Database Systems and Query Processing in Mobile Environment: A Survey

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Abstract: ***The mobile devices became effective seeds of information, which are thrown to world through various platforms like social networking, cloud computing, peer-to-peer communications and so on. Such information has been transformed in form of databases and further utilised to nurture the queries from other users. Databases are generally kept on the powerful and reliable workstations, so called servers and hence client-server architecture became very well-known in database field. In recent era, mobile devices are transformed in more powerful computing devices on which the various small-sized databases are stored e.g., phone-book, address-book, system settings etc. This motivates us to explore the mobile database systems and how the effective query processing is to be implemented on those systems. The main contributions of this survey include (a) the exploration of mobile applications, (b) the applicability of mobile databases and (c) the effective query processing approaches in mobile databases.***

Keywords: Database systems, Query processing, Mobile application, Mobile databases

1. Introduction

Today's world revolutionized the communication devices from the bigger telephonic medium to the tiny but powerful computing and information sharing devices. They are handy and so easily movable; hence those devices are called **mobile devices**. Furthermore, the increased usage of mobile devices causes the exponential increase in information network size, which effectively becomes a mobile environment.

Information Telecommunication Union (ITU) [13] gathers data about the mobile subscriptions registered across the globe and generates the various statistical reports, which show the proliferation of mobile devices. Based on ITU's reports, Figure 1 depicts the growth of mobile cellular subscriptions over past 12 years (2000-2011) in the developed and developing countries. In year 2000, mobile usage in the developing countries was almost half of that in the developed countries. Interestingly, by 2005, developing countries' mobile usage just crossed the developed countries' mobile usage and by 2011, this ratio became just inverse by 3 times i.e., the mobile usage in the developing countries is just thrice of the mobile usage in the developed countries. According to the telecommunication data almost 87% of population has mobile devices in today's era.

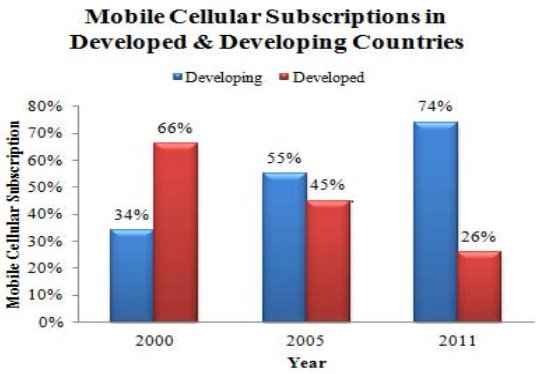

Figure 1. Mobile cellular subscriptions over the globe

Figure 2 represents the worldwide growth of mobile cellular subscriptions per 100 inhabitants. In 2001, the growth was comparable in the developed and the developing nations. This was because the cellular infrastructure was not much established in the developing nations as compared to that in the developed nations. As the communication infrastructure became wider and stronger; and the availability of mobile devices became higher, the growth in the developing nations became almost double than that in the developed nations.

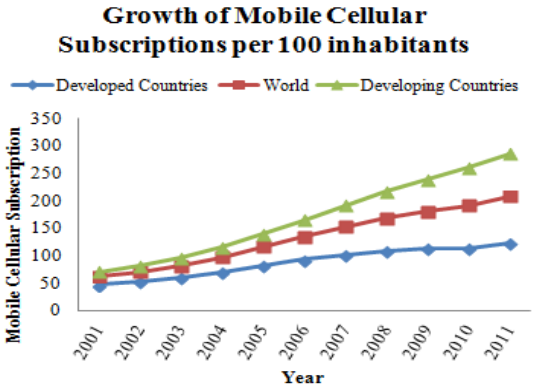

Figure 2. Growth of mobile cellular subscriptions

To explore the recent mobile usage across the society, we have carried out a small-scale survey, which shows the significant usage of mobile systems in various fields such as social networking, information sharing, entertainment etc. This survey was performed using the cross sectional method. Here, we present the related results and the analysis of those results. We have collected data of around more than 6000 mobile users through online feedback system. Figure 3 depicts the results of the percentage of mobile users based on network facilities. Observe that, the large percentage of communication is done over the short-range technology Bluetooth, as it is more cost-effective and handy to use. Interestingly, the result also demonstrates that recently the mobile users are more relied on 3G network communications over GPRS due to their faster and more reliable connectivity.

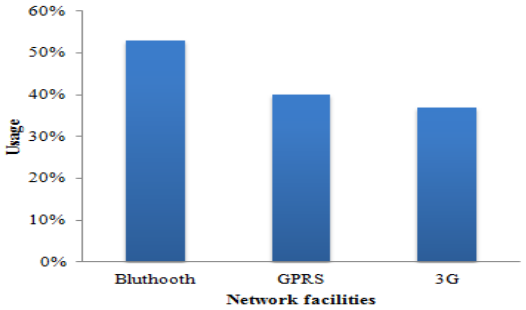

Figure 3. Usage of different facilities in mobile devices

Figure 4 presents the application-based mobile usage over three different priorities i.e., low, medium and high of the mobile users. Here, priority is based on the user's preference of applications. For example, the percentage of mobile users, who has high priority to E-mail system, is 22%, while the percentage of mobile users with low priority to E-mail system is 48%. The results show that mobile users have high priority for the applications related to audio-video and web-access compared to others. While low-priority applications include those applications, which rely on GPS like technology due to its more power consumption.

Moreover, increasing proliferation of mobile devices is there because of increase in availability of various facilities in recent mobile devices. Such provisioning on tiny device facilitates the ease of data transfer, effective gathering of geographical information (on the move), improving reliability of data through uploading and downloading on remote server, exchange of various types of data like text, image, audio, video.

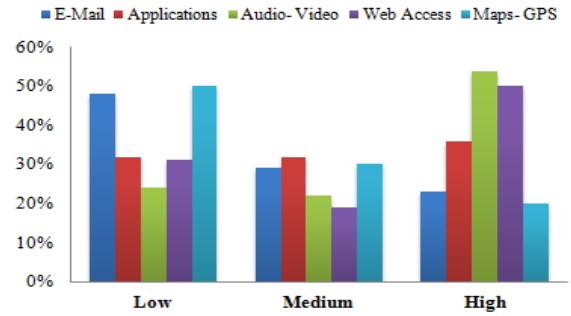

Figure 4. Priorities of various applications available in mobile devices

The remainder of this paper is organized as follows. Section 2 presents the various application scenarios related to mobile environment. Section 3 discusses the existing mobile database systems, while Section 4 explains the existing query processing approaches for mobile databases. Finally, we have concluded the mobile database survey in Section 5.

1. Mobile Applications

This section motivates the mobile computing by means of exploring several areas where the mobile devices become handy computing tools for effective analysis and rapid sharing of the information *on-the-go*. Here, we have focused on mobile applications related to e-commerce, data dissemination, medical healthcare, public services, geographic systems etc.

1.1. Mobile e-commerce

Electronic commerce (E-commerce) is the field of sales and procurements of supplies and services using information systems. It incorporates three-step execution in the real-world application scenarios as follows: (i) advertisement through uploading of marketing information on the web (ii) sell through taking orders online (ii) payment through construction of electronic exchanges. E-commerce examples include online shopping/retailing, electronic transactions through e-cheque and e-wallet, online reservation system (for air and railway).

In a similar vein, mobile e-commerce is the notion of e-commerce in mobile environment, where the access mechanism is via a wireless phone or terminal rather than the fixed telephone network. The work in [20] presents the mobile e-commerce establishment and its applications. They use mobile peer-to-peer (M-P2P) based information propagation of merchant's sale and inventory. This facilitates a customer to locate a desired product wherever he/she requires e.g., at the entry of the mall through customer's cell phone, which is Mobile-P2P enabled device. This also motivates merchants to provide inventory/sale/coupon's information electronically to its nearby potential customers with the help of mobile databases.

1.2. Data Dissemination:

Data dissemination is a passive mode of communication in which the usage rate of information is much higher than the rate of information production [28]. In other words, it is an asymmetric communication, where downloading rate is much higher than uploading rate. Data dissemination related applications become very crucial due to the rapid growth of information generation and their distribution over communities. The recent social networking-based applications became a vital platform for the data dissemination. For managing multi-flavoured information and retrieving the specific information in real time in mobile environment, we need to have some semantics to be associated with the every piece of information.

The works on semantics-based information management on resource-constrained mobile environment have been proposed in [25]-[29]-[7]. The work in [7] proposed OntoWiki framework, which is the novel approach for semantics-based information management through mobile semantic collaboration. OntoWiki allows users to browse data in offline mode. This enables users to retrieve information even though they are in no network area such as forest, villages etc. Such platform is very handy to collect semantically rich information like biodiversity expeditions to remote areas, where network connectivity is very low and discontinued or sometime totally unavailable.

1.3. Medical Healthcare:

The healthcare environment comes with major constraints and requirements such as confidentiality of the medical data, privacy of the doctor-patient relationship, genuineness of the source of information which is to be diagnostics and so on. Such vital issues must be satisfied by the mobile environment [1] in order to deploy the mobile applications for medical healthcare systems. Recently, the mobile applications related to biomedical information become more attractive to the medical users as the small screen devices such as PDAs and smart-phones permits the healthcare practitioners to access online biomedical resources whenever and wherever they need. In the similar vein, the other recent application proposals on mobile devices have been explored in [1]-[22].

Interestingly, some applications are hard to deploy on tiny mobile devices due to their resource constraints such as small screen size, which restricts the variety of information to be displayed on the same screen at a time.

To overcome this barrier, the system called multi-modal transcoder has been proposed in [22]. It does transcoding of the full-text information of the biomedical resources in various compatible formats to support heterogeneous mobile devices. Furthermore, it also proposed a novel algorithm based on visual template matching and piglet detection process to understand the structure of biomedical resources. In this work, the usability study showed that the system's usability is improved by the simplification and summarization technique as well as to deliver the compressed information to the mobile user.

Moreover, the usage of wireless technologies play significant role in telemedicine, which is also known as 'mobile health'. The work proposed in [33] shows that the telemedicine is used to calculate, to communicate and to deliver high quality medical care apart from location. The work also carried out the survey on wireless telemedicine based applications and their related research issues.

1.4. Public Services:

The social interactions become more easy and effective due to mobile environment as per recent survey of mobile subscriptions shown in Figure 2. This enables many public services such as transportation, weather, m-commerce and healthcare to be deployed on mobile environment. For example, the mobile devices are capable to facilitate the transportation related services as follows: (a) real-time navigation or location-based search through GPS (b) information provisioning related to current traffic situation such as congestion or accident through message exchange (c) suggesting alternate pathways through *M-P2P interaction*. The works in [10]-[9] provides the wide probabilities to deploy the mobile services for the users.

The mobile passenger guide [10] is used to help the passengers to purchase electronic tickets using mobile terminals as well as to guide the passengers via short messages. It incorporates a personal database, which acts as an electronic ticket as per the user's requirements. Similarly, the work related to the passenger support system is also been proposed in [9]. In this work, the system allows user to make their travel plans and purchase necessary tickets by accessing the booking system via mobile computing devices. This facilitates the public transport to be used more effectively due to easiness and quick access of travelling information to the end-users. Moreover, it proposed multi-channel data communication mechanism to support passengers. In addition to this, they also showed the successful implementation and testing the proposed system on railway stations for visually handicapped passengers.

Furthermore, mobile databases enable travellers to cooperate intelligently and automatically which improves safety and mobility [20]. When vehicle encounters an accident, congestion or dangerous road surface, the system is able to sent “slow speed message” to trailing vehicles, which helps other drivers to make decisions like finding alternative roads and also pile-ups in some situations. Moreover, the mobile-P2P based ride-sharing application has potential to alleviate problems related to transportation system such as environmental pollution, fuel consumption, risk of public safety and congestion. Such M-P2P applications require matchmaking and provision of information that is simultaneously relevant in time, location and interest. In a similar vein, incorporating mobile P2P databases in navigational devices facilitate disseminating information about relevant resources, like ride-sharing partners, free parking slots and available taxicabs.

2. Mobile Databases

Mobile database system is defined as a distributed database system, where the database may be placed or scattered across the mobile hosts i.e., capable to communicate via short-range technologies such as Wi-Fi or Bluetooth [15]. Due to proliferation, preferential and propagation of mobile marketing, information flow need to be managed and directed intelligently, so to support applications for effective data management.

In mobile environment, data is distributed across the network majorly in the form of pushing (data dissemination) and pulling (data hosting) techniques. Few of the possible techniques based on push/pull mechanism have been surveyed in [2]. This includes data dissemination over limited bandwidth channels, location-dependent data querying and advanced interfaces for mobile computers. Moreover, these approaches have few issues to be addressed such as how to store information on database, how to effectively and optimally design database for mobile network, low bandwidth in network; and frequent network partitioning caused by mobility and energy constrained of peers. The works in [3]-[31]-[27] show the several approaches to address these research issues in mobile networks.

Furthermore, the work in [18] presents the new execution scheme and concurrency control mechanisms to take full advantage of mobile databases, where the transaction management deals with number of their related constraints. Similarly, in mobile environment, each mobile host has limited local storage capacity, their mobility constraints to distribute the copy of datasets among mobile hosts, decentralized causes hard to locate and access data.

Moreover, [18] reports study on multi-versions transaction processing approach and deadlock-free concurrency control mechanism based on multi-version two-phase locking scheme integrated with timestamps approach. They also performed the comparison of schemes using reference model by observing the behaviour of the proposed model with simulation study in a mobile environment. The outcome of the experiments shows that this model reduces the response time and minimizes the restarts and aborts. Thus, it improves the degree of concurrency and provides significantly higher throughput. It is also proposed an approach in [3] to effectively utilize limited mobile storage to store mobile databases using data compression technique, known as Database Summarization.

In mobile environment, one of the notable constraints is low-bandwidth, which is responsible for slow data access. To resolve this issue, [31] proposes Cedar, which effectively manages the weak connectivity by using disk storage and processing power of mobile client. It follows the central organization principal. This approach considers the old copy of a client and the commonality between client and server results. These are helpful to reduce the data volume to be transferred from the database server, hence the communication between client and server becomes more faster while minimizing bandwidth requirement.

In a similar vein, [27] proposes an object oriented model to manage mobile database system more effectively. They also addressed the issues related to mobile application development and deployment on a mobile database system by considering GSN based mobile network, which provide data services to allow the accessibility of database server through tiny devices such as portable devices, mobile phones etc. The system also improves the performance due to the access of light weight objects, which are more adoptable by tiny and limited resource-based mobile devices.

One more issue is raised related to the stability of the mobile agents in mobile network due to peers' movement. The free nature of mobile networks, where peers can join and leave the network anytime, provides flexible data hosting as well as improves data availability into the network by replicating useful data across the network. Hence, as mobile agents are roaming into the network, they may provide better services at the door-step of the mobile users. Additionally, to resolve the issues related to transaction management such as energy consumption, node mobility etc., [11] proposed the strategy to balance the energy consumption on mobile hosts and to reduce the number of failed transactions due to deadline missing.

Moreover, [32] focuses on location-based service oriented mechanisms, in which the characteristics of the information sources have been utilized to do dynamic data management more effectively. They proposed a set of dynamic data management strategies, which reduce the service cost and improve the response time in continuously changing user mobility and data access patterns. To provide easy and fast data access to the user anytime/ anywhere in Mobile-Ad-hoc Network (MANET), there is a requirement of processing mobile transactions optimally. Also an issue of concurrency control is crucial in mobile database system, as transactions may be inconsistence due to node mobility. A proposed concurrency control algorithm in [34], called Sequential Order with Dynamic Adjustment (SODA), is based on optimistic concurrency control strategy in mobile environment. To reduce the aborts, the SODA can utilize and adjust the sequential order of committed transactions to improve response time. SODA provides major performance improvement by reducing abort rate.

3. Query Processing

Queries offer the content-based information access to discover the various information and services across a network or in the database. User obtains its desired information by sending the relevant query to the database, which is being processed by the database engine and send a query result to the user. Here, the query is possibly to be optimized to perform fast query response and to obtain query result more efficiently. In general, query processing involves the following steps: (a) interpretation and transformation of the global query (b) use of local cache and (c) transformation to location specific queries. Query optimization is intended to improve the efficiency of query evaluation procedures as described in [14].

3.1. Decentralized

The join-based query processing cannot be directly applied to the mobile environment due to its asymmetric features [16]. Hence, the usage of semi joins may help to reduce both the amount of data transmission and energy consumption. By considering the asymmetric features of mobile environment such as computer compatibility, energy consumption in context of message communication, [23] introduces the query processing methods based on semi-joins. Moreover, Multi-point queries can be processed by considering clustering of data and objects, which have been proposed in [6], so that mobile hosts are able to access data in short latency.

In distributed environment, the shared data must be transferred to the mobile hosts in synchronized fashion, which can be achieved by following the scheduling. To allocate the shared data to the moving users in mobile environment, [24] represents the effective data allocation algorithm. The purpose of this approach is to minimize the occurrences of costly remote accesses and to improve the performance. To achieve local and global optimization, two algorithms, namely SD-Local and SD-Global are proposed for infrequent and frequent users respectively.

The work in [4] introduces trajectory-based search algorithm and a new measurement spatio-temporal distance (STDist). Here, STDist is computed as a spatio-temporal difference between two trajectories of moving objects on road network. The algorithm considers both spatial and temporal properties of a moving object w.r.t. motion of the query trajectory.

Furthermore, majority of the dynamic query optimization methods proposed in literature are centralized, which are not applicable to the (generally large-scale) distributed environment. One way to handle the dynamic query optimization in distributed environment is a mobile relational algebraic control over query processing [19]. The result shows that the proposed approach is more effective due to proactive migration policy, which is also applicable to mobile environment on small or large-scale systems.

3.2. Location-based

Due to the mobility, a key factor in mobile environment, location-based queries become more prominent in mobile networks. Moving peers are looking for the information on-the-go, which are located to their current location or may be located at remote places. Hence, mobile environment needs more dynamic query processing mechanisms to achieve such fully dynamic and location-based query processing. Thus, the Location-Dependent Applications (LDA) and Location-Dependent Queries (LDQs) are become more interested areas to the researchers [12]. In the applications such as advertising, safety & security, tourism, traffic management, a position data plays a central role. Moreover, hierarchical database structure [17], which is a tree like structure, manages the location information of mobile users in location database. This tree structure is static and disables to settle with the changes of mobility patterns of mobile users.

When query deal with semantic similarity and spatial locality, the concept of the provision of caching is competent for effective query processing. In general, to process the result of LDQ the existing caching schemes require the database (DB) servers to provide validity regions (VR). However, the work in [8] proposed a novel LDQ proxy-based caching scheme, which does not require the DB for estimating the VR due to proxy mechanism. Also, the result shows the reduction in LDQ response time and database workload.
The work in [21] presents a novel approach to the top-*k* query processing in Mobile Peer-to-Peer (M-P2P) environment. Here, they considered that the queries are spatio-temporal in nature, which are being broadcasted by the query-issuing peer in order of obtaining the top-*k* information from the *nearby* mobile peers, who contribute to the query. This shows that how the top-*k* query processing can be effectively utilized to search location-based information in mobile environment.

Moreover, location-based services enable the usage of GPS or Wi-Fi to locate a device, which are more energy consumed, while energy is a major constrained in mobile devices. Hence, the location-aware computing consumes more power on tiny devices, so to need of effective query processing to have minimized location information retrieval. In location aware system, the mobile user continuously gets the messages related to the updates of locations which utilize the power most. To solve this problem, [30] proposes a state-based mobility model (SMM) and state-based location update protocol (SLUP). The experiment of this model shows that these methods improve the energy efficiency by 2-3 times with the additional 10% cost.

Furthermore, the broadcasting method is more common and easy to reach every peer in mobile environment, but at the cost of higher communication overhead. One way to reduce communication in broadcasting, by constructing effective broadcast schedule, in which the data in nearby grids are linearly clustered [35]. The focus of this approach is to minimize the energy expenditure of Mobile Host (MH). The performance evaluation shows better results of each clustering method by measuring the average setup time of MHs. Another application for querying the trajectories data, consist of sequence of connected line segments for each moving object, is proposed in [26], which is capable of exploiting any infrastructure constraint.

More recently, location-based services (LBS) has obtained major focus from the mobile application developers because of the ubiquity of mobile devices with global positioning functionality with WWW. The examples include local business search, e-marketing, social networking and automotive traffic monitoring.

Interestingly, LBS have obtained major focus from the mobile application developers because of the ubiquity of mobile devices with global positioning functionality with WWW. The examples include local business search, e-

marketing, social networking and automotive traffic monitoring. There are two types of LBS, namely snapshot LBS and continuous LBS. Snapshot LBS requires to obtain location information on a particular event, while continuous LBS needs location information in a periodic manner. It is difficult to maintain security of data in continuous LBS because advertisement information may use the spatial and temporal correlations in the user's samples to assume user's location. For many applications like business analysis, city planning and intelligent transportation, these types of user trajectories are important. Notably, in a continuous LBS, privacy protection and data publication are more important as compared to a snapshot LBS.

The literature of [5] provides a survey of an overview of the state-of-the-art privacy-preserving techniques in snapshot LBS and continuous LBS.

The [36]contains the work related to scheduling methods of location-dependent queries, in which the data objects are stationary (fixed) and clients are moving objects (mobile) that issue the queries. To get better data reusability, there is a need for indexing, which has been a proposed in [36] using Voronoi diagram. While, to get better performance, [36] offers three scheduling methods called priority method, intelligent method and hybrid method for the handoff clients, along with the study of the methods by means of simulation and performance evaluation.

4. Conclusion:

This survey presents the motivation of mobile databases through exploring wide variety of mobile applications, which incorporate the multi-angle usage of mobile databases to facilitate easy and handy access to the static and dynamic information (based on mobility). It also discussed the various possibilities of mobile databases with existing platforms, which enable mobile applications to be more effective and reliable. Finally, the survey also explores the effective query processing approaches in mobile databases.

In future, we will discuss the important research issues in more detail related to mobile databases.

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