Peer-to-Peer Epidemic Algorithms for Reliable Multicasting in Ad Hoc Networks

Zülküf Genç, Öznur Özkasap

Abstract**—** Characteristics of ad hoc networks and even their existence depend on the nodes forming them. Thus, services and applications designed for ad hoc networks should adapt to this dynamic and distributed environment. In particular, multicast algorithms having reliability and scalability requirements should abstain from centralized approaches. We aspire to define a reliable and scalable multicast protocol for ad hoc networks. Our target is to utilize epidemic techniques for this purpose. In this paper, we present a brief survey of epidemic algorithms for reliable multicasting in ad hoc networks, and describe formulations and analytical results for simple epidemics. Then, P2P anti-entropy algorithm for content distribution and our prototype simulation model are described together with our initial results demonstrating the behavior of the algorithm.

Keywords**—** Ad hoc networks, epidemic, peer-to-peer, reliable multicast.

I. INTRODUCTION

Ad hoc networking is defined as the art of networking without a network [1]. This definition relies on the infrastructure-less characteristics of ad hoc networks. Indeed, ad hoc networks do not depend on any stationary infrastructure and they do not have a central administration. Mobility of the nodes is another fact and a challenging issue of these networks as illustrated by an example in Fig. 1. The nodes in such a network are free to move arbitrarily and this random motion results in frequent and unpredictable changes in the network topology.

The unpredictable topology changes cause the non-determinism in the mobile ad hoc networks. Thus, it is unlikely to adapt the traditional reliable multicast protocols, which are naturally deterministic, to the highly dynamic environment of the mobile ad hoc networks. These reliable multicast protocols can not produce desirable throughput in a network exposed to frequent topology changes when aiming reliable and scalable multicast (e.g., [2]-[3]) [4].

Moreover, most of the multicast protocols employ the tree-like based structures for multicast in ad hoc networks to provide network connectivity. However, they do not try to guarantee packet delivery and loss recovery during the tree/mesh reconfiguration process [5]. In the case of high mobility, frequent topology changes can greatly reduce the multicast delivery rate.

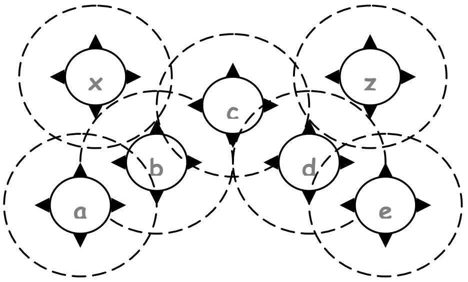

Fig.1. - n ad hoc network consisting of 7 mobile nodes. These nodes are free to move arbitrarily. Dashed lines represent the wireless range and connectivity is provided by the peer-to-peer connections (e.g., “a” and “e” can communicate each other through “b”, “c” and “d”. “x” and “z” are currently unreachable.)

II. EPIDEMIC ALGORITHMS IN AD HOC NETWORKS

A. Overview

Epidemic algorithms are efficient solutions for information dissemination in distributed settings. For instance, they may involve peer-to-peer propagation of updates by use of gossiping. The gossiping mechanism can roughly be considered that each group member periodically informs a set of randomly selected nodes about its state. For reliable multicasting in ad hoc networks, the state of a member involves multicast messages received by that member. In the case of state inconsistency between two members, they exchange the state information for recovering the missing messages over peer-to-peer connections. Random selection of the peers to be updated is the source of non-determinism in the epidemic algorithms. This non-deterministic nature and the peer-based communication style are well matched to the requirements of ad hoc networks. Additionally, gossip based multicast algorithms run independently from the network topology, and they distribute the load equally to the group members just as the ad hoc networks do. Thus, power, memory and bandwidth sources, which are the most severe constraints in ad hoc networks, are consumed in stability. Additionally, prediction of the protocol performance and obtaining the preferred trade off between reliability and

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scalability are achievable thanks to stochastic models derived from epidemiology [4].

B. Relevant Prior Work

There are a number of recent studies that utilize the gossip mechanism in the ad hoc networks. Chandra et al. [5] offer a method that can be implemented on top of any tree and mesh based multicast protocols to improve the multicast reliability in ad hoc networks. Their protocol advances in two phases. They use the underlying unreliable multicast protocol, currently Multicast Ad hoc On-demand Distance Vector (MAODV), to disseminate the data in the first phase. In the second phase, they run the anonymous gossip mechanism to guarantee the almost all reachable members receive the multicast packets recovering the lost messages.

Luo et al. [4] also propose a probabilistic reliable multicast protocol for ad hoc networks but with a different approach than [5]. Instead of using an underlying multicast protocol, it employs only a routing protocol, currently Dynamic Source Routing (DSR) at the network layer. As in the dissemination of negative acknowledgements, multicast packets and membership information are also carried by the gossip messages. Thus, this pure gossip schema does not require multicast primitives in the underlying routing protocol. Also, it tracks the availability of routing information interacting with the DSR to determine the gossip targets. Besides, they present the analytical results predicting the performance of Route Driven Gossip (RDG) and compare these results with the outcomes provided by simulations in ns-2.

Luo et al. [7] upgraded the [4] to a group communication system for ad hoc networks adding the data sharing mechanism to existing multicast schema.

In [8] the gossip mechanism is employed to disseminate the routing messages. They propose the performance gains compared to flooding technique.

Vahdat and Becker [9] apply gossiping to unicast routing in ad hoc networks. They attempt to provide that messages are eventually delivered even if there is not any connected path between host and ultimate location at the time a message is originated. To ensure this eventual message delivery, they employ the random peer-to-peer message exchange mechanism.

C. Summary

Previous studies use two different approaches for the dissemination of multicast data. The first one is using one of the existing multicast routing algorithms. The second option is making use of gossiping for the dissemination of multicast messages. Luo et al. [4] employed the second option whereas Chandra et al. [5] utilized an underlying multicast routing protocol. In the latter, you have to provide only reliability leaving the data propagation and membership management to multicast protocol. Thus, the performance of the protocol is restricted by a second protocol. The former approach offers putting all data into gossip messages and sending those to randomly selected members. However, it is possible to send the same multicast data to the same user more than one time since the receivers are determined randomly. Another solution for disseminating data by gossip messages can be use of message digests. In this case, firstly, the message digests are propagated by gossip messages. Then, the members lacking the multicast data request it from the gossiper. Thus, replication of data can be prevented on the network; however, it costs extra time and even modest overhead. We are searching the best approach for ad hoc networks through the simulations.

III. FORMULATIONS FOR SIMPLE EPIDEMICS

Distribution of data among a group of nodes in a distributed system should be fast, robust (in spite of node crashes), efficient and should scale many nodes. Both multicast and broadcast can be effectively used with push mode of dissemination, and they would be very efficient if the underlying network supports them. Otherwise, flooding for broadcast or application-level dissemination trees for multicast can be utilized. Another efficient solution is to use epidemic algorithms that involve pair-wise or peer-to-peer propagation of updates. In this section, we give formulations and analytical results for simple epidemics. Epidemic algorithms are based on the theory of epidemics which studies the spreading of infectious diseases through a population. One of the main differences between flooding/application-level multicasting and epidemic paradigm is that the former is based on message forwarding, whereas the latter is based on state exchange for information dissemination.

One of the fundamental results of epidemic theory shows that simple epidemics eventually infect the entire population. If there is a single infective site at the beginning, updates will eventually be spread across all sites. Full infection is achieved in expected time proportional to the logarithm of the population size. When we consider a fixed population of size n, k peers are already infected, and infection occurs in rounds; the probability of infection can be formulated as follows. Assume that $P_{inf}(k,n)$ is the probability that a particular susceptible (uninfected) peer is infected in a round if k peers are already infected.

$$P_{inf}(k,n) = 1 - P(\textit{nobody infects the susceptible peer})$$
$$= 1 - (1 - 1 / (n-1))^k$$

Then, the expected number of newly infected peers would be: $(n-k) \times P_{inf}(k,n)$

Expected number of total infections in round r can be formulated as the expected total number of infections in round $(r-1)$ plus the expected number of newly infected peers in round r. Depending on the application, the initial value for k may differ and that would also affect the time needed for full infection. Using the above formulation and considering different values for k, we compute the expected number of newly infected peers as a function of round number for n = 100 (Fig.2(a)). The number of rounds needed for full infection decreases when the initial value of k increases. Initial rounds up to the peak point in the curve (for the cases where $k < n/2$) reflect the fact that there are few state exchanges (since k is relatively small) but most of these exchanges result in infection. On the other hand, the tail of the distribution corresponds to the case where there are many state exchanges (current value of k is large) but most of them do not cause infection. Expected number of total infected peers as a function of round number is depicted in Fig.2(b) for different values of k.

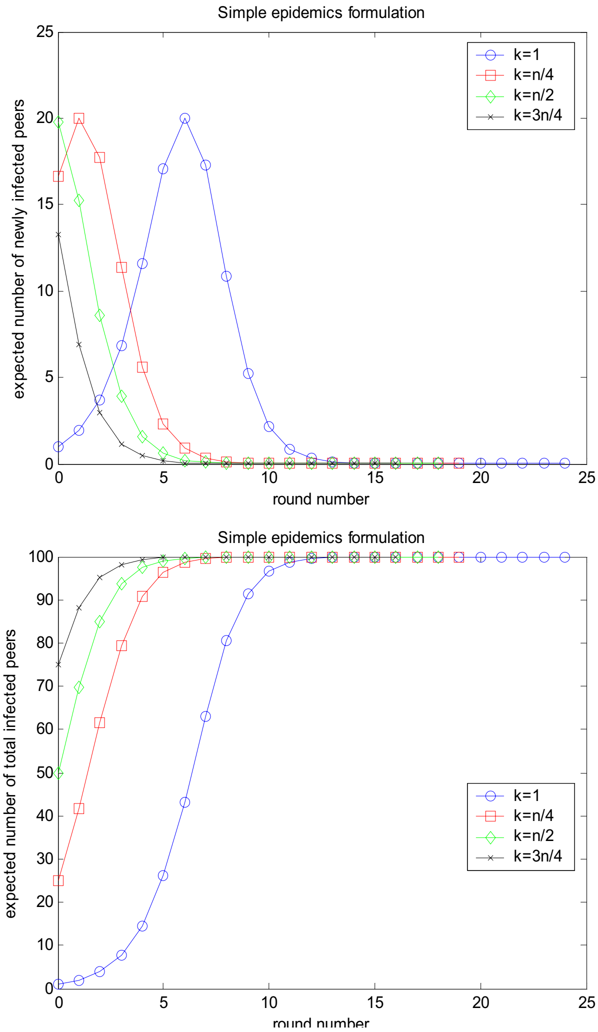

Fig. 2 - (a) Expected number of newly infected peers as a function of round number for n = 100, (b) Expected number of total infected peers as a function of round number

IV. P2P ANTI-ENTROPY ALGORITHM FOR CONTENT DISTRIBUTION

Epidemic communication mechanisms were first proposed for spreading updates in a replicated database [10]. The aim in this case is to infect all replicas with new updates as fast as possible. Epidemic or gossip style of communication has been used for several purposes. Examples include large-scale direct mail systems [11], group membership tracking [12], support for replicated services [13], deciding when a message can be garbage collected [14], failure detection [15], loss recovery in reliable multicast [16], and distributed information management [17].

A popular distribution model based on the theory of epidemics is the anti-entropy [18]. According to the terminology of epidemiology, a site holding information or an update it is willing to share is called infective. A site is called susceptible if it has not yet received an update. In the anti-entropy process, non-faulty sites are always either susceptible or infective. In this model, a site P picks another site Q at random, and exchanges updates with Q.

In this study, we consider the P2P anti-entropy for content distribution settings. A target setting would be ad hoc networks where the nodes employ peer-to-peer communication to provide network connectivity and act as routers forwarding the each others' packets. Nodes can communicate directly with the nodes in their wireless coverage and indirectly with the others that are out of their wireless range through intermediate nodes using dynamically-generated multi-hop route information.

According to the principles of anti-entropy model, our algorithm for content distribution execute in a fully distributed manner. For each peer, we define four events that trigger the actions of the algorithm: *Interrupt for epidemic round*, *Digest*, *Request* and *Retransmission*. The algorithm is given below.

```
Interrupt for epidemic round (Periodically, in each round)
    Pick a peer at random
    Send a Digest of local content to the peer
    Schedule a timer for next round
Digest (When a digest message is received)
    Compare digest with local content
    If missing some parts of the content
        send a Request for each missing part (message) to the
        digest owner
Request (When a Request message is received)
    Retransmit the message to the requested peer
Retransmission (When a Retransmission message is
received)
    Update the content with the retransmitted message
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V. PROTOTYPE SIMULATION MODEL

Using the algorithm described, we are developing a simulation model for evaluating the behavior of content distribution with P2P anti-entropy on ns-2 [6] network simulator. The simulation model will enable us to analyze the impact of various parameters of the model as well as the underlying network. Our initial prototype assumes that $k = 1$ which is a plausible value considering the content to be distributed is available at a server initially. As described in the algorithm, the exchange of updates is pull-based. In other words, the receiver of a Digest triggers the state exchange by requesting a missing part of the content rather than pushing the content that Digest owner is missing. This model slightly differs from simple epidemic, since peers exchange digest of the content first, and then if needed they try to update their local content. Considering a large content size, digest exchanges would decrease the bandwidth consumption and redundant data transmission. In our simulations, we consider fully-connected peers with the same distance from the initially infective peer. There are several parameters of the dissemination model such as population size (n), gossip rate (round duration), fan-out (number of peers that a peer sends digest in each round), update-exchange (pull-based, push-based, hybrid, etc.), overhead per peer and also network parameters such as failure rate of links or nodes, network size, topology.

VI. RESULTS

Our initial results based on the simulation model are described next. The content (with size 21000 bytes) to be distributed over the population is assumed to be consisting of 100 messages. There is only one infective peer (or content server) at the beginning ($k = 1$). For a gossip rate of 100ms, and population size of 100, we measure the time that each peer gets infected using the content distribution algorithm. The distribution is given in Fig. 3 where x axis is the time of infection and y axis is the number of peers getting the full content so far. This is consistent with the principle of simple epidemics (blue line in Fig. 2(b)). We also approximate the round numbers, and compute the number of new and cumulative infections as a function of the round number. These results are given in Fig. 4. Compared to expected values for simple epidemics, the distribution is quite consistent. We also explore the variation of gossip rate (round duration of 100, 500 and 1000ms) to observe its effect on the performance of content distribution (Fig.5). As expected, an increase in gossip rate results in an increase of the time needed for full infection. But, as a benefit this decreases the average overhead (digest and request messages) per peer.

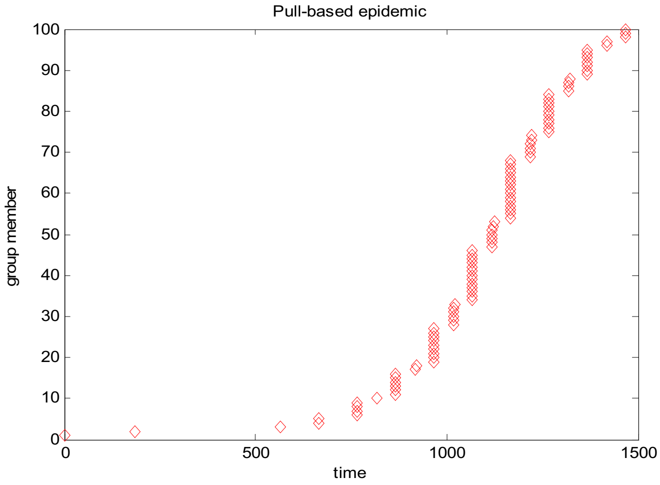

Fig. 3 - Time of infection for each peer, n=100

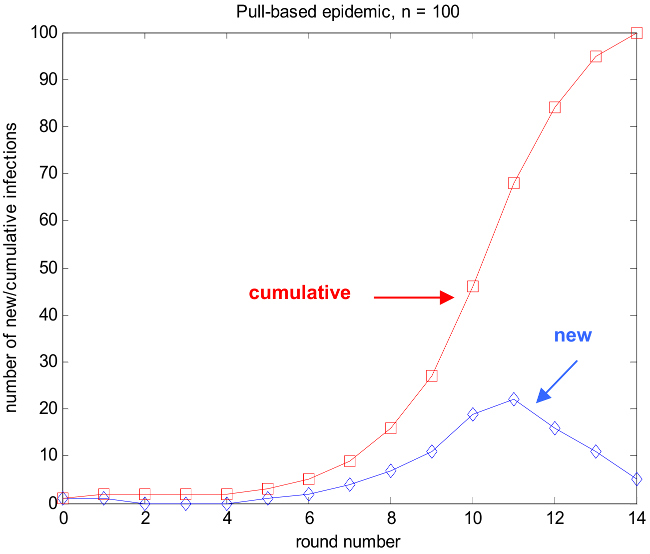

Fig. 4 - Number of new and cumulative infections as a function of round number

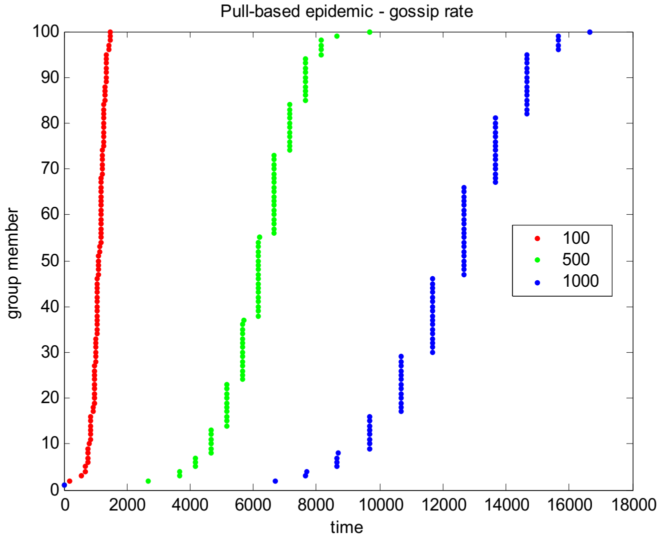

Fig. 5 - Variation of gossip rate (round duration of 100, 500 and 1000ms)

VII. CONCLUSION

Epidemic algorithms are efficient solutions for information dissemination in distributed settings. The non-deterministic nature and the peer-based communication style in epidemic algorithms are well matched to the requirements of ad hoc networks. As a further work, we consider to develop a reliable multicasting mechanism for ad hoc networks and construct its analytical model to determine the best network parameters for a current scenario more accurately and easily.

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