J. Parallel Distrib. Comput. 74 (2014) 3128–3140

Contents lists available at ScienceDirect

J. Parallel Distrib. Comput.

journal homepage: www.elsevier.com/locate/jpdc

Peer-to-peer bichromatic reverse nearest neighbours in mobile ad-hoc networks

Thao P. Nghiem [a,*], Kiki Maulana [a], Kinh Nguyen [b], David Green [a], Agustinus Borgy Waluyo [a], David Taniar [a]

[a] *Faculty of Information Technology, Monash University, Melbourne, Australia*

[b] *Faculty of Science, Technology and Engineering, La Trobe University, Melbourne, Australia*

HIGHLIGHTS

- Introducing a new direction in mobile P2P query processing for RNN queries.
- Proposing and evaluating three different search algorithms: BFA, RBA and TBA.
- Substantially saving more time and energy compared with the centralised system.
- TBA outperforms by filtering unnecessary peers and maintaining high accuracy rate.

ARTICLE INFO

Article history:
Received 7 September 2013
Received in revised form
19 April 2014
Accepted 29 July 2014
Available online 12 August 2014

Keywords:
Reverse nearest neighbours
P2P spatial queries
Mobile database
Mobile ad-hoc networks
Collaborative caching

ABSTRACT

The increasing use of mobile communications has raised many issues of decision support and resource allocation. A crucial problem is how to solve queries of Reverse Nearest Neighbour (RNN). An RNN query returns all objects that consider the query object as their nearest neighbour. Existing methods mostly rely on a centralised base station. However, mobile P2P systems offer many benefits, including self-organisation, fault-tolerance and load-balancing. In this study, we propose and evaluate 3 distinct P2P algorithms focusing on bichromatic RNN queries, in which mobile query peers and static objects of interest are of two different categories, based on a time-out mechanism and a boundary polygon around the mobile query peers. The Brute-Force Search Algorithm provides a naive approach to exploit shared information among peers whereas two other Boundary Search Algorithms filter a number of peers involved in query processing. The algorithms are evaluated in the MiXiM simulation framework with both real and synthetic datasets. The results show the practical feasibility of the P2P approach for solving bichromatic RNN queries for mobile networks.

1. Introduction

The growing importance of mobile communication systems has highlighted the need for solutions to many problems of geographic searching. One of these needs is the problem of Reverse Nearest Neighbour (RNN), in which a query returns all objects that consider the query object as their nearest neighbour. Reverse Nearest Neighbour (RNN) queries were first introduced in 2000 by Korn and Muthukrishnan [14]. They have since attracted a growing number of studies in a wide range of applications, such as decision support systems, mobile navigation systems and resource allocation. The problem is raised from the objects' point of view. Instead of finding the nearest objects from the query point q, it asks which objects consider q as their nearest neighbour.

There are two types of RNNs. Firstly *monochromatic* RNN (MRNN), in which query objects and objects of interest are of the same category. A typical example of MRNN is that in mixed reality games such as BotFighter, players need to shoot only other players who are the closest to them. Therefore, the strategy is finding her own reverse nearest neighbours to avoid their shootings. Secondly, *bichromatic* RNN (BRNN), in which they are of different categories. Specifically, in MRNN, we have all objects are of the same type and the answer of a MRNN from a query object $q \in 0$ is $MRNN(q) = \{o_i \in O | \forall o_j \in O, dis_E(q, o_i) \leq dis_E(o_j, o_i)\}$, where $dis_E(,)$ is the Euclidean distance function. The problem becomes more challenging in BRNN since there are two distinct types of objects: P and O in the network as illustrated in Fig. 1. The return of BRNN

* Corresponding author.
E-mail address: phuong.thao.nghiem@monash.edu (T.P. Nghiem).

http://dx.doi.org/10.1016/j.jpdc.2014.07.007

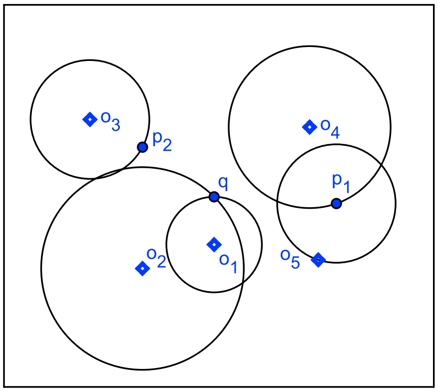


Fig. 1. Bichromatic Reverse Nearest Neighbours. o_1, o_2 are the RNNs of query node q because q is the nearest neighbour of o_1 and o_2. Similarly, o_4 and o_5 are the RNNs of p_1; and o_3 is the RNNs of p_2.

are objects in O that consider the query object in P as the nearest neighbour. Formally, for a query node $q \in P$, $BRNN(q) = \{o_i \in O | \forall p_j \in P, dis_E(q, o_i) \leq dis_E(p_j, o_i)\}$. For instance, in everyday applications, police patrols can communicate with each other to distribute their team members to locations that needs them most, for example, sites of car accidents or intersections congested with traffic. In disaster management, to reduce redundancy, optimise human resources and maximise the support, a rescuer would rather save a victim who considers him as the closest support.

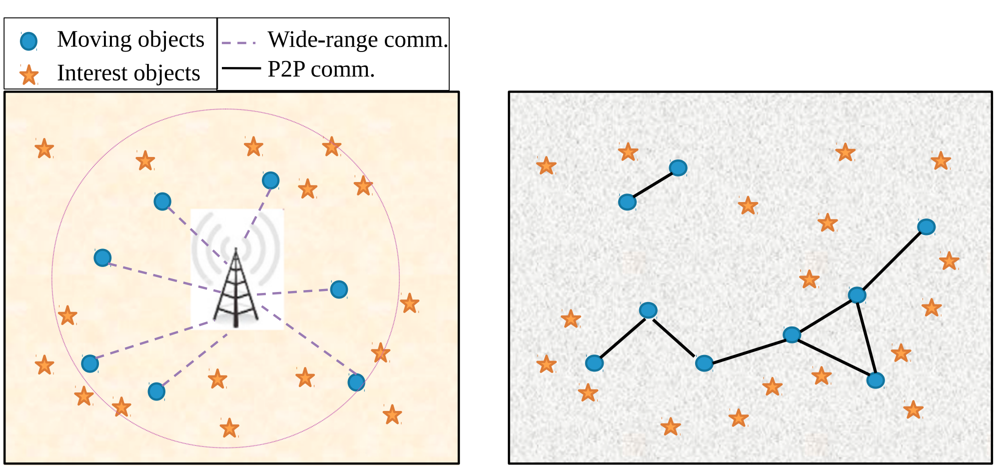
In the literature, there is a wide variety of research on RNN queries; however, their query processing is based on a centralised base station (BS) as in Fig. 2(a) [30]. Scalability, bottlenecks and low fault-tolerance are critical issues of those centralised approaches, especially in large-scale systems. In particular, centralised systems contain only a central point of failure, which is likely to be corrupt in several scenarios. For example, in a natural disaster, the headquarters is vulnerable to unavailability or traffic congestion [22].

In response to the limitations of centralised query processing systems and the advance of mobile technologies, the emergence of mobile peer-to-peer (P2P) query processing systems is a promising solution. A typical mobile P2P network consists of a collection of moving objects (Fig. 2(b)) that are equipped with a Global Positioning System (GPS) and able to communicate with each other in a P2P manner to share common interests via short-range wireless technology standards such as IEEE 802.11, Bluetooth, or Ultra Wide Band(UWB), etc. [19,29,35]. When a moving object q invokes an RNN query, it sends a query message to surrounding peers which are in its communication range instead of performing wide-range communication to the BS. In order to reply to the query from q, neighbour peers return their cached data, for example, their k nearest neighbours (kNNs) retrieved two minutes ago. Using data received from its peers about objects of interest, q makes a selection to answer its RNN queries.

While most recent research has proposed index structure or query processing algorithms in centralised database systems [2,12,17,26,32,33], there are very few studies based on P2P approaches. A distributed multi-dimensional index structure, called P2PRdNN, was introduced in [3] to solve RNN queries. However, this research focused only on static MRNN queries and it was based on super-peer-based overlay. In addition, the work in [5,7,22] proposed a framework to find answers for spatial queries in mobile P2P environments, but it dealt only with range and kNN queries, respectively. A peer-tree was also presented in [6] to work with nearest neighbour queries, but in sensor networks. Speaking from our best knowledge, there is no previous work in the context of P2P-bichromatic RNNs (P2P-BRNNs) for Mobile Ad-hoc Networks even though there are many potential practical applications in this context with high rate of location update and under no central supervision.

Therefore, we have developed three distinct P2P algorithms focusing on bichromatic RNN queries based on a boundary polygon around a mobile query object. The Brute-Force Search Algorithm (BFA) [21] makes use of available information from the peers while two Boundary Search Algorithms reduce the number of queried peers. Tight Boundary Search Algorithm (TBA) is an enhancement of Regular Boundary Search Algorithm (RBA) [21] in which a significant number of peers are filtered in processing an RNN query. Specifically, we make the following overall contributions:

1. We introduce a new direction in mobile P2P query processing in solving bichromatic RNN queries.
2. We propose and evaluate three different algorithms to search cached spatial data of objects of interest from mobile peers.
3. From our experimental study involving a real-dataset, we found that our proposed system is substantially more efficient in saving time and energy compared with the centralised system.
4. Our simulation of three proposed algorithms also shows that the accuracy rate of BFA is higher than that in RBA in most scenarios. Vice versa, the RBA reduces query response time as a number of queried peers are pruned. Nevertheless, TBA is the optimal algorithm as it outperforms in saving processing and communication cost by filtering unnecessary peers and maintain high accuracy rate.



(a) Centralised Systems. (b) P2P Systems.

Fig. 2. Centralised Systems versus P2P Systems. Circles represent moving objects; stars: objects of interest; dashed lines: wide-range communication; continuous lines: P2P communication; dots: the Base station network range.