Reducing Resource Discovery Time by Spatio-temporal Information in Vehicular Ad-Hoc Networks

Ouri Wolfson
Department of Computer Science
851 South Morgan Street (M/C 152)
Chicago, IL 60607USA
1.312.996.6770
wolfson@cs.uic.edu

Bo Xu
Department of Computer Science
851 South Morgan Street (M/C 152)
Chicago, IL 60607USA
1.312.996.4881
boxu@cs.uic.edu

Huabei Yin
Department of Computer Science
851 South Morgan Street (M/C 152)
Chicago, IL 60607USA
1.312.996.4881
hyin@cs.uic.edu

Categories and Subject Descriptors
C.2.1 [**Computer-communication Networks**]: Network Architecture and Design – *wireless communication.*

General Terms
Algorithms, Management, Measurement, Experimentation.

Keywords
Resource Discovery, Peer-to-Peer, Broadcast, Ad-Hoc Network.

1. INTRODUCTION
A few recent papers augment routing protocols of mobile ad-hoc networks (MANET) in order to enable discovery of physical resources (see [1]). However, the existing work does not distinguish between competitive and non-competitive resources. A competitive resource is used by at most one consumer at any point in time (e.g. a parking slot); whereas, a non-competitive resource can be used by more than one consumer at any point in time (e.g., a gas station). In this paper, we consider discovery of competitive physical resources in a vehicular ad-hoc network (VANET). Particularly, we examine a *peer-to-peer broadcast* (PPB) paradigm, in which each vehicle periodically broadcasts the *M* most relevant reports it carries to neighboring vehicles.

We further compare this peer-to-peer mode with the ideal situation of information dissemination, in which each resource, once available, is known by all the vehicles instantaneously. A system that is close to the ideal situation is a client-server system. In client-server mode, a sensor senses the availability of the resource, and sends a report to a central database when the resource becomes available. The mobile consumers access the server through a cellular network. A major disadvantage of client-server mode is that installing a server in many local areas, and accessing these servers through the cellular infrastructure may be expensive. In this paper we compare peer-to-peer and client-server modes in terms of the time it takes to discover a competitive resource in each mode. In this sense, we answer quantitatively a question that was considered only in a qualitative sense in [3].

2. PEER-TO-PEER BROADCAST AND INFORMATION GUIDED SEARCH
Let us introduce some concepts first. In our model each resource-report contains at least three attributes: the resource type, the location of resource, and a *timestamp* which indicates the time when the report is transmitted by the resource. Each report has a relevance when it is received. The relevance is computed based on the following theorem:

Theorem 1: Assume that consumers arrive at a resource *R* according to a Poisson process with intensity λ. Let *V* be a consumer that moves at a constant speed *v*, and receives a report of *R* *t* time units after the timestamp of the report, at distance *d* from the location of *R*. The probability that *R* remains available when *V* reaches it is $e^{-(\lambda \cdot t + \lambda \cdot d/v)}$ □

Thus, we define the relevance of a report of *R* to a consumer that receives it *t* time units after the timestamp of the report, and *d* distance units from the location of *R* to be $e^{-(\lambda \cdot t + \lambda \cdot d/v)}$.

Peer-to-Peer Broadcast (PPB). In the PPB dissemination, the resource-reports are periodically broadcast by resources to the vehicles that pass by, i.e. within transmission range. A report is broadcast only during the available duration, and each report is time-stamped with the broadcast time. Upon receiving new reports, a vehicle *V* incorporates the new reports into its local reports database. Periodically, *V* sorts the reports in its local database according to their relevance, and broadcasts the top *M* reports. *M* is called the *broadcast size*.

Information guided search (IGS). IGS defines how resource reports are used by consumers to capture a resource. With IGS, a consumer starts by moving around the area where a resource of interest could possibly be located. The search continues until either an available resource is encountered (i.e. passed by in the road network), or some resource-report is received. In the latter case, the consumer attempts to capture the resource *R* (i.e. moves along the shortest path to *R*). If *R* is not available when the consumer reaches it, then the consumer discards its report, returns to the closest point in the search space, and continues the blind search. Clearly, if an available resource is passed by on the way to *R*, then the consumer captures it and the search ends. If another resource-report is received during the trip to *R*, and its relevance is higher than the relevance of *R*'s report, then the consumer goes to new resource.

3. EXPERIMENTAL ANALYSIS

Simulation Method. We synthetically generated and moved vehicles within a 1.2mile×1.2mile grid network. The distance between two neighboring grid points is 0.1 mile (approximately the length of one street block). Each simulation run is executed as follows. At the beginning of the simulation run, 121 resources are generated, each at one four-way intersection. 100 consumers and g×1.2×1.2 brokers (i.e. vehicles that are not consumers but participate in PPB dissemination) are introduced at time 0 at random locations. g is a system parameter. Each consumer moves along a square with side length of 0.6 mile at a constant speed v'. 10% of the consumers use the IGS strategy and they may move off the square. The rest do not use IGS strategy and they simply move along the square until an available resource is encountered. Each broker follows a random-way-point motion at a constant speed v'. v' is randomly selected from [15, 25] miles/hour. The transmission range r ranges from 50 to 250 meters. Each broadcast is correctly received by a neighbor with certain probability; this probability and the broadcast period are calculated based on the parameters of 802.11b and the analytical model of [2]. This model gives the throughput (i.e., the fraction of time in which the communication channel of a vehicle is engaged in successful transmission of user data) of the wireless channel in an 802.11 ad hoc network as:

$$Th = \frac{L \cdot (p \cdot e^{-p \cdot \theta \cdot \pi \cdot r^2 \cdot (1+9 \cdot (2 \cdot L/\tau+1))})}{\tau + p \cdot (L+\tau)} \qquad (1)$$

where L is the transmission time of the broadcast message (which is proportional to the length of the message), τ is the length of the media-access time slot (20μs for 802.11b), p is the broadcast probability, i.e., the probability with which a vehicle broadcasts at each media-access time slot, θ is the average number of vehicles per unit size of area, and r is the transmission range in meters. Given τ, L, θ, and r, there is an optimal value of p that leads to the highest throughput of the wireless channel. We then translate this optimal p into the broadcast period. The baseline bandwidth is chosen to be 5.5Mbps. The size of each resource report is 32 bytes. For all the node densities, transmission ranges, the broadcast sizes we test, calculated broadcast periods are smaller than 1 second (time unit of a simulation). Thus the broadcast period is rounded up to 1 second for all the simulations. The sending and receiving of each broadcast is completed instantaneously (i.e. they take 0 time).

Impact of the Broadcast Size on PPB. We tested the discovery time of PPB-IGS with different values of the broadcast size M. The results show that increasing the broadcast size does not improve the performance of PPB (Figures omitted due to space limitations). In fact, with the PPB algorithm, broadcasting only the top one report is as good as broadcasting the whole database (121 reports). This is because PPB chooses the broadcasted reports based on their spatio-temporal relevance which reflects the benefit of the reports. The fact that broadcasting the top one report is enough is a nice property. It indicates that PPB is efficient in bandwidth consumption, and it is drastically different than flooding that would broadcast all the reports in the database.

Comparison with the ideal dissemination case. PPB-IGS approaches the ideal case (Ideal-IGS) when the broker density is high enough (200 brokers per square mile. Figure 1) or the transmission range is high enough (200 meters. Figure 2). Intuitively, the increase of transmission range and broker density generates two contrary effects on performance. On the one hand, the reliability of broadcast decreases due to higher contention. On the other hand, each successful broadcast is likely to reach more objects and a bigger area. Figures 1 and 2 show that the positive effect outweighs the negative one. Thus as the transmission range and the broker density increase, the newly generated reports are propagated more quickly and reach the consumer sooner, giving the consumer a higher probability of capturing a resource.

Conclusions: (i) By broadcasting only most relevant report in the local database of a vehicle, PPB achieves high efficiency in bandwidth consumption. (ii) With very reasonable broker density and wireless transmission range, the performance of the PPB reaches that of the ideal dissemination case (e.g. client-server). This indicates that the peer-to-peer approach could serve well as an alternative to the client-server mode but with much less operational cost.

Figure 1 (M = 1, r = 150 meters)

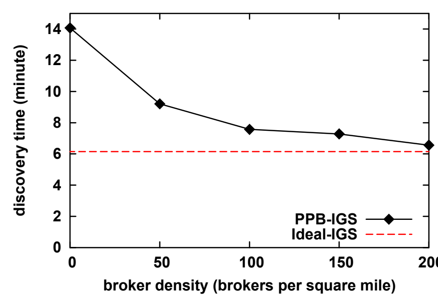
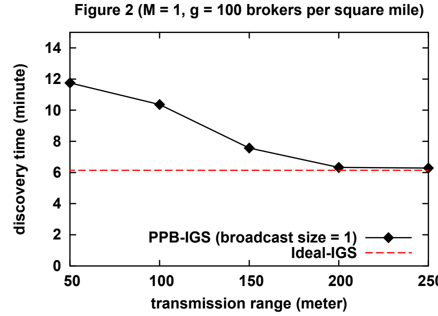


Figure 2 (M = 1, g = 100 brokers per square mile)



Research supported by NSF Grants 0326284, 0330342, ITR-0086144, 0513736, and 0209190.

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