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Energy-efficient algorithms for data retrieval from indexed parallel broadcast channels

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ABSTRACT

Constraints on the energy, bandwidth, and connectivity of mobile devices and wireless communication medium complicate the timely and reliable access to public data. Energy is often the most stringent constraint, necessitating techniques that facilitate operation in energy-saving modes. Broadcasting, typically over parallel channels, has proven to be an effective method for dissemination of public data to mobile devices. However, the employment of parallel channels introduces challenges associated with channel switching and conflicts due to concurrent accesses to multiple data items that ultimately increase energy consumption and response time. The detrimental effects on energy consumption and response time can be alleviated by scheduling the retrieval of data items in an order that reduces the number of passes over the air channels and channel switching between the parallel channels.

In this paper, several scheduling algorithms are proposed and analyzed that achieve the aforementioned objectives. To further improve energy consumption and response time, the scope of our scheduling algorithms has been enhanced by replication of popular data items. The proposed scheduling algorithms, both with and without replication, have been simulated, and simulation results are presented and analyzed. These results show that the proposed scheduling algorithms, compared to some heuristic based methods, have greater impact in reducing energy consumption and response time. This reduction is shown to be more pronounced with replication of data items.

1. Introduction

The advent of *mobility*, in which a user accesses data and services through a wireless medium with limited resources, has introduced additional complexity to traditional approaches in database systems. In current practice, regardless of the underlying computational model, hardware devices, and connection media, data sources can be classified as follows:

- Private data, e.g., personal daily schedules and phone numbers. The reader of this type of data is mainly the sole owner/user of the data.
- Public data, e.g., news, weather information, traffic information, and flight information. This type of data is maintained by one source, and shared by many. Consequently, a user mainly queries the information source(s).
- Shared data, e.g., traditional replicated and/or fragmented databases. A processing node may actually contribute to maintaining consistency of and participate in distributed decision making with this type of data – a user usually sends transactions as well as queries to the information source(s).

The increasing ubiquity of mobile devices, such as smart phones, and proliferation of global positioning systems have brought the vision of ubiquitous and anytime, anywhere access to public data closer to reality. Broadcasting has been proposed as an efficient method to disseminate data to a large number of users [1]. Broadcasting is invaluable during and after catastrophic events, as it can guide evacuation, search, and rescue efforts. Broadcasting can be used to disseminate location information and schedule updates in venues such as airports, large shopping malls, or amusement parks. Live video streaming that has gained popularity can take advantage of data broadcasting. Travel and traffic information (TTI) systems, whether based on decentralized inter-vehicle communication over radio [14], or centralized digital radio systems [7], also can take

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advantage of broadcasting. It is anticipated that future evolutions of ground transportation system will ultimately end up being a cyber-physical system (CPS). In such an environment, broadcasting of traffic information and traffic pattern to either manned or unmanned vehicles can play a significant role to increase safety and reduce travel cost.

Services similar to Microsoft Network (MSN) direct which used FM radio to deliver location-based services to navigation systems are other prime examples of applications where broadcasting would be the most efficient means of dissemination of data. The information available through MSN direct in large urban areas in North America included traffic reports, gas prices, weather reports, stock quotes, and event schedules [13].

Hybrid communication platforms that use both the cellular infrastructure and wireless radio facilitate a wide range of broadcasting-based services [7]. The extension of MSN Direct to the Windows Mobile Platform is an example. The same concept could be applied to wireless sensor networks, both in fixed installations and in rapid deployments following events such as wildfires.

The aforementioned applications are dissemination-oriented, and their data access and data flow characteristics differ considerably from those of traditional client-server database applications. Asymmetry of communication (as the majority of the traffic is retrieval of data items by the mobile devices (downlink), and the uplink carries minimal (or sometimes no) data [1]) and significant overlap of requests (e.g., live video stream) are distinct characteristics of broadcast based applications. Mobile data devices such as portable navigation systems or other handheld devices with wireless communication capability are typically switched on by the user sporadically, as needed for retrieval of information, and then powered off, precluding the use of intelligent caching strategies for efficient data retrieval [2].

Advances in the development of temporary energy sources have not kept pace with the increasing ubiquity of handheld mobile devices, and as such, the energy efficiency of data retrieval by mobile devices is likely to remain a concern for the foreseeable future. To manage energy consumption, one needs to develop energy-efficient protocols that run hardware devices in different operational modes [6,8–10]. The literature has suggested indexing techniques and broadcasting over parallel channels as means to reduce the active time of mobile devices and the broadcast length – hence reducing the *energy consumption* and the *response time*. However, *access conflicts* and *channel switches* are natural by-products of broadcasting over parallel channels [8]. Access conflicts (see Section 2.4) force additional passes over the parallel channels, which in turn increase the response time and energy consumption. Moreover, channel switching incurs additional energy consumption at the mobile device. As a result, in the presence of conflicts, one must develop energy efficient protocols for prudent scheduling of accesses to the requested data items in an attempt to reduce the number of broadcast passes and channel switches.

Within the scope of indexed parallel broadcast channels, heuristic rules were employed to schedule access to the data items such that both the number of passes and the frequency of channel switching were reduced [8]. Simulation results have proven the effectiveness of these approaches. However, as expected, these heuristic-based algorithms do not necessarily generate reduced response time and energy consumption in all cases.

Replication can be employed to increase the availability of popular data items on parallel broadcast channels. This technique has both advantages and disadvantages; replication should offer reduced response time and energy consumption if the replicated data items are requested, however, it increases the broadcast length, and hence the response time and energy consumption, for non-replicated data items.

This work extends the scope of our earlier investigation [8,10]. It proposes and evaluates several scheduling algorithms that generate access patterns that reduce response time and energy consumption of data retrieval from indexed parallel broadcast channels. The proposed scheduling algorithms have been further simulated and studied for their energy consumption and execution time. Finally, data replication is employed, and its effect on energy consumption and response time is studied.

This article is organized as follows. Section 2 provides background information, discusses related studies, and formulates the problem. The proposed scheduling algorithms for data retrieval are articulated in Sections 3 and 4 report on our efforts to employ replication. The simulation results of the proposed algorithms are presented and analyzed in Section 5. In Section 6, the conclusions are drawn, and future research directions are addressed. Finally, for the sake of completion and in light of space limitation, running examples of the proposed algorithms have been presented in the Appendix.

2. Background and related work

2.1. Wireless computing

The wireless computing architecture consists of both mobile and fixed devices. The network servers communicate with mobile devices through mobile support stations (MSSs), as depicted in Fig. 1. In this environment, one could recognize three types of services:

- Interactive/on-demand service: In this case, clients obtain answers to requests through a dialog (two-way communication) with the database server(s): the user request on the uplink channel is pushed to the server(s), data sources are accessed, query operations are performed, partial results are collected and integrated, and the generated information is communicated back to the user – the channels are bi-directional and asymmetric. Issues related to on-demand services are beyond the scope of this work; the interested reader is referred to [4].
- Broadcast-based service: Many applications are directed toward public information characterized by (i) the multitude of users and (ii) the similarity and simplicity of the requests made. In such applications, information is generated and periodically provided to all users on the wireless channels. Mobile users are capable of searching the wireless channels and pulling their required data – the channels are unidirectional from servers to mobile devices. In the architecture of Fig. 1, each MSS can broadcast to mobile devices within its communication range. This broadcast could take place over the cellular phone infrastructure, or through wireless radio.
- Pervasive service: In on-demand and broadcast-based services, the user initiates the process. In pervasive service, computers work in the background, intelligently and autonomously gathering the potential information and services, and making them available to the user.

2.2. Data broadcasting

The main advantage of broadcasting is the fact that it scales up as the number of users increases, eliminating the need to multiplex bandwidth among users accessing the wireless channel. Furthermore, broadcasting can be considered as additional storage available over the air for the mobile devices. This is an attractive solution, due to the limited storage capability of a typical mobile device. Data on a broadcast channel is read-only and must be accessed sequentially. Data can be broadcast either on a single