Towards Social Profile Based Overlays

David Isaac Wolinsky, Pierre St. Juste, P. Oscar Boykin, Renato Figueiredo
University of Florida

Abstract—Online social networking has quickly become one of the most common activities of Internet users. As social networks evolve, they encourage users to share more information, requiring the users, in turn, to place more trust into social networks. In centralized systems, this means trusting a third-party commercial entity, like Facebook or MySpace. Peer-to-peer (P2P) systems can enable the creation of online social networks extending trust to friends only. In this paper, we present a novel approach to constructing completely decentralized social networks through P2P overlays. A common directory overlay facilitates friend discovery and bootstraps connectivity to individualized profile overlays, mapping the ownership of an overlay to the ownership of a profile. Profile management transperntly uses a public key infrastructure (PKI). We define necessary interfaces for constructing the system and describe some examples of user interactions with the system.

I. Introduction

Online social networking has become pervasive in daily life, though as social networks grow so does the wealth of personal information that they store. Once information has been released on a social network, known as a user's profile, the user and the data are at the mercy of the terms dictated by the social network infrastructure, which today is typically third-party, centrally owned. If the social network engages in activities disagreeable to the user, due to change of terms or opt-out programs not well understood by users such as recent issues with Facebook's Beacon program [1], the options presented to the user are limited. The options include leaving the social network, surrendering their identity and features provided by the social network; accepting the disagreeable activities; or to petition and hope that the social network changes its behavior.

As the use of social networking expands to become the primary way in which users communicate and express their identity amongst their peers, the users become more dependent on the policies of social network infrastructure owners. Recent work [2] explores the coupling between social networks and P2P systems as a means to return ownership to the users, noting that a social network made up of social links is inherently a P2P system with the aside that they are currently developed on top of centralized systems. In this paper, we extend this idea with focus on the topic of topology; that is, how to self-organize social profiles that leverage the benefits offered by a structured P2P overlay abstraction.

Structured P2P overlays provide a scalable, resilient, and self-managing platform for distributed applications. Structured overlays enable users to easily create their own decentralized systems for the purpose of data sharing, interactive activities, and other networking-enabled activities. In this paper, we extend our previous work [3] to enable social network profile overlays. The previous work addresses the challenges of bootstrapping secure, private overlays in NAT and firewall environments by using a public overlay for discovery and as a relay or communication transport.

A typical social network consists of users and groups. Each user has a profile, a set of friends, and private messaging; and each group consists of one or more managers, users, and a messaging board. Profiles contain user's personal information, status updates, and public conversations, similar to a message board. Friends are individuals trusted sufficiently by a user to view the user's profile. Private messaging sends messages discretely between users without leaking the message to other members. Groups have similar features, though identity is hared by many users.

Using this social networking model, we describe how a public overlay can be used as a directory for finding and befriending friends or finding and accessing groups. Once access has been enabled, the public overlay can be used to bootstrap connectivity to existing profile and group overlays. Security for profile are provided by a public key infrastructure (PKI), where profile owners or group managers are the certificate authorities (CA) and all members have signed certificates. The overlay stores profile data or group information in its distributed data store, supporting decentralized access using scalable mechanisms regardless of the profile owner's online presence. In this paper, we present the architecture of these overlays, as presented in Figure 1.
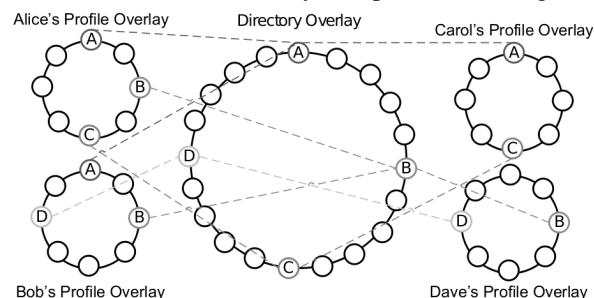

Fig. 1. An example social overlay network. Alice has a friendship with Bob and Carol, hence both are members of her profile overlay. Bob has a friendship with Alice and Dave but not Carol; hence Alice and Dave are members of his profile overlay, while Carol is not. Each peer has many overlay memberships but a single root represented by dashed lines in various shades of gray. For clarity, overlay shortcut connections are not shown.

The rest of this paper is organized as follows. Section II provides background and related work. Section III describes our multi-overlay approach, explaining how to map social networks onto structured P2P overlays. We express our expectations for user interaction with the system in Section IV. In Section V, we explore some of the remaining challenges introduced by our approach. We conclude the paper in Section VII.

II. BACKGROUND

In this section, we review structured P2P overlays, challenges and solutions for bootstrapping overlays, and other methods for constructing decentralized online social networks. P2P systems build upon existing decentralized concepts by creating scalable, autonomic environments, thereby limiting user exposure to the gory details of system configuration and organization. Since our system consists of many profile overlays, we focus on the challenges of bootstrapping P2P systems, when the system lacks dedicated bootstrapping nodes.

A. Structured P2P Overlays

P2P systems typically come in two flavors: unstructured and structured. Unstructured systems are generally constructed by peers attempting to maintain a certain amount of connections to other peers in the P2P system, whereas structured systems organize into well-defined topologies, such as 2-D rings or hypercubes. Though unstructured systems are typically simpler to bootstrap and maintain, they rely on global knowledge, flooding, or stochastic techniques to search for information in an overlay and thus creating potential scalability constraints. Alternatively, structured systems have guaranteed search time typically with a lower bound of $O(\log N)$, though recent research has shown that these systems can be constructed to support $O(1)$ search time. Some examples of structured systems are Pastry [4], Chord [5], Symphony [6], Kademlia [7], CAN [8], and Dynamo [9].

A key component of most structured overlays is support for decentralized storage / retrieval of information by mapping keys to specific node IDs in an overlay called a distributed hash table (DHT). At a minimum, the data is stored at the node ID either smaller or larger to the data's node ID and for fault tolerance the data can be stored at other nodes. DHTs can be used by peers of systems to coordinate allocation and discovery of resources, making them attractive for self-configuration in decentralized collaborative environments. DHTs provide the building blocks to form more complex distributed data stores as presented in Past [10] and Kosha [11].

One of the key challenges to overlays is the bootstrapping problem, that is, how does one find an active member in the overlay in order to become a member. In large public systems, often times, the owners of the project and sometimes corporate sponsors provide these resources, though these types of bootstrapping peers are typically not available for small, private overlays. The bootstrapping problem can be divided into two components: finding a bootstrapping member of the overlay and handling connectivity constraints if the overlay has no members with public addresses. In [12, 13], the authors discuss the concept of a single overlay supporting services through the use of additional overlays, which use the underlying overlay to assist in discovery, this deals with the component of finding a bootstrap peer. To address the challenge of bootstrapping peers behind NATs, we described a system in [3], which enables the public overlay to act as a NAT traversal rendezvous point. More specifically, a peer, attempting to join a private overlay, queries the public overlay's DHT to obtain a list of currently online private overlay peers who have matching public IDs. The peers then use the public overlay, in addition to direct UDP or TCP links, to communicate with the private overlay nodes and bootstrap into the private overlay. This method enables peers even behind firewalls and NATs to have publicly available addresses in the public overlay. Additionally this work describes mechanisms that enable the use of PKI technologies to seamlessly secure both point-to-point and end-to-end communication in a structured overlay.

B. Peer-to-Peer Social Networks

In [14], Buchegger et al. describe how to use a DHT to store social networking profile. The DHT provides look-up services for storing meta data pertaining to a peer's profile. Peers query the DHT for updated content from their friends by hashing their unique identifiers (e.g. friends' email addresses). The retrieved meta data contains information for obtaining the profile data such as IP address and file version. Their work relies on a PKI system that provides identification, encryption, and access control. In contrast, our approach provides each user their own private overlay secured by point-to-point encryption and authentication amongst all peers in the profile overlay. The profile overlay provides a clean abstraction of access control, whereby once admitted to a private overlay, users can access a distributed data store which holds the contents of the owners profile.

Shakimov et al. in [15] take a different approach by depending on virtual individual servers (VIS) hosted on a cloud infrastructure such as Amazon EC2. Friends contact each other's VIS directly for updates. A DHT is used as a directory for groups and interest-based searches. Their approach assumes bidirectional end-to-end connectivity between each VIS, where a profile is only available during the up time of the VIS. Because of the demands on network connectivity and up time, the approach assumes a cloud-hosted VIS and has difficulty being used on user-owned resources. Our approach enables users to avoid the need for all-to-all connectivity and constant up time through the use of NAT traversal support and the ability to store the profile in the overlay's distributed data store.

The approach presented by Cutillo et al. in [16] relies on a central system to host identities and certificates that can then be used to query a DHT to discover an initial hop in a route to a specific peer through their circle of friends. The circle of friends consists of an unstructured overlay, where direct friends maintain direct connections with the peer, and outer circles consist of friends of friends and friends of friends of friends. The main goal of this work is to remove the private components of a profile from a central entity, whereas our approach makes a clean break from all centralization and emphasizes scalability through distributed replica techniques.

Unlike the above approaches, the P2P social network presented by Abbas et al. in [17] uses an unstructured overlay without a DHT where peers connect directly to each other rather than through the overlay establishing unique identifiers

to deal with dynamic IPs. Peers cache each other's data to improve availability. While helper nodes are used to assist with communication between peers behind NATs. The approach lacks security and access control considerations and lacks the guarantees and the simplicity of the abstraction offered by a structured overlay.

III. Social Overlays

In this section, we explain how to map online social networking to virtual private overlay based social network consisting of a public directory overlay with many private profile overlays. The directory overlay supports friend discovery and verification and stores a lists of peers currently active in each profile overlay. Profile overlays support message boards, private messages, and media sharing.

A. Finding Friends

In a traditional social network, a directory provides the ability to search for users using public information, such as the user's full name, user ID, e-mail address, group affiliations, and friends. The search results return zero or more matching directory entries. To map this to our proposed social overlay directory entries are inserted into the DHT of a public overlay. Since the public information has many components, each could be used as indexes into the DHT pointing to a common complete listing of their public information. For example, a user can store a pointer at the DHT key $hash("alice")$ or $hash("alicebob")$. The key here is that any subset of the user's public information in lower-case format can be hashed into DHT index that would eventually direct the searching user to one or more user. More explicit searches could sift through the results and present to the user only those peers, which match all the search parameters. The amount of information shared publicly should be configurable by the user.

While looking for an individual, a peer may discover that many individuals have overlapping public information components, such as the user's name. Assuming all entries are legitimate, the overlay must have some method of supporting multiple, distinct values at the same key, leaving the peer or the peer's DHT client to parse the responses and determining the best match by reviewing the contents of each certificate. Alternatively, a technique like Sword [18], which supports distributing the data across a set of nodes and using a bounded broadcast to discover peers that match all information, could be used for searching.

When searching for friends, it is desirable that their public information is presented with some level of trust. PGP certificates can be used to store user's public information and verify user's friends. The main portion of a PGP certificate contains information such as user name, name, e-mail address, potentially other user-defined, and signature packets from those that trust the certificate including groups and individuals. The signature packets can be used to provide a verifiable list of friends. Each time a user befriends someone, they should exchange signature packets containing at a minimum the friends PGP certificate ID, a signature expiration time,

and a signature binding this information with the new friend's existing PGP certificate. This increases the trust level of individual searching for others if they have common friendships. The use of a time stamp in the signature assists in deciding whether or not a friendship link is still active without accessing the profile overlay of either peers. Thus peers that maintain friendships need to periodically exchange signature packets.

B. Making Friends

Once a user, *Alice*, has found a friend candidate, *Bob*, *Alice* can issue a friendship request and store it in the DHT using the hash of Bob's certificate as an index, this acts a public overlay mailbox. *Bob* can review the public information of *Alice* prior to making a decision. If *Bob* accepts the request, *Alice* and *Bob* exchange signature packets and are granted access to each other's profiles. Once profile access has been enabled, the *Alice* and *Bob* can learn more information, and if it turns out to be a mistake, either one of them can unilaterally end the relationship.

Alice's friendship request should contain a pointer to her certificate in the overlay, a time stamp, Bob's certificate identifier, and a signature. The friendship request could be encrypted using symmetric algorithms with the symmetric keys encrypted by Bob's public key for the purpose of anonymity. When Bob receives the signature request, he can verify Alice's identity and that the request was made by her. Upon Bob receiving Alice's friendship request, he has three choices a conditional accept, an unconditional accept, or a reject. During an unconditional accept, Bob signs Alice's PGP certificate and issues a request to befriend her. Alternatively, he could issue a request to befriend her and wait for her to sign his certificate and investigates her profile prior to signing hers.

Discovery of a user is not limited to the directory entries. Because users have a public overlay based mailbox, they are not required to discover each other only through the directory. Instead, they can use out of band discovery, using mechanisms like e-mail, chat, or personal websites to exchange certificates. Once a peer has received another peer's certificate, they can submit secure friendship requests using the public overlay.

C. The Profile Overlay

In a traditional social network, the profile or user-centric portion consists of private messaging, data sharing, friendship maintenance, and a public message board for status updates or public messages. In this section, we explain how these components can be applied to a structured overlay dedicated to an individual profile.

Using the techniques such as those described in [3], it is feasible to efficiently multiplex a P2P system across multiple, virtual private overlays enabling each profile owner to have a profile overlay consisting of their online friends. For access control, we employ a PKI, where each member uses the signed certificate generated during the "finding and verifying friends" stage. All links are encrypted using

symmetric security algorithms established through the PKI, thus preventing uninvited guests from gaining direct access to the overlay and hence the profile. Because the profile owner also is the CA for all members of the overlay, they can easily revoke users from access to the profile overlay. [3] describes efficient mechanisms for overlay revocation through the use of broadcasting for immediate revocation and the use of DHT for indirect and permanent revocation.

The message board of a profile can be stored in two ways: distributed within the profile overlay via a data store or stored on the profile owner's personal computing devices. The distributed data store provide the profile when the owner is offline and also distributes the load for popular profiles. For higher availability, each peer should always be a provider for all data in their profile when they are online. To ensure authenticity and integrity, all peers should sign their messages and each peer's certificate should be available in the overlay for verification. Messages that are unsigned should be ignored by all members of the overlay. An ideal overlay for this purpose should support complex queries [19] allowing easy access to data stored chronologically, by content, by type, i.e., media, status updates, or message board discussions.

Private messaging in the profile overlay is unidirectional; only the profile owner can receive private messages using their overlay. To enforce this, a private message should be prepended with a symmetric key encrypted by the profile owners public key, the message should be appended by a hash of the message to ensure integrity and the entire message encrypted by the symmetric key. This approach ensures that only the sender and the profile owner can decrypt the private message. The contents of the private message should include the sender, time sent, and the subject. Messages can be stored in well known locations, so that the profile owner can either poll the location.

D. Event Based Message Notification

Both the directory and profile overlays have methods by which peers can receive messages. In the directory overlay, these take form by means of friendship requests and friendship accepts, certificate signature packets. The profile overlay supports private messages. While polling the location in the DHT occasionally will allow peers to receive the messages, polling has inherent delays and network costs. Alternatively, event enable peers to receive sent messages very quickly after they have been sent with minimal impact on network throughput.

A simple method for implementing an event notification system involves using the DHT. Each event would have an identification that would map to a list of peers wanting to know when an event occurred and the data associated with it. Thus mapping the $(eventid, listener)$ to the DHT could be done by hashing a string such as "private messages for me" or taking a hash of the user's certificate hash for public overlay messages and storing the profile owners active nodes into the list of listeners . When a message is inserted into the user's mailbox, the sender could query this list and send to each listener a notification of the new private message. Alternatively, if a higher degree of anonymity is required, the DHT server could be modified to forward the response to the listeners directly rather than returning a list of listeners. Of course, this does not prevent potential race conditions occurring, such as a situation where a peer recently joined their profile overlay, had already queried their mailbox and found it empty, while simultaneously a private message was sent to them yet they were not in the listeners list. Thus occasional polling is required, though can be minimized, the longer a node has been online.

E. Active Peers

The directory overlay should be used to assist in finding currently active peers in the profile overlays. By placing their node IDs at a well-known, unique per-profile overlay keys in the DHT, active peers can bootstrap incoming peers into the profile overlay. We implemented and evaluated this concept in [3]. Because the profile overlay members all use PKI to ensure membership, even if malicious peers insert their ID into the active list, it would be useless as the peer would only form connections with peers who also have a signed certificate.

F. Groups

Groups can be considered extensions of profile overlays. The fundamental difference between a group and a profile is that a group lacks private messaging and has shared ownership. So just as a peer can find a profile in the directory by hashing the name of the user and other identifiable information, so can the user find the group. Like the certificate of the user, the members of a group sign the group's certificate to represent their membership to that group. The user requests membership to the group and a group manager can sign the certificate allowing that member access to the group. Finally, the group can be bootstrapped in the same way as the profile overlay through the directory overlay.

The unique challenge presented by groups is the sharing of the CA task. A decentralized solution would be for all members of the group to be listed in the groups DHT and when a peer becomes a manager, their certificate is added to the certificate chain for the group enabling them to sign certificates for that group. If an administrator loses their position, then all members who had their certificate signed by that administrator would need to obtain a new certificate. Alternatively, the owner of the group and the original CA could sign the group members certificates again, so that they are signed by the root CA and would not lose access if administration changes.

IV. USER INTERACTION

Though this paper involves many components that are outside the realms of many users, use of the system should be transparent to the user such that interaction with this system should be no different than existing online social networks. The user space implementation could consist of a downloadable application or a browser based Flash or Silverlight application. If the user, Bob, had already created an account, Bob would be presented with an interface showing

their friends profiles. Based upon Bob's configuration, the social application could retrieve profile updates as he navigates to individual profiles or as soon as the application joins an individual profile overlay, reactive versus proactive profile querying.

If this was Bob's first time starting the application, he would be presented with screens asking for his privacy preferences, such as whether or not he wants his information in the directory overlay, if he felt comfortable enough with the idea of people knowing he was a member of the social network and who his friends are. Then the application would ask for personal information to populate his profile and to generate his directory information. At which point, the application would join the overlay and create Bob's private overlay. Bob could then start searching for friends, make friend requests, and respond to friend requests.

Recently, Bob had been thinking about his high school days and was curious if Alice was also a member of this social network, though Bob did not have Alice's e-mail address, just her first and last name. Bob enters Alice's name into the search box and is presented by a list of Alice's. As Bob reviews each of the entries, he recognizes an Alice that is friend's with some of the same people Bob was in high school. Bob selects to become her friend. At which point, the application transparently inserts a friendship request to Alice and signs Alice's certificate so Alice can view Bob's profile. Of course that is because Bob has chosen to allow user-initiated friend requests access to his profile. Alice receives Bob's request, peruses his profile and feels fine becoming friends with Bob, which initiates a transparent process of signing Bob's certificate and placing the result in the public overlay. There is one problem though, when Bob receives Alice's signature and views her profile, he realizes that this is some other Alice. He quickly chooses to defriend her. This causes Bob's application to broadcast a revocation for Alice's signature and to store the revocation in the DHT. Alice, who was viewing Bob's profile, is notified of this sudden loss of trust and while she is able to view the contents of Bob's profile, which she has already accessed and obtained, she can no longer receive updates as members of Bob's overlay prevent her from accessing it.

In another instance, Bob bumped into Carol, who e-mailed Bob a copy of her certificate. Bob points his social application to the certificate, and it verifies that he wants to become friends with the identity associated with it. When he accepts, the application immediately submits a request to become Carol's friend. Carol receives notification and accepts Bob's friendship request. At this point, both Bob and Carol have transparently exchanged signed certificates and have mutual access to each other profiles. As Bob reads Carol's latest news, he remembers a funny personal story and that he would like to share with Carol. So he sends Carol a private message. Carol is offline though. The next time Carol goes online, her social application discovers the message and presents it to her. In this scenario, Bob's application has taken the private message, secured it with her public key and a symmetric key and signed it with

his private key. After which, it inserts the message into the DHT and sends a notice to the event notification system, which detects that there were no listeners. When Carol's application comes online, it queries the DHT receiving the message. Prior to presenting Carol the message, the application decrypts and verifies the message.

V. Challenges

While structured P2P overlays have been well-studied in a variety of applications, their use in social profile overlays raises new interesting questions, including:

1) Handling small overlay networks - P2P overlay research typically focuses on networks larger than the typical user's friend count (Facebook's average is 130[1]). Because social profile overlays are comparatively smaller, this can impact the reliability of the overlay and availability of profile data. A user can host their own profile; however when the user is disconnected it is important that their profile remains available even under churn. It is thus important to characterize churn in this application to understand how to best approach this problem. An optional of per-user deployment of a virtual individual server (VIS) and the use of replication schemes aware of a user's resources provide possible directions to address this issue.

2) Overlay support for low throughput, unconnected devices - devices such as smart phones cannot constantly be actively connected to the overlay and the connection time necessary to retrieve something like a phone number may be too much to make this approach useful. Similar to the previous challenge, this approach could benefit from using a VIS enabling users access to their social overlays by proxy without establishing a direct connection to the overlay network.

3) Reliability of the directory and profile overlay - Overlays are susceptible to attacks that can nullify their usefulness. While the profile overlay does have point-to-point security, in the public, directory overlay, the lack of any form centralization makes policing the system a complicated procedure. While our approach of appending friends list can assist users in making decisions on identity, it does not protect against denial of service attacks. For example, users could attempt create many similar identities in an attempt to overwhelm a user in their attempt to find a specific peer. Previous work has proposed methods to ensure the usability of overlays even while under attack. For the social overlay to be successful, we must identify which methods should be used. A possible approach is to replicate public information within a user's profile overlay thus providing an alternative directory overlay for querying prior to using the public directory overlay.

VI. Initial Results

This environment presents many challenges in terms of providing user seamless similar to that of a centralized environment. Using tools that we developed to evaluate the virtual private overlays, we performed some experiments that focus on connectivity times to profile overlays and querying

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[1]http://www.facebook.com/press/info.php?statistics

data in the directory overlay. Both systems were evaluated using a network modeling tool, though the virtual private overlay technique was also tested using PlanetLab using Brunet [20], a P2P framework supporting virtual private overlays.

To evaluate the public overlay, peers first queried the DHT to obtain a pointer to a certificate and then obtained the certificate in a following request. So the result presented is effectively the time it takes to make two requests into a DHT. Using the network modeling tool, the average time for a network size of 100,000 was 4.04 seconds.

To evaluate the virtual private overlays, we created various sized public and private overlays and determined the time it took for a new peer to join both overlays. The incoming peer joined the public overlay, then queried the public DHT for members active in the private overlay. At which point, the peer created another private overlay node and used these results to bootstrap connections into the private overlay. When the private overlay node became connected, the correct peer on both sides, as determined by the structured overlay, the test was completed. In the PlanetLab experiments, the public overlay consisted of 600 nodes and a random distribution of peers in the private overlay with point-to-point security links enabled, the time to connect was less than 22 seconds. The network modeler focused on larger systems, up to 100,000 peers in both overlays. In these environments, it never took longer than 48 seconds to become connected to both overlays.

VII. CONCLUSION

In this paper, we proposed methods by which a social network can be decentralized through the use of structure P2P overlays. P2P systems, in general, have very nice properties that make them attractive for average users. Namely, they require minimal configuration and organization of resources, in addition, P2P systems naturally handle increased demand to additional peers. Our approach is based upon the use of a multiple overlay system, where all users join a public directory overlay and their's as well as their friends profile overlays. The directory overlay enables users to find and befriend other peers and bootstrap connections into the secure profile overlays. Upon forming a friendship through the directory overlay, peers are given CA signed certificates that allow them to join each other's profile overlay. The owner of the profile overlay acts as CA enabling unilateral dismissal of friendships via certificate revocation using efficient and reliable methods. Additionally, the profile overlay provides a clean abstraction for privacy purposes that simplfies access to profile data, as only members of the overlay have access to the profile. Existing work in the realm of structured overlays describes mechanisms for efficiently and securely storing profile information into the profile overlay. Our proposed system returns control of the social network and more importantly users' identity to the users and eliminates the need for centralized social networks.

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