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Ad Hoc Networks 6 (2008) 1168–1181
Ad Hoc Networks
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On search sets of expanding ring search in wireless networks ☆

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Received 13 December 2006; received in revised form 17 October 2007; accepted 9 November 2007
Available online 19 November 2007

Abstract

We focus on the problem of finding the best search set for expanding ring search (ERS) in wireless networks. ERS is widely used to locate randomly selected destinations or information in wireless networks such as wireless sensor networks. In ERS, controlled flooding is employed to search for the destinations in a region limited by a time-to-live (TTL) before the searched region is expanded. The performance of such ERS schemes depends largely on the search set, the set of TTL values that are used sequentially to search for one destination. Using a cost function of searched area size, we identify, through analysis and numerical calculations, the optimum search set for the scenarios where the source is at the center of a circular region and the destination is randomly chosen within the entire network. When the location of the source node and the destination node are both randomly distributed, we provide an almost-optimal search set. This search set guarantees the search cost to be at most 1% higher than the minimum search cost, when the network radius is relatively large.

Keywords: Flooding; Expanding ring search; Wireless networks; Search cost; Optimum

1. Introduction

In wireless communication networks such as wireless ad hoc networks [7] and wireless sensor networks [1], network nodes may need to inquire destinations that are unknown to themselves thus far. Since such an inquiry may take place before a routing path is found, routing information is usually unavailable in the context. One way to send the inquiry packet is to use the flooding technique, in which the packet is broadcasted and each neighboring node forwards the packet once. The process continues until every node in the network has forwarded the packet once. Such a flooding scheme is usually termed as pure flooding. Pure flooding is rather expensive since it involves all nodes in the network. In fact, a "broadcast storm" problem [12] may appear when inappropriate rebroadcasts are performed and when packet collisions occur frequently, requiring more rebroadcasts. These collisions degrade the overall network performance

☆ A preliminary version of this work was presented in ITC-19, Beijing, PR China, September 2005.

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doi:10.1016/j.adhoc.2007.11.003

and should be avoided. Advanced techniques have been developed to reduce the number of redundant rebroadcasts while maintaining the reachability of the flooding process [12].

Since the destination may reside in an area that is relatively close to the source node, an expanding ring search (ERS) technique is employed in a number of networking protocols, such as routing [9,13] and information query [10]. In the ERS scheme, the query packet is broadcasted with a time-to-live (TTL) value. When the packet is received by other nodes, the TTL value on the packet is decremented. Then the packet will be rebroadcasted only if the TTL value is positive. The exact implementations of the ERS scheme vary in different protocols. For instance, in some ERS techniques, the initial TTL value is set to 1 for the first (ring) search. If such a search fails to find the destination, a new search is initiated with an incremented TTL value 2. The process continues until the initial TTL value reaches a threshold, L. Then a network-wide flooding is initiated [8]. The ERS scheme in dynamic source routing (DSR) [9] uses the California split rule [2], where the TTL value is doubled every time when the previous TTL value fails. In ad hoc on-demand distance vector (AODV) routing [13], an ERS scheme is implemented to start with a TTL value of TTL_START and to increase the TTL by TTL_INCREMENT after each failure.

Recently, several research papers have been published with the focus of analyzing search strategies such as the ERS schemes under various network settings [5,3,8]. It has been shown that the ERS schemes that increment the TTL value by one after each failure are generally ineffective. Therefore, it is interesting to identify the best search strategy, in terms of which set of TTLs should be used, for ERS. In this work, we analyze the cost of different search sets in the ERS technique and investigate the optimum search sets. We develop a general analytical framework to measure the search cost of different search sets in the ERS schemes. Based on this framework, we study wireless networks from which a destination is randomly chosen. When the source is at the origin of the circular network region, we identify the optimum search sets. When the source is randomly chosen from the network region, we provide an almost-optimal search set, which guarantees the search cost to be at most 1% higher than the minimum search cost when the network radius is relatively large.

Similarly to other researchers [5,3,4], we neglect the effect of underlying medium access control (MAC) schemes and broadcast collisions in our analysis. Our focus in this work is on first-order effect of different search sets. We do not consider second-order effects such as those caused by different MAC protocols. We further argue that such collisions and, when necessary, rebroadcasts, will only change the search cost proportionally. Using this approach enables us to focus on the search cost caused by different search sets.

The difference of our work with related work [5,3,4,8] is that our work focus on identifying a search set that performs close to the optimum search set. We develop a general analytical framework to find such search sets. The framework can serve as a tool for further study in this field. We also provide guidelines for search set selections under various network setups.

The rest of this paper is organized as follows. In Section 2, we summarize the related work. In Section 3, we present the network model of our analysis and our analytical framework to investigate the optimum search sets in ERS. We study the scenarios where the source is at the origin of the circular network region in Section 4. The scenarios in which the source is randomly chosen from the circular region are studied in Section 5. Section 6 presents numerical results on integer search sets. We conclude our work and state future work directions in Section 7.

2. Related work

Cheng and Heinzelman investigated geography-based and hop-based flooding control methods [5]. It was proved that two-tier and three-tier hop-based flooding control methods can reduce the cost of broadcast. Both of the cost and the latency were studied. A general formula to determine good parameters for two-tier and three-tier schemes was provided and investigated. Different to their work, we provide a general analytical framework and use it to investigate networks with different source distributions.

Chang and Liu revisited the TTL-based controlled flooding search extensively [3]. When the probability distribution of the location of the searched object is known *a priori*, a dynamic programming formulation of the optimal search sets can be used. They also presented the necessary and sufficient conditions on the location distribution under which pure flooding and incremental