PeB: Periodic Broadcast for Information Distribution in Large Wireless Networks

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***Abstract*— Large wireless networks are envisioned to play increasingly important roles as more and more mobile wireless devices are available to use. In these networks, it is often the case that some critical information needs to be readily accessible by the regular nodes, requiring a careful design of the information distribution technique. In this work, we propose PeB, Periodic Broadcast, that takes advantage of periodic broadcast from the information server(s) to leave traces for nodes requesting for the information. One salient feature of the PeB scheme is its periodic broadcast schedule that maintains the freshness of the trace toward the information servers. We present our extensive investigation of the PeB scheme on cost and network dynamics.**

I. Introduction

Large wireless networks are expected to play an increasingly important role for information availability. Examples include mobile ad hoc networks (MANETs) and wireless sensor networks (WSNs). WSNs are composed by a large number of sensors that can communicate with each other locally and monitor environmental conditions cooperatively. In such networks, nodes often assume the same role and support multi-hop routing.

In these large wireless networks, there will usually be information that should be readily accessible to regular nodes throughout the entire network. Examples of such information are security certificates, public key copies, service directories, etc. The main goal of the information distribution is to store such information on one or several servers (or caches) so that, when other regular nodes need them, they can request for them.

Many techniques allow nodes to search for information in such large wireless networks. For example, a Time-To-Live (TTL) based flooding can be used, but this has been found to cause the broadcast storm problem [1]. In [2], a swarm-intelligence based scheme termed Ant-Based Evidence Distribution (ABED) was proposed. In ABED, query packets are treated as ants looking for food sources. Reply packets with certificate copy are considered as ants returning with food. These packets (ants) leave traces for other querying packets (ants) to find the certificate copy (food source). As we will demonstrate in this work, such an approach does not work well in mobile and dynamic networks because traces can become outdated quickly. The Anycast routing protocol was proposed in [3], [4] for ad hoc pervasive networks. Anycast applies the behavior of the real ant colonies to find a shorter path to a neighboring server efficiently and quickly. Setting different parameters in anycast in networks with different network dynamics could be a huge challenge.

In this work, we propose PeB, Periodic Broadcast, that takes advantage of periodic broadcast from the information server(s) to leave traces for nodes requesting for the information. One salient feature of the PeB scheme is its periodic broadcast schedule that maintains the freshness of the trace toward the information servers. We present our extensive investigation of the PeB scheme on cost and network dynamics.

The paper is organized as follows: Section II discusses recent related works. In Section III, our scheme is explained in detail. Simulation-based performance evaluation is presented in Section IV. In Section V, we summarize our work and discuss future works.

II. Related Work

Information dissemination is a challenging task in large wireless networks due to the topology uncertainties. Flooding is a simple and straight-forward method to send out queries toward the certificate nodes. There have been many works trying to improve flooding efficiency. Cheng and Heinzelman [5] designed an optimal flooding strategy minimizing cost and latency for target discovery, although a large volume of querying traffic and potential collisions will be generated, especially with multiple queries. Similar approaches were taken in peer-to-peer systems due to the similarities between such networks and ad hoc networks. For example, Passive Distributed Indexing (PDI) [6], based on peer-to-peer technology, addresses the file sharing problem in mobile scenarios by eliminating the need of flooding to the entire network.

Swarm intelligence [7] is the property of a system in which the collective behaviors of group species interact with their environment. The environment causes them to act as cohesively and highly self-organized. Research on ant-colony based swarm intelligence has been developed and often used in dynamic optimization problems, such as traveling salesman problem and routing in communication networks. The power of such an approach can be explained below: consider how a certain ant specie find the shortest path to food source merely by laying and following pheromone on trials. In a simple case, ants starting from nest to search for food would leave pheromone on trials. While some trials go nowhere, others lead them to food sources especially when the ants come back with food. Other ants follow (or are attracted by) these pheromones on the trails. Based on this observation, Jiang and Baras [2] presented an approach to distribute trust evidence in ad hoc networks. In their approach, query messages are considered as forward ants that may be broadcasted or unicasted. The return information is considered as backward ants that leave traces for future forward ants to follow. However, communication cost and latency are high in their approach because many forward ants are likely to be broadcasted (flooded) in the neighborhood. Furthermore, complicated reinforcement rule can lead to trial loops in mobile networks, diminishing the benefits of such traces.

A core-based multicast routing algorithm based on swarm intelligence was introduced by Shen and Jaikaeo [8]. A similar announcement strategy was used in their proposed algorithm, although for multicast routing. An anycast routing protocol using swarm intelligence for service server was proposed and studied by Hoh et al. [3], [4]. Compared to ABED, the proposed scheme in [3], [4] has a unique feature of the EXPLORE packet sent by every node and forwarded with a small probability. When an EXPLORE message is received, the server responds the same way as it receives a regular QUERY message. In [9], a Stigmergic Landmark Routing was proposed for MANETs. The main feature of the proposed protocol is the use of landmarks, instead of all nodes, to record directions toward successful routing paths. A similar approach was suggested by Garcia and Pedraza [10], although load balancing is obtained through the exploitation of available information on forwarding choices by intermediate nodes. An energy saving and load balancing routing technique was proposed in [11], using a novel pheromone updating policy based on multiple performance metrics. In [12], an energy-aware routing was designed based on swarm intelligence and multipath transmissions.

The problem we are focusing on shares many similarities with data dissemination in wireless networks [13]–[16]. In fact, the certificate information we discuss in this work can be any other information that is needed throughout the network. In order to improve data availability, researchers proposed and investigated data caching [15], [17]–[19]. A similar approach is investigated in [20] with a Markovian chain analysis, although we focus on a technique making information available for query instead of information delivery by simple broadcast.

III. PeB: Periodic Broadcast for Information Distribution

A. Primary

The operation of PeB is based on query messages and reply messages, which are standard in many information distribution systems or routing techniques. What makes PeB unique are the traces and the way how the traces are updated. Traces are numbers stored on each node and will lead query messages toward the information servers, each of which carries a copy of the information.

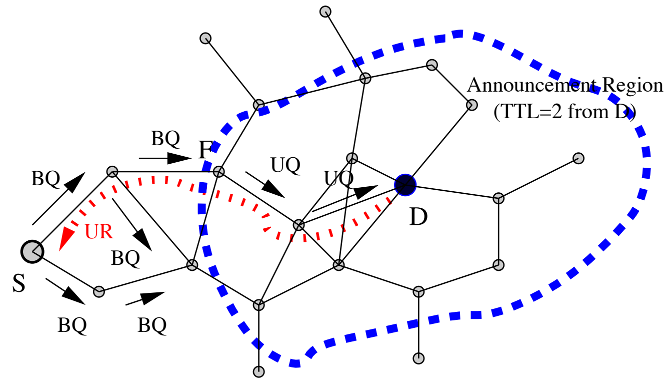

Fig. 1. Illustration of the PeB scheme. Node D is one of the information servers. The querying node, node S, is searching for it. Broadcast Query (BQ) messages are sent from node S and re-broadcasted by intermediate nodes with no trace to the any information server. Node F has a trace toward the information server and sends out a Unicast Query (UQ) message instead. Unicast Reply (UR) messages are sent from node D back to node S (the red dotted line). The large dashed circle (in blue) shows the range of the periodic broadcast sent from node D. Each node carries a Trace Table (TT) and uses it to choose the best next-hop node to send UQ messages whenever possible.

Every node stores a data structure called Trace Table (TT), which serves as a guide for local decision making (see Figure 1). Each entry records the trace for a known information source. In network routing, trace is basically a probability value of reaching the information server when the node is chosen to forward the query packet.

TABLE I
Trace Table

Neighbor	N_1	N_2	.....	N_m
Trace	τ_{N_1}	τ_{N_2}	.....	τ_{N_m}

In Table I, we show an example of Trace Tables. The node has m active neighbors, $N_1, N_2, \cdots N_m$. The trace of the information server through node N_1 is recorded as τ_{N_1}, N_2 with τ_{N_2}, etc. These values will be updated through two mechanisms: the UR messages and Broadcast Announcement (BA) messages. The UR messages will travel through the reverse of the original path through which the query message has gone. And the trace will be updated (details to be provided in Section III-B). The BA messages will be sent from the information servers periodically to announce the existence and locations of the information servers. The scope and the frequency of the broadcast will affect the PeB scheme's performance and will be investigated in Section IV.

The PeB scheme shares some similarities with ant swarm intelligence and other schemes with the swarm intelligence approach. In ant swarm intelligence, for instance, trial pheromone is a secreted chemical substance that laid on trials by ants when they bring food back to their nest. It attracts other ants and serves as a guide to find food. As more and more ants take the same route, they too lay pheromone, further amplifying concentration of pheromone and attractiveness of the trial. An evaporation process that slowly lowers the pheromone concentration is responsible to erase any old and outdated trials.

There are several aspects that distinguish the PeB scheme from swarm intelligence:

- Periodic broadcast from information servers.
- PeB does not have an evaporation process. Such a process is unnecessary for PeB since periodic updates are sent from the information servers.

The acronyms of different messages are summarized in Table II.

TABLE II
DIFFERENT MESSAGES IN THE PEB SCHEME

Acronym	Details
BQ	Broadcast Query message
UQ	Unicast Query message
UR	Unicast Reply message
BA	Broadcast Announcement message

B. Algorithm Details

Our scheme can be divided into three phases: Announcement phase, Query phase, and Response phase. While the Response phase usually follows the Query phase, the Announcement phase has its own schedule that is independent of the other two phases.

1) Announcement Phase: In the announcement phase, the information servers make periodic announcements of their existence in their neighborhood. This is one of the main differences of the PeB scheme with other previously proposed schemes such as [2]. We argue that such periodic announcements update the trace table in the neighborhood of the certificate copies especially in mobile networks and allow the query messages to be routed toward the information server accurately.

In contrast, other schemes rely on the broadcast technique to look for the information servers and keep track of the traces left by the reply messages. While such a technique works well in static networks, mobile networks introduce a much more difficult problem: outdated traces. Trace can become invalid quickly in mobile networks and the implemented trace degradation technique cannot reflect the process accurately. This is also true for techniques that employ the evaporation process, which is in parallel to network topology changes.

The announcement will be made in the local neighborhood of each information server. In particular, the announcement messages will be flooded to the TTL-hop of the neighborhood. We argue that an appropriate TTL value will allow a majority of the querying nodes to have access to updated traces. Obviously, a large TTL will lead to higher overhead and should be avoided. In addition, a larger TTL may not always be better even we neglect the extra cost that it introduces. This is because each information server has a region of nodes that should contact itself for the information. Further increasing TTL over this region size can only complicate the path selection process at the forwarding nodes. We investigate the effect of different TTL values in Section IV.

Another important system parameter in the Announcement phase is the broadcast interval, T_b. A small T_b will cause too much of message transmission overhead; on the other hand, a large T_b can easily leave the traces outdated especially in large wireless networks with mobile nodes. We present our investigation of T_b based on network dynamics in Section IV.

The information carried by the announcement messages includes server identity, announcement sequence number, TTL, etc. An illustrative packet format is provided on Table III.

TABLE III
ANNOUNCEMENT MESSAGE FORMAT

FIELDS	REMARKS
seq_num_	announcement sequence number
len_	packet length
src_addr_	address of announcement node
server_id_	carrying server identity
last_sender_	ID of the previous sender
hop_count_	hop count from the information server
ttl_	time-to-live

When a node overhears an announcement message, it updates its trace toward the last sender (last_sender_) of the message:

$$\tau_{n+1} = \gamma\tau_n + (1-\gamma)(H-h) \tag{1}$$

where γ represents the weight toward old estimate, h is the hop count from the announcement server, and H is the maximum hop count of the network. We use the trace as $H-h$ because the shorter the hop count, the higher weight the node should have. Furthermore, $H-h$ ensures that the term is non-negative.

2) Query Phase: A node requesting for the information initiates the Query phase, in which a query message is sent and intermediate nodes help to route the query message toward an information server.

The difference of regular packet routing and the Query phase is the self-duplication of query message. In fact, the duplication of the query message in the Query phase is between unicast and broadcast. In unicast, a single copy of the message is forwarded throughout a network path. In broadcast, every node receives a copy of the message and forwards it at least once. In the Query phase of the PeB scheme, only those nodes without any trace toward the information server will broadcast the query message (BQ); all other nodes with some traces toward the information server will unicast the query message (UQ) toward the best candidate, which will forward the message in a similar fashion.

The logic behind such a strategy is rather straightforward: when none of the neighbors knows about the information server, the sending node has no other choice but to send it to every neighbor. When one or more neighbors have traces toward the information server, the neighbor with highest trace will be chosen to forward the query message.

The query message also carries the IDs of nodes through the path of which it travels. Such a path information will be needed in the Response phase, which is in charge of sending the requested information back to the querying node.

Care must be taken to remove query messages running the network endlessly, either through a loop or some mis-routes. In order to ensure this behavior, a TTL value is inserted in each query message generated by the querying node. Every node processing a message will decrement the TTL value. When TTL reaches 0, the message will be purged from the network.

3) Response Phase: Once a query message reaches one of the information servers, the Response phase will be initiated by the information server. In particular, a UR message will be generated and sent back to the querying node.

There are two issues worth of discussion: the UR message will use the route information stored on the arriving query message; there might be more than one query message arriving at the information server. This is an obvious result of the BQ transmission. The information server can either ignore the subsequent messages or reply some of them. In this work, we assume that the information server only replies to the first request and ignores the rest.

All nodes forwarding the UR message will update their trace table based on its hop count from the information server and the last sender of the UR message. The trace update formula is the same as the updating formula for nodes receiving BA messages. Even though a different weight can be used, we use the same weight in both UR and BA messages.

IV. Performance Evaluation

A. Experiment Setup

In order to study the characteristics and evaluate the performance of the PeB scheme, we set up simulation experiment using MATLAB. In our future work, we will present results based on packet-level simulators such as NS2 and/or OPNET. Packet loss due to collisions will be investigated as well. A total of $N = 250$ nodes are uniformly distributed in a field of 1000×1000 meters. The transmission range is 200 meters. Four information servers carrying the same copy of information are randomly distributed throughout the network. More advanced cache placement techniques can be used [21], but are considered out of the scope of this work. All simulation results are the average of 100 runs with different seeds.

The nodes move with a random way-point mobility model. The pause time is 60 seconds. Unless specified otherwise, the minimum speed is 2 meters per second and maximum is 10 meters per second.

Queries toward information servers are sent at a normalized rate of one query per second.

B. Performance Metrics

Our evaluations focus on the following metrics: *Cost*, *Success Rate*, and *Hop Count*.

- Cost, M, is defined as the total number of messages transmitted on each query. Since packet transmission is mostly proportional to energy consumption and use of other network resources, such a cost also represents the energy cost to query the information. In addition The second major metric that we will investigate is latency.
- Hop Count, H, is defined as the average hop count of all the successful queries' paths. This metric represents the accuracy of the traces toward the information servers.

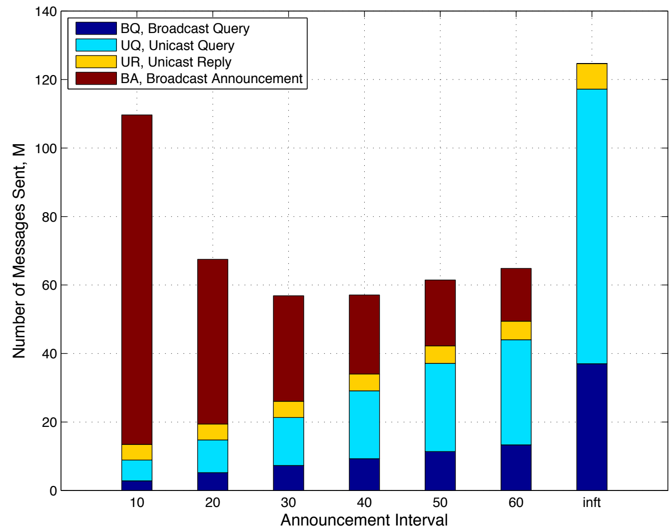

Fig. 2. Comparison of cost, M, for the PeB scheme with different announcement intervals. The numbers of BQ, UQ, UR, and BA packets are shown. In order to demonstrate the effectiveness of the broadcast, the numbers of a no-broadcast variation of the PeB scheme is also presented. It can be seen that the overall cost of an announcement interval of 30 seconds is lowest.

Other evaluation metrics are also possible, such as success rate, but we omit it due to page limit.

C. Results and Discussions

The cost of supporting queries from nodes is presented in Figure 2. In this figure, we show the numbers of BQ, UQ, UR, and BA packets in the PeB scheme with different announcement intervals. When the announcement interval is too large, the trace becomes outdated and more BQ packets are needed in order to locate information servers. On the other hand, short announcement intervals lead to large number of BA packets to the overall cost. The optimum announcement interval can be observed as 30-40 seconds.

We investigate the performance of the PeB scheme under various mobility and show the results in Figure 3. As the maximum speed, from which mobile nodes chooses their speed randomly, increases, nodes have higher mobility. The cost to support information server queries increases with speed. More interestingly, the optimum announcement interval naturally decreases with the increase of mobility. This is because, with higher mobility, more announcements will be needed to keep the traces from becoming invalid.

The effect of different residual ratios, γ, is presented in Figure 4. Except when γ is close to 1, when no new trace is accepted, the PeB scheme performs similarly with different γ values. In all other simulations, we choose $\gamma = 0.5$.

The effect of different announcement scope, announcement TTL, is presented in Figure 5. A large TTL means that the

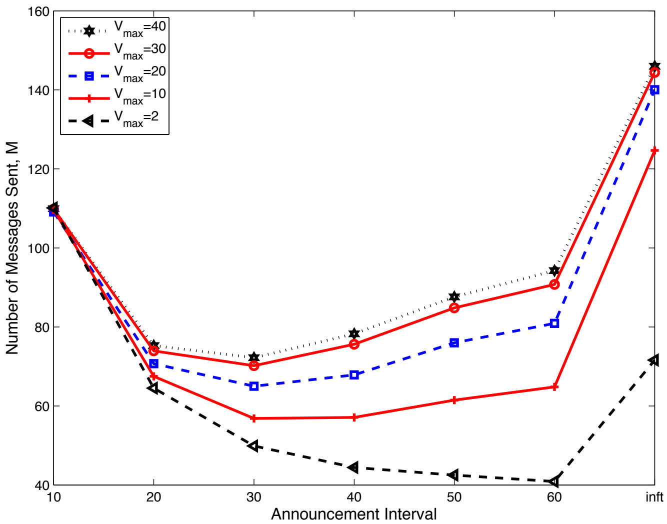

Fig. 3. Comparison of cost, M, for the PeB scheme with different mobility. As the maximum speed increases from 2 to 40 meters per second, the shape of cost versus announcement interval remains similar. The optimum announcement interval shifts smaller. Furthermore, the cost of supporting such queries increases with the maximum speed.

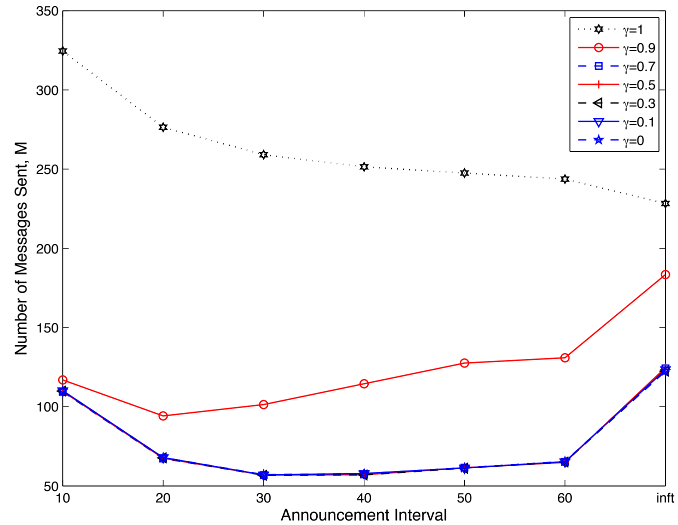

Fig. 4. Comparison of cost, M, for the PeB scheme with different residual ratios, $0 \leq \gamma \leq 1$. This is the ratio to keep the old value as compared to use the new value of trace. A large γ puts more weight on the old trace and a small γ puts more weight on the new trace (see Equation (1)). It can be seen that the performance of the PeB scheme is not affected by γ except when γ is close to 1, when no new trace is accepted.

broadcast scope covers a large number of hops (larger region) surrounding the information server. A smaller TTL reduces the scope and the total number of BA messages is reduced, hence the cost. It can be observed that, the lowest cost is achieved when TTL=3 for appropriate announcement interval of 30 seconds. In all other evaluations, we choose $TTL = 3$.

We present the hop count performance of PeB under different announcement intervals and different maximum speed, V_m, in Figure 6. As can be seen, the hop count of paths toward information servers increases with announcement interval and V_m. As announcement interval increases, cache information toward the information servers become more outdated. Higher speed has a similar effect.

We present the performance of different announcement intervals under different node density in Fig. 7. A similar performance shape can be observed. However, a counter intuitive result is observed: as node density increases, the optimum announcement interval decreases (meaning more frequent announcements). However, the large region of flat bottom on each of the lines means that the performance of the PeB scheme remains close to optimum even if the announcement interval is not precisely optimized.

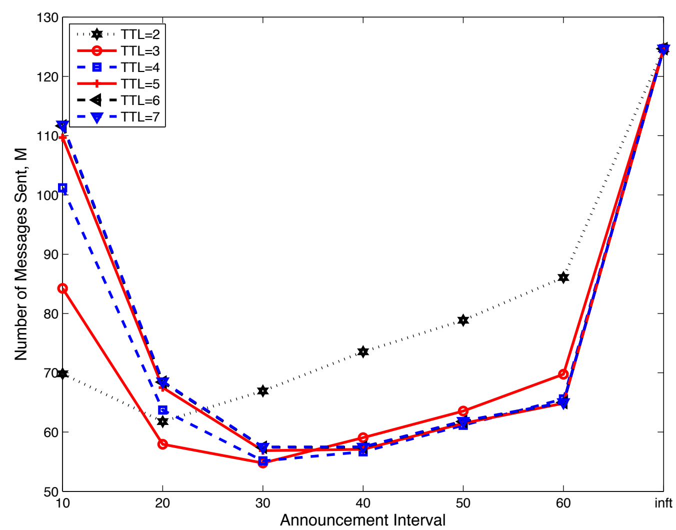

Fig. 5. Comparison of cost, M, for the PeB scheme with different announcement TTL. This is the scope of the broadcast announcements. An announcement TTL of 3 can be seen to be the best.

V. Conclusion

In this paper, we have introduced and investigated an approach to distribute trust evidence in mobile ad hoc networks based on the swarm intelligence paradigm. Besides having advantages inherited from swarm intelligence, such as local information possession that does not cause extra overhead of interaction with environment and lowered transmission number in network, our approach announces trace information on those potentially optimal paths that can yield better performance in cost and delay, allowing querying nodes to locate requested information more quickly and efficiently both in static and dynamic network.

Our scheme can be used for data dissemination and query in other mobile wireless networks such as vehicular networks. Instead of searching for certificates, other essential data or information can be queried. In our future work, we plan to compare our scheme with other state-of-the-art schemes and implement it on mobile devices for field tests. Theoretical analysis of the optimum TTL and pheromone update rules can be beneficial as well.

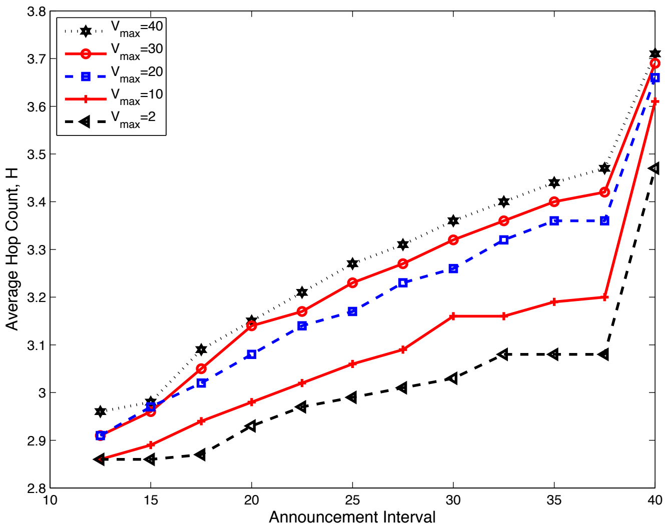

Fig. 6. Hop counts of found paths toward the information servers, H. As the announcement interval increases, H increases. Furthermore, H increases with speed of node movements.

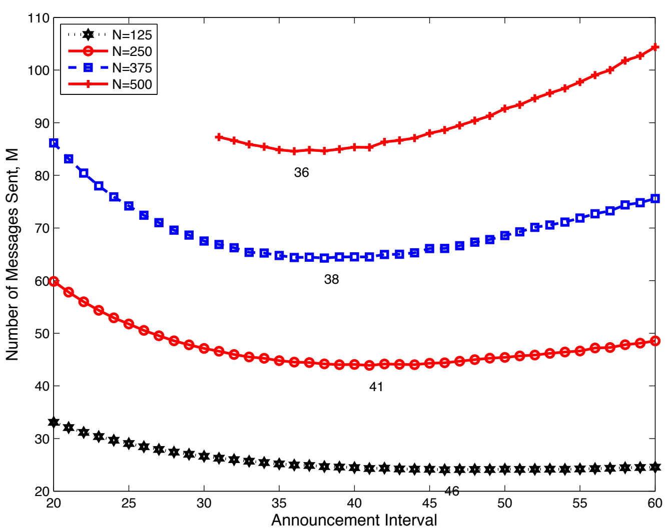

Fig. 7. Performance of different announcement intervals under different node density. The best optimum announcement interval decreases with the increase of node density. We also plotted the optimum announcement intervals in the figure.

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