Cross-Layer Support for Group-Communication Applications in MANETs*

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Abstract

P2P systems are a natural way of supporting group-communication applications in MANETs. In this paper we discuss our experiences in developing such an application in the real world. We highlight limitations of legacy P2P systems, and show that solutions based on cross-layer optimisations are very promising.

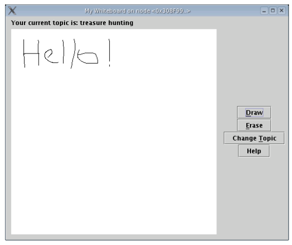

Figure 1. The WB application interface

1 Introduction

One of the most interesting class of applications that can be envisaged for MANETs is represented by group-communication applications. In the framework of the MobileMAN Project [6], we are investigating the viability of developing such kind of applications in MANETs. To this end, we developed the Whiteboard application (WB), which implements a distributed whiteboard among MANET users. WB usage is very intuitive (see Figure 1). Each MANET user runs a WB instance on her device, selects a topic she wants to join, and starts drawing on the canvas. Drawings are distributed to all nodes, and rendered on each canvas. We believe that these simple, "Plug&Play" applications will be of great value for MANET users.

Developing this kind of applications in MANETs is a challenging task. In this paper we present the networking solutions we have envisaged and tested to this end. We present alternative networking frameworks for supporting WB-like applications (Section 2). Then, we compare a standard P2P system (Pastry [8]) with CrossROAD [5], the P2P system optimised for MANETs that we have designed within these frameworks (Section 3). Advantages of the CrossROAD approach are presented by means of experimental results in Section 4. Finally, Section 5 concludes the paper.

2 WB integration in MANETs

Group-communication applications such as WB are distributed, self-organising, decentralised in nature. Designing them on top of P2P systems allows for great flexibility and ease of development. Figure 2 depicts the abstractions we have used to support WB. The network level provides basic connectivity among nodes through IP-like routing and transport protocols. On top of them, the overlay level builds a P2P overlay network comprising nodes that participate in the WB application. The overlay abstraction is the fundamental substrate for any P2P application, providing functionalities such as logical node addressing (instead of topological, IP-like addressing) and subject-based routing. Finally, an additional multicast level is used to efficiently distribute contents generated by application users to all nodes in the overlay. These abstractions make developing group communication applications quite straightforward. They hide the complexity of low-level communications, group management, and data distribution, and provide a robust, flexible, self-organising networking environment.

Figure 3 shows the complete networking solutions we have used to support WB in real-world MANETs. We have defined a first architecture (referred to as *legacy*), that uses state-of-the-art components for implementing the abstractions in Figure 2. Specifically, it uses either AODV [1] or OLSR [7] at the network level, Pastry [8] at the overlay level, and Scribe [2] at the multicast level. While AODV and OLSR are standard representative for ad hoc reactive and proactive routing protocols, respectively, Pastry and Scribe have been designed for wired networks. Evaluating the performance of the legacy architecture indicates weaknesses of these components, and ways to improve them. The architecture depicted on the right-hand side of Figure 3 has been proposed in [4] as a *cross-layer* solution, optimised for MANET environments. Its main innovation consists in the NeSt component, which allows cross-layer interactions by working as an intermediary between different-layer protocols. It is well-known that cross-

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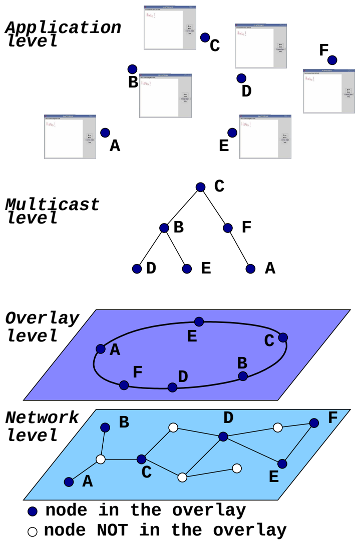

Figure 2. Abstractions supporting WB

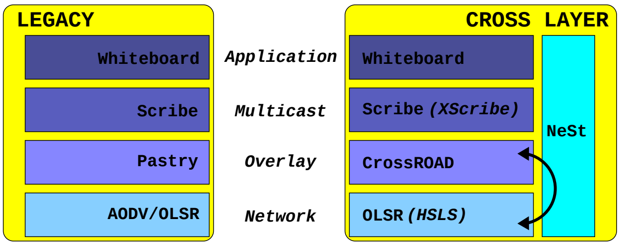

Figure 3. Network solutions: legacy (left) and cross layer (right)

layer interactions are a great benefit in MANETs. In addition, NeSt provides well-defined interfaces and data abstractions to protocols. Therefore, it joins the advantages of cross-layering and the scalability of traditional layered approach. Specifically, it allows for easy replacement of protocols, and avoids spaghetti-like network architectures. As we will explain in the following section, CrossROAD interacts through NeSt with a proactive routing protocol (OLSR in this case) to optimise the creation and management of the overlay network. In this paper we do not discuss any other MANET-optimised components that could be integrated into the cross-layer architecture. However, in the framework of the MobileMAN project, other such components both at the routing level (Hazy Sighted Link State), and at the multicast level (X-layer Scribe) are being developed and analysed.

3 Pastry vs. CrossROAD

Pastry generates an overlay network by organising nodes in a logical ring. Specifically, it assigns to each node a *logical* identifier by hashing, for example, the node IP address. Logical identifiers determine the node position in the ring. In addition, messages are routed over the ring by following a subject-based model, rather than a topology-based one.

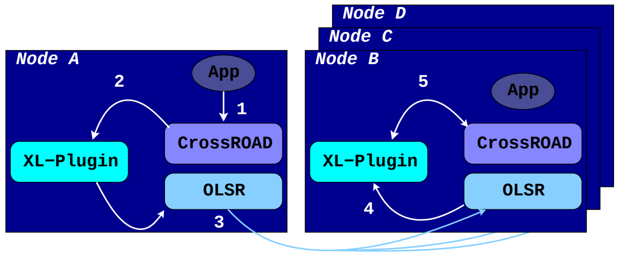

Figure 4. Cross-layer interactions between CrossROAD and OLSR

An application wishing to send a message m has to provide a key k linked to m. The k value is hashed to obtain an identifier in the space of nodes' logical ids, and the hashed value of the key is used as the destination for m. Pastry then routes the message to the node in the ring whose id is the closest one to the key hashed value. Subject-based routing is the basis for several P2P services. For example, Scribe exploits subject-based routing to build and maintain multicast distribution trees.

To implement subject-based routing, Pastry builds at each node a middleware routing table storing a subset of other nodes' ids. This table is initialised (during a bootstrap phase) and updated (periodically) by exchanging information with the other nodes. When adopted in MANETs, this approach generates quite a lot of network overhead. CrossROAD [5] provides the same Pastry functionalities through the P2P commonAPI [3], but drastically reduces the overlay management traffic by exploiting cross-layer interactions with a proactive routing protocol (OLSR in this case). CrossROAD implements a Service Discovery protocol, represented in Figure 4. Applications running on CrossROAD register themselves by specifying a *service id* (step 1). The list of service ids registered at the local node (Node A in the figure) is maintained by the Cross-Layer Plugin (XL-Plugin), which can be seen as a portion of the NeSt module (step 2). The XL-Plugin embeds the list of service ids into periodic Link-State Update packets generated by OLSR (step 3). The XL-Plugin of remote nodes (Nodes B,C,... in the figure) gets notified by the corresponding OLSR module about the services available at Node A (step 4). This way, the CrossROAD modules have complete knowledge of all nodes running a particular service in the MANET, and are thus able to build the corresponding overlay network without generating any further management traffic (step 5). Furthermore, upon topology changes, the status of the overlay network converges as quickly as the routing protocol does.

4 Experimental Results

The networking solutions described in Figure 3 have been implemented and tested in a read-world multi-hop ad hoc network. Specifically, the testbed consisted of 8 homogeneous laptops, out of which 6 run the WB application, and the remaining 2 were used just as routers. Experiments have been run, which mimic the behavior of WB users concurrently drawing strokes on their canvas. Users are represented by software agents that continuously interleave active phases (during which they draw a burst of strokes), and idle phases (during which they just receive others' bursts). Idle phase durations and burst sizes are exponentially distributed. A traffic load of 100% is defined as the load generated by a user drawing – on average – 1 stroke per second.

Due to space constraints, we cannot provide here detailed measurements. Therefore, we discuss the outcomes of some selected experiments, that allow us to highlight several benefits induced by CrossROAD[1]. Table 1 shows the aggregate throughput (in the sending and receiving directions) of each node during the Pastry 80% and CrossROAD 100% experiments, respectively[2]. These results account for the traffic generated from the routing up to the application level. We mark node C as "C(R)" since it was the root of the Scribe tree. Finally, the last two rows show the average throughput computed over the nodes running WB including and excluding C, respectively. Overall, when CrossROAD is used instead of Pastry, the throughput is drastically reduced. The average value over all nodes in the CrossROAD setup is about one third of the average value in the Pastry setup. It should be noted that, due to Scribe mechanisms, the root node has to handle a far greater amount of application-level traffic than other nodes. Therefore, the throughput reduction due to CrossROAD can be better emphasised by focusing on the last row of the table. If we exclude node C, the average throughput in the CrossROAD setup is about *one fourth* of the average throughput in the Pastry setup. Finally, we found that CrossROAD also improves the stability of the Scribe tree. Table 2 shows the number of sub-trees that are generated in Pastry and CrossROAD setup, respectively. When Pastry is used, the Scribe tree is often partitioned in several isolated sub-trees, resulting in nodes to be isolated from the rest of the network. Instead, this misbehavior is always avoided when CrossROAD is used. It can be shown that this misbehavior is a byproduct of the Pastry network overhead and bootstrap procedure.

Node	Pastry	CrossROAD
A	16529	2966
B	21278	5069
C(R)	48542	21146
D	29066	7819
E	18047	5993
F	14964	4313
avg	24738	7884
avg (no C)	19977	5232

Table 1. Throughput (Bps) in the Pastry 80% and CrossROAD 100% setup.

Load	Pastry	CrossROAD
20%	1	1
50%	2	1
80% (100%)	3	1

Table 2. Number of sub-trees at the Scribe level.

5 Conclusions

In order to support P2P group-communication applications in MANETs, legacy network architectures designed for P2P *wired* networks are not the real solution. Specifically, such solutions require too much management traffic, and tend to saturate the scarce MANET resources. Optimising the network stack components through cross-layering is a very promising way. In this paper, we have highlighted drastic performance improvements by replacing Pastry with CrossROAD, i.e., by utilising a cross-layer optimised P2P substrate. Further improvements can be envisaged if also the other P2P components (e.g., Scribe) would be optimised according to the cross-layer paradigm.

[1]In the Pastry case, we herafter show only results from OLSR experiments, since OLSR generally allowed to achieve better performances than AODV.

[2]We were not able to run Pastry experiments at 100% traffic load, because the testbed crashed due to excessive network load.

References

[1] AODV, Dept. of Information technology at Uppsala University (Sweden), http://user.it.uu.se/ henrikl/aodv/.

[2] M. Castro, P. Druschel, A-M. Kermarrec and A. Rowstron, "SCRIBE: A large-scale and decentralised application-level multicast infrastructure", IEEE Journal on Selected Areas in Communication (JSAC), Vol. 20, No, 8, October 2002.

[3] F. Dabek and B. Zhao and P. Druschel and J. Kubiatowicz and I. Stoica, "Towards a common API for Structured Peer-to-Peer Overlays", Proc. of the the 2nd International Workshop on Peer-to-peer Systems (IPTPS'03), Berkeley, CA, Feb. 2003.

[4] M. Conti, G. Maselli, G. Turi, and S. Giordano, "Cross layering in mobile ad hoc network design", IEEE Computer, Feb. 2004.

[5] F. Delmastro, "From Pastry to CrossROAD: Cross-layer Ring Overlay for Ad hoc networks", in Proc. of Workshop of Mobile Peer-to-Peer 2005, in conjuction with the PerCom 2005 conference, Kauai Island, Hawaii, Mar. 2005.

[6] "Mobile Metropolitan Ad hoc Network (MobileMAN)", IST-2001-18113 Project, funded by the EC FET-IST Programme, `http://cnd.iit.cnr.it/mobileMAN/`

[7] OLSR, Andreas Tonnesen, Institute for informatics at the University of Oslo (Norway),http://www.olsr.org.

[8] A. Rowstron and P. Druschel, "Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems", Middleware 2001, Germany, November 2001.