

# PILOT: Probabilistic Lightweight grOup communication system for Mobile Ad Hoc Networks

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## 1. INTRODUCTION

*Group Communication Systems* (GCSs) [1] are useful infrastructures on which various reliable distributed computing functions can be built. The need for such systems arises not only in wired networks but also in mobile ad hoc networks. Also, some computing functions, which traditionally rely on a centralized service, have to be implemented in a distributed way for ad hoc networks, since the service provided by a single node is not dependable. Unfortunately, the complexity of building reliable GCSs, which is prohibitively high already in wired networks, is further amplified in ad hoc networks due to highly dynamic and unpredictable topology changes. In fact, even guaranteeing reliability of multicast, a key building block of GCSs, becomes extremely hard. As a result, many distributed computing functions that depend on reliable GCSs have to either rely on the fragile “reliability” provided by flooding [2] or make assumptions about such a service while waiting for it to appear [3].

In this paper, we identify two fundamental problems in the context of group communications, namely (i) multicast and (ii) data sharing, and we define notions of probabilistic reliability for these problems, aimed at ad hoc networks. We then present our protocol suite, called Probabilistic Lightweight group communication system (PILOT) for ad hoc networks, as a solution. Innovating on the principles of gossip mechanisms and probabilistic quorum systems, PILOT provides probabilistic reliability for multicasting and data sharing. It is based only on a unicast primitive (rather than a multicast primitive like MAODV [4]) in order to improve the adaptability to future technology developments. We present analytical results predicting the performance of PILOT in terms of message overhead and reliability degree. We then compare these results with simulation results obtained with the *ns-2* simulator to show that we can obtain useful predictions on the performance of PILOT. To the best of our knowledge, the work presented in this paper is the first to provide a complete solution to the problems of reliable multicast and data sharing in ad hoc networks, along with both analytical and simulation results. It smoothly integrates, expands and completes our previous individual results [5, 6] into a compound group communication system.

## 2. PROBLEM STATEMENT

Within the broad scope of group communication, we address two fundamental problems, namely multicast and data sharing, and associate each of them with a notion of *probabilistic reliability*. Based on this notion, we define two metrics: reliability degree  $\mathcal{R}_d$  and network load  $\mathcal{N}_l$ . The goal is

to design protocols that can be tuned to trade overhead  $\mathcal{N}_l$  for reliability  $\mathcal{R}_d$ , or the other way around.

## 3. LAYERED ARCHITECTURE OF PILOT

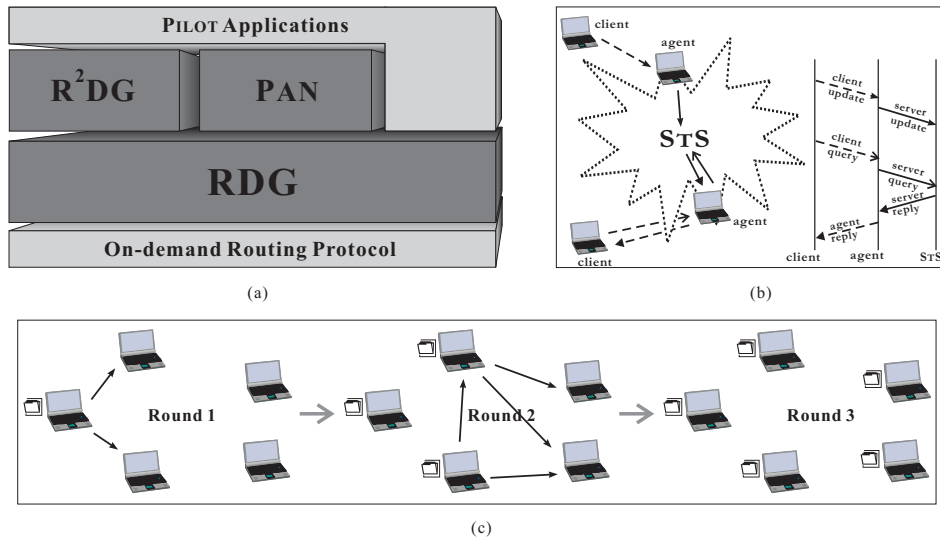
PILOT is a two layer system, illustrated by the dark grey part in Fig. 1(a). It has a probabilistic multicast protocol, Route Drive Gossip (RDG), as its basis. The protocol is gossip-based [7] in nature, as shown in Fig. 1(c). Upon this layer, two dedicated services are built. R<sup>2</sup>DG (Reliable RDG) is devised for continuous packet dissemination. It exploits the fact that packet losses can be detected by observing gaps in the *pid* sequence and thus piggybacks a negative acknowledgement with each packet sent (or relayed) to *pull* the lost packet back. The other service, Probabilistic quorum system for Ad hoc Networks (PAN), provides reliable data sharing. It assumes a special group STS to store the shared data in a replicated manner. Any node  $i \in \text{STS}$  is termed *server*, whereas the rest of the nodes are termed *clients* of the STS. Data queries and updates are directed to an arbitrary server in the STS while the message dissemination within the STS is performed by RDG, as shown in Fig. 1(b). According to their requirements, applications can either use the upper layer services or directly call RDG if only single packet dissemination service is required.

### 3.1 RDG and R<sup>2</sup>DG: Reliable Multicast

Our Route Driven Gossip (RDG) protocol applies a pure gossip scheme. It proceeds round by round and gossips uniformly about multicast packets, negative acknowledgements, and membership information, i.e., the message receivers in each round are randomly chosen and they *relay* packets to the receivers of the later round(s). RDG relies only on unicast routing protocol and a partial view of membership for each member; these random subviews result from the randomness of routing information that nodes can have. R<sup>2</sup>DG is built on RDG but has certain extended schemes. The spread of the information in R<sup>2</sup>DG is propelled mainly by a *gossiper-push* (each group member forwards multicast packets to a random subset of the group) provided by RDG but complemented by a *gossiper-pull* (multicast packets piggyback negative acknowledgements of respective forwarding group members).

### 3.2 PAN: Reliable Data Sharing

Our PAN system includes two protocols: a client protocol and a server protocol. The client protocol consists of interactions between clients and servers. In both cases of data update and query, a client sends a request to an ar-



**Figure 1: Principles of Pilot.** (a) Architecture of Pilot: the basic probabilistic multicast protocol (RDG) is at the bottom; R<sup>2</sup>DG and Pan are built upon the basic protocol. (b) Message exchanges for updating and querying the StS in Pan. (c) Gossip-based multicasting in RDG.

bitrary server in the server group StS and later receives responses from that server. Since the client protocol can always implement certain mechanisms (e.g., ARQ) to ensure reliability, we focus only on the server protocol. The server protocol specifies interactions within the StS. The server that receives a request from a client, termed *agent* for that client, accesses a quorum of servers by invoking the underlying RDG. In practice, PAN guarantees that a quorum accessed by a query intersects a quorum accessed by an update with high probability, hence a query acquires, with a high probability, the most recent update of the queried data.

## 4. CONCLUSION

In this paper, we are concerned with probabilistic reliable group communication in mobile ad hoc networks. We have identified two fundamental problems within this framework and specified performance metrics that take the peculiarities of mobile ad hoc networks into account. We have proposed our PILOT system as a solution, based on the principle of gossip mechanisms and probabilistic quorum systems, to address the problems. The performance of PILOT has been analyzed by making use of, notably, epidemic theory. The evaluation and investigation of PILOT have also been carried out by simulations in *ns-2*. Our main contributions are: (i) an ad hoc adapted gossip mechanism, (ii) a hybrid gossip including both push and pull, (iii) gossip-based quorum access protocols, and (iv) an asymmetric quorum construction.

We have proposed an analytical model to predict the performance of both RDG and PAN. The validity of the predictions is evaluated by simulations. The results show that our analytical model provides predictions that are adequate for tuning the tradeoff between reliability degree  $\mathcal{R}_d$  and network load  $\mathcal{N}_l$ . Our simulation results also show that, even under frequent topology changes, the reliability degrees of RDG/R<sup>2</sup>DG and PAN are fairly high in practice. Finally, we have investigated also other aspects of PAN with intensive

simulations, which confirm its robustness, in the sense that it can sustain a large access rate  $\lambda_o$ , different network sizes, and up to 50% server failures.

We are in the process of improving the analytical model by further investigating the effects of various factors. In addition, we are considering other models in order to further understand the benefits of gossip-based protocols and to provide numerical comparisons between PILOT and similar systems for ad hoc networks, which would better justify the deployment of PILOT.

## 5. REFERENCES

- [1] D. Powell et al, "Group communication (special issue)," *Communications of the ACM*, vol. 39, no. 4, pp. 50–97, 1996.
- [2] S. Nesargi and R. Prakash, "MANETconf: configuration of hosts in a mobile ad hoc network," in *Proc. of INFOCOM 2002*, 2002, pp. 1059–1068.
- [3] L. Zhou and Z. Haas, "Securing ad hoc networks," *IEEE Network*, vol. 13, no. 6, pp. 24–30, 1999.
- [4] E.M. Royer and C.E. Perkins, "Multicast operation of the ad-hoc on-demand distance vector routing protocol," in *Proc. of the 5th ACM/IEEE international conference on Mobile Computing and Networking (MobiCom'99)*, 1999, pp. 207–218.
- [5] J. Luo, P.Th. Eugster, and J.-P. Hubaux, "Route driven gossip: Probabilistic reliable multicast in ad hoc networks," in *Proc. of INFOCOM 2003*, 2003.
- [6] J. Luo, J.-P. Hubaux, and P.Th. Eugster, "PAN: Providing reliable storage in mobile ad hoc networks with probabilistic quorum systems," in *Proc. of the 4th ACM/SIGMOBILE Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc'03)*, 2003.
- [7] K.P. Birman, M. Hayden, O. Ozkasap, Z. Xiao, M. Budiu, and Y. Minsky, "Bimodal multicast," *ACM Trans. on Computer Systems*, vol. 17, no. 2, pp. 41–88, 1999.