies. In both approaches, event filtering and aggregation should be done to reduce network traffic and processing time and without negatively affecting the accuracy and optimality of the decision making in the real-time big-data application.

B. Real-time situation discovery

This step is designed to detect in real-time business or operational situations and exceptions in the current events. For instance, a significant drop in a stock price for an important company in a financial market trading application, an unexpected huge traffic in a certain important area in an intelligent transportation application, or sudden high power consumption in a certain part of the city in a smart grid application. The detection process can be based on some business or operational rules. These rules can be predefined rules set mainly by the application developers or interactive rules defined by other modules in the real-time big data application such as analytical or decision making modules that can alter, drop, or add some business and organizational rules to change the operation of situation discovery process. These rules should be defined or organized to reduce the time needed to detect business or operational situations and exceptions. Real-time situation discovery processes can define and alter the policies used to filter and aggregate event transfer. In addition, it can activate analytical or decision making processes that we will discuss next to respond to the detected business or organizational situations.

C. Real-time analytics

This involves invocations of real-time analytical services to determine the root causes for business and operational situations and exceptions. Real-time analytical processing may involve single or multiple integrated analytical services. These real-time analytical services should predict the performance and assessment of the risks for changing the operations and business environment. It relies on real-time information passed from the situation discovery process and other offline stored big data such as maps, previous transactions, situations and decisions. Dealing with stored big data is usually challenging. However, it can be abstracted into smaller data sets such that it can significantly enhance the execution time of analytical processing. Providing abstracted information to enhance processing time can also be very challenging. Real-time analytical services need to deploy fast algorithms that provide alternative options within a bounded time. These options can be optimal or semi-optimal due to the limited time and resources available. As this part could be very processing intensive, high performance platforms are usually needed. These platforms can be equipped with special hardware to execute special algorithms or with cluster computing systems.

D. Real-time decision making

Based on the real-time analytics results it is possible to select the best option for improving the current business operations or profitability and determine the most appropriate actions for a response to the business or operational environment. Configurations of decision making can be done by defining business or operational rules that are developed by domain experts and derived from strategic decisions. These rules help to interactively and intelligently respond to evolving business and operational situations. A decision process checks for predefined business and operational rules to take specific business or operational actions based on the options provided by the real-time analytics modules. It can also notify responsible individuals or trigger other processes to conduct further actions. The most challenging part is in how to define business and operational rules that facilitate correct and timely decisions making.

E. Real-time responses

This involves initiating, executing and monitoring an action defined by the real-time decision making process. For example, a decision is taken to buy a specific stock quantity for a company, thus the real-time response process will initiate a stock buying transaction, send the transaction request, and monitor its execution. Furthermore, in wild land fires, if the real-time big data application determines a prospective fire expansion pattern, fire fighters and all relevant resources need to be informed and actions must be taken to contain the expansion area before the fire spreads too far. This process usually needs to interact with different distributed systems to perform its tasks. These interactions should be reliable and achieved in real-time.

V. Discussion

There are a number of important and critical real-time big data applications such as intelligent transportations, financial market trading and surveillance, crowd control, military decision making, large-scale emergency response, smart grids, and early warning for natural disasters. The successful design, implementation, and operations of these applications can have significant advantages and benefits in saving the lives of thousands people, enhancing the quality of life, reducing risks, and enhancing profitability. However, there are a number of technical challenges that need to be thoroughly investigated before many of these applications can be used effectively. These challenges are mainly due to the real-time requirements that dictate very special attention to fast collection, transfer and processing of big data. These applications are required to perform a number of steps in real-time. These applications need to collect current events, perform data analytics, make decisions, and respond in different time levels that are shown in Table 1. The most challenging application is financial market trading which requires very fast actions to gain any available opportunities before other financial competitors.

TABLE 1. TIME REQUIREMENTS FOR DIFFERENT REAL-TIME APPLICATIONS.

Big Data Applications	Time Requirement
Financial Market Trading and Surveillance	Milliseconds
Military Decision Making	Seconds
Intelligent Transportations	Seconds
Smart Grid	Seconds
Crowd Control	Seconds
Large-Scale Emergency Responses	Minutes
Early Warning for Natural Disasters	Minutes

The performance of real-time big data applications can be enhanced if the latencies of different steps in these applications are minimized. These include minimizing latencies of event transfers, analyses, decision making, and response execution. Scalable platforms and solutions are required for most of these steps. One of the available solutions is relying on cloud computing services [12]. Using cloud computing, computing capabilities can be quickly scaled in or out based on the users' varying demands. Cloud services follow a multi-tenant model allowing resources to be pooled and shared among users. Real-time big data can automatically benefit from Cloud services without communicating with the service providers. In addition, standard protocols can be used easily to access the computing resources over the Internet.

VI. CONCLUSION

Big data collection and analysis requires long periods of time to complete. As a result real-time applications cannot immediately benefit from big data analytics. However, many situations and applications have to deal with big data and generate results in real-time. In this paper we explored the different application domains that could benefit from big data applications operating in real time. Rescue operations, battle field tactics and decisions, financial operations and crowd control are some of these application domains. To build effective real time big data applications several challenges need to be addressed including: real time event (data) transfer; real time situation (exceptions) discovery; real time analytics; real time decision making and executing real time responses. Understanding the nature of these applications and the challenges ahead is the first step to creating more effective and efficient applications in this domain. The next step is to identify the most suitable solutions to these challenges and building real time big data applications that are reliable and capable of meeting the real time demands. The effective approaches to address these challenges will highly improve the development and use of real time big data applications, which in turn will provide numerous advantages such as saving lives, improving the quality of life, reducing risks and enhancing profitability.

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