Scribble: an Efficient Reliable Manycast protocol for Ad-hoc Networks

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1. Introduction

The problem of efficient message delivery to multiple nodes has been widely studied for ad-hoc networks, be it sensor- or mobile ad-hoc networks (MANETs). The proposed solutions include broadcast [14], multicast[9] and manycast[1] protocols, with numerous application domains suggested. Additionally, there has been considerable interest in enhancing the reliability of these *best-effort* protocols, which are known[8, 10] to have highly variable per-packet delivery ratios once modest mobility, interference or transient network partitions are possible. These reliability enhancement efforts include gossiping [2, 13], optimised flooding[11], transmitting on encounters[3], and using selective[12] or negative [19] acknowledgments to trigger retransmissions. These protocols are shown to offer a higher average delivery ratio through simulations, stochastic analysis or both. The delivery ratio actually obtained in a given execution can be below (or above) the average observed or estimated. Since the actual delivery ratio for a given message cannot be known precisely, if an application needs to satisfy certain application-specific requirements, remedial action has to be taken. For example, periodic session messages are used in [6] to maintain data consistency, which adds overhead even where the delivery ratio is high enough. Similar measures are necessary if a minimum number of nodes in a sensor network must be re-tasked for the fidelity of the data to be high enough; the fact that too few nodes have received a message might not be observed until after the fidelity of the data is found to be too low, at which point the event being observed might have disappeared.

Here, we are concerned with *deterministic delivery guarantees,* i.e. the delivery ratio for any given message is guaranteed not to fall below a threshold specified for that message. This threshold can be considered to take the special case value of 100% in the protocols of [15, 17, 16, 4, 5] where message delivery is guaranteed to all nodes. Guaranteeing delivery to *all* in a group, however desirable, often involves making a simplifying assumption that no destination node leaves the group nor crashes during an execution of the protocol (see assumptions in [15, 16]). Without this assumption, attempts to deliver a message to a departed or crashed node must, strictly speaking, continue until that node is known to have departed or crashed; these attempts obviously increase the overhead. However, the nodes that make up an ad-hoc network are both prone to failures (due to, say, running out of batteries) and are likely to leave the group, something which undermines the validity of the assumption.

We here outline a protocol, called *Scribble*, which permits the minimum threshold to be less than 100%, thus allowing a few nodes to depart or crash during the execution. More precisely, it provides what we call *k-deterministic delivery guarantees,* where delivery is guaranteed to *at least k destination nodes*. The value of *k* is chosen by the application is required to be a realistic value. Such a service is called *manycast* in [1] to which we refer the reader for a collection of applications, including distributed database consistency applications, mobile ad-hoc certificate authorities and various ubiquitous computing applications, for which Scribble will be an ideal candidate.

2. Scribble

Scribble achieves the desired coverage (i.e., at least *k* receiving *m*) in a distributed manner. The responsibility for dissemination initially rests with the manycast originator and is subsequently passed around to other nodes which deem themselves to be in a better position than the currently responsible node. The idea used in Scribble is similar in spirit to the *counter-based* optimized broadcast flooding presented in [14], but has been adopted for reliable broadcast. The approach taken allows the desired coverage to be achieved with a small transmission overhead. A further benefit of Scribble is that this distribution of responsibility is carried out requiring no access to a routing protocol, whether unicast or multicast, and that it does not therefore depend on the availability and accuracy of information about network topology, such as 1- or 2-hop neighborhood knowledge. This means that the protocol can avoid making assumptions which are unlikely to hold in a real world scenario, such as those highlighted by Kotz, Newport and Elliot in their very interesting study; "The mistaken axioms of wireless-network research" [7].

Given that the desired coverage is achieved, this fact needs to be deduced so that the manycast can terminate. Scribble ensures that any responsible node deduces the achievement of the desired coverage once the latter is obtained, and does so using *signatures*. Signatures are notionally unique node ids, and each node adds their *own* signature (scribbling it) to the header of any message it receives. This allows any node to realize that a message has been received by a sufficient number of nodes in a distributed manner, using only local information and without requiring centralized control. Once a node has made this realization, this information is eventually diffused throughout the network by means of small control packets.

When the network conditions are extremely hostile, any scheme used for message dissemination which is also cost-effective in terms of transmission overhead, cannot by itself guarantee the desired coverage. However, a deterministic protocol should not terminate until and unless the desired coverage has been obtained. So, a deterministic protocol has to resort to a more aggressive (and thus more expensive) measure, when the cost-effective scheme is deemed ineffective. The measure our protocol takes on is guaranteed to succeed once the ad-hoc network satisfies a requirement for liveness.

The liveness requirement on network connectivity is simply one of what should *not* occur: a permanent group partition; any partition that may occur due to mobility or obstructions occurs must heal. It is easy to see that this rquirement is as minimal as it can practically be, since no delivery guarantees can be offered when groups of less than k nodes are permanently partitioned from each other.

A full description of Scribble, including how the effective message dissemination technique works and how signatures can be represented in a compact manner is described in [18]. This paper also includes the formal definition of the minimal liveness requirement we believe is required in order to provide reliable broadcast, and describes the aggressive measure which we prove *any* reliable broadcast or manycast protocol must be able to resort to if the protocol only makes this minimal liveness requirement.

3. Protocol Performance

We have compared the performance of Scribble when k = *all* (i.e. when providing deterministically reliable broadcast) to ODMRP[1]. ODMRP is a well known *best-effort* multicast protocol which has been shown to perform well in various simulation studies[10, 8]. (Caution: Setting $k = all$, as noted earlier, permits no node crashes and requires that the value of all be known precisely or at least not be an over-estimate.)

The simulations were carried out using the Glomosim[20] wireless network simulator with 50 nodes in 1000m^2 area. Each simulation ran for 3000 seconds, multiple runs were made with differing random seeds for any given simulation parameter and the collected data was averaged over those runs. The only service assumed to be available to the protocols was that of omni-directional wireless transmit (for example no link-layer feedback was assumed) using a CSMA MAC layer. We used the Two-Ray (Ground Reflection) propagation model with a channel capacity of 1Mbps. The Random Waypoint mobility model was used, keeping the minimum speed constant at 1m/s and varying the maximum speed.

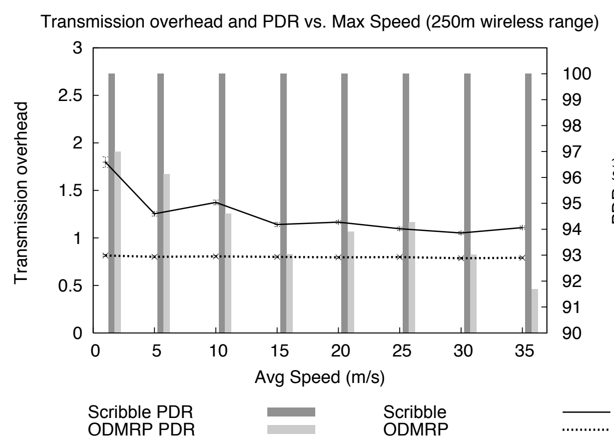

Figure 1.

Figure 1 shows the impact that relative change of topology has on the two protocols, when the wireless range of the nodes is set to 250m. The average packet delivery ratio (PDR) is shown as bars with a range from 90-100% as shown on the right y-axis, while the transmission overhead is drawn as lines relative to the left y-axis.

As expected, ODMRP performs relatively well with these parameters (these conditions are in fact very similar to that chosen by the ODMRP authors themselves in [9]), with mobility having little impact on the transmission overhead, as there are no reconstruction efforts in place in case the routing mesh breaks. This naturally then results in its PDR being very variable and suf-

1 We are grateful to the Network Research Group at University of Oregon for supplying a crucial bug-fix to the ODMRP implementation used.

fers as mobility increases. Scribble, on the other hand, provides its delivery guarantees with little additional overhead compared to ODMRP, with this additional overhead being higher when the mobility is relatively low. The reason for this is that Scribble guarantees delivery to all nodes including those which might be transiently partitioned of from the rest. When the mobility is low, these partitions takes longer to heal, so the cost of guaranteeing delivery to partitioned nodes is higher, thus increasing the overall cost of guaranteeing delivery.

4. Conclusions and future work

In this paper we have argued that dissemination primitives that offer deterministic or full reliability guarantees to some specified number of receivers are useful for applications in the ad-hoc networking domain. We have then outlined a deterministically reliable manycast protocol called Scribble. We have also shown that although it offers much stronger reliability guarantees than a *best-effort* multicast protocol, such as ODMRP, Scribble has an overhead not much larger than ODMRP.

Our future plans for Scribble includes using the protocol to build higher level distributed services such as group membership and consensus. Preliminary investigations reveal some promising, albeit counter-intuitive, results; one of them is that these higher level services can be built in adhoc networks easily and at an affordable cost, provided that the underlying dissemination layer offers deterministic reliability guarantees.

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