SNSAPI: A Cross-Platform Middleware for Rapid Deployment of Decentralized Social Networks

Pili Hu*, Qijiang Fan+ and Wing Cheong Lau*

* Department of Information Engineering, The Chinese University of Hong Kong
+ School of Computer Science and Technology, Huazhong University of Science and Technology

Abstract

In this paper, we present the design, implementation and our year-long maintenance experience of SNSAPI, a Python-based middleware which unifies the interfaces and data structures of heterogeneous Social Networking Services (SNS). Unlike most prior works, our middleware is user-oriented and requires zero infrastructure support. It enables a user to readily conduct online social activities in a programmable, cross-platform fashion while gradually reducing the dependence on centralized Online Social Networks (OSN). More importantly, as the SNSAPI middleware can be used to support decentralized social networking services via conventional communication channels such as RSS or Email, it enables the deployment of Decentralized Social Networks (DSN) in an incremental, ad hoc manner. To demonstrate the viability of such type of DSNs, we have deployed an experimental 6000-node SNSAPI-based DSN on PlanetLab and evaluate its performance by replaying traces of online social activities collected from a mainstream OSN. Our results show that, with only mild resource consumption, the SNSAPI-based DSN can achieve acceptable forwarding latency comparable to that of a centralized OSN. We also develop an analytical model to characterize the trade-offs between resource consumption and message forwarding delay in our DSN. Via 20 parameterized experiments on PlanetLab, we have found that the empirical measurement results match reasonably with the performance predicted by our analytical model.

1 Introduction

Online Social Networks (OSN) like Facebook and Twitter have become an essential part of our daily life, e.g. Facebook has over 1 billion monthly active users – 1/7 of the world population. Despite their overwhelming success, the centralized control of these services have led to serious concerns about user privacy, censorship and operational robustness. They are now obvious targets or even vehicles of many totalitarian regimes which constantly seek to monitor and control information dissemination among their people. Some even argues that the centralized and absolute control power associated with OSN services have resulted in many non-user-friendly management styles or policies, e.g. the real world cases reported by IndieWebCamp participants. The aforementioned concerns have motivated the active development of Decentralized Social Networks (DSN) in the recent years with the goal to let users regain better control over their personal data.

Although numerous DSN projects have been launched in the past few years, to date, very few of them have managed to proceed beyond the prototyping or paper-publishing stage. Even the most successful, often cited example of DSN, namely, Diaspora, has only about 0.4 million users, let alone active ones. While this may not be surprising given the wide range of challenges in implementing, bootstrapping and operating a DSN, we believe that the biggest hurdle for the widespread adoption of DSN services is the lack of a gradual transition path for a user to migrate to a DSN without leaving behind a large portion of his/her friends who are likely to stick with only existing OSNs for convenience. As such, even for the minority early adopters who are determined to move to a DSN service for its enhanced privacy protection and possibly richer functionalities, the ability to perform cross-platform socialization will be critical. Towards this end, we propose SNSAPI, a middleware which enables an end-user to aggregate and stitch together all of his/her online social activities and become a node in a “meta social network” as illustrated in Fig. 2. In fact, many existing SNS users already consciously

1In this paper, we will also use another term: Social Networking Services (SNS) to refer to not only OSN services, but also other generic communication channels, e.g. RSS and Email, that can be used to support online social interactions
2http://newsroom.fb.com/download-media/4227
3http://indiewebcamp.com/
4Sept 25, 2013, estimated by https://diasp.eu/stats.html
or subconsciously “stitch” the heterogeneous platforms together by selectively relaying messages across different platforms after some manual filtering and editing. For example, after reading a “juicy” gossip from a blog, you may forward it manually to your personal friends on Facebook. Such manual cross-platform forwarding operations can be viewed as the formation of a meta social network which overlays on top of the existing SNS. Our objective is to provide the tools and systems that can help users to better perform cross-platform socialization. We expect those tools and systems can gradually detach users from existing centralized OSNs and allows a smooth transition to the decentralized ones. In summary, this paper has made the following technical contributions:

- After reviewing related work in Section 2, we analyze the challenges of building a DSN and propose a meta social networking approach in Section 3.
- As described in Section 4, we have designed, implemented, and released multiple iterations of an open-source middleware called SNSAPI to support cross-platform socialization over existing SNS. Sample applications built using SNSAPI are also presented to demonstrate its flexibility and extensibility.
- Design choices, observations and maintenance experience of SNSAPI are discussed in Section 5.
- We have conducted an experimental deployment of a 6000-node DSN over PlanetLab based on the SNSAPI middleware and measured its empirical performance. As a comparison, we also provide an analytical model to characterize the performance of the system with results presented in Section 6.
- We conclude our findings and propose follow-up work for the future in Section 7.

2 Related Work

To overcome the drawbacks of centralized SNS, Decentralized Social Networks (DSN) such as Diaspora [11], Musubi [12] and OneSocialWeb [3] have recently been proposed and implemented. According to our classification in Section 5, most works are Distributed Social Network (DisSN). Two examples of federation protocols are OneSocialWeb [3] and Ostatus [5], which are not bound to any particular software implementation. For the DisSNs, there are several different system architectures. PrPl [19] and Musubi [12] are two examples of fully decentralized systems. Each user corresponds to a DSN node and they only have the view of their direct connections. Diaspora [11] is a super-node based system. Users can setup their own “pod” (server) or register on other “pods”. PeopleNet [18] and RFlex [16] are systems combining heterogeneous communication technologies. PeopleNet [18] first routes messages to the neighborhood of the target using cellular infrastructures and then leverages opportunistic forwarding to complete the last hop(s) of the delivery. RFlex [16] targets spontaneous group messaging and transparently switches between the cloud backend and NFC/D2D connections. ePOST [17] and PeerSoN [10] are two DHT-based solutions. While ePOST [17] follows DHT loop for message delivery, PeerSoN [10] only uses DHT to locate users before establishing direct connections for data transfer. These systems and protocols adopt a clean-slate design and have few or none provisions to support migration. Although some systems have import functions from existing service providers, they still have the lock-in effect because they do not give a common data structure abstraction to support convenient export and inter-operation.

In terms of the ability to perform cross-platform operation, there are many existing aggregation services on the Internet. For example, IFTTT [2] abstracts Internet-based information services as “channels” and allows users to define “IF-This-happens-Then-do-That” (IFTTT) forwarding recipes. Yahoo Pipes [8] supports fewer platforms but allows more sophisticated processing by designing a story-board of logical operations (e.g. condition, loop, etc). Yoono [9], SocialOomph [6], and Hootsuite [13] are other example services which provide partial interoperability between heterogeneous platforms with some basic personalization functions. While these services are useful for novice users, they have at least one of the following problems: 1) Only configurable but not programmatic, which severely limits their functions; 2) Non open-source and thus less reusable for automation; 3) Not readily extensible to other platforms. The open-source projects, OpenSocial [4] provides an abstraction for different OSNs but it requires a steep learning for simple tasks. ThinkUp [7], an open-source web service, reads messages from several OSNs and stores them in a local database to facilitate the mining of important information. However, it does not provide a comprehensive abstraction of heterogeneous SNS like SNSAPI and its web service nature also requires more infrastructure support (e.g. LAMP environment), making it hard to run under resource critical environment, e.g. mobile devices.

3 A Meta Social Networking Approach for Decentralization

Before delving into the details of our approach for the decentralization of SNS, we briefly discuss three alternative paths towards this goal. According to the degree of decentralization, there are three types of DSN as illustrated in Fig. 1.

- Distributed Social Network (DisSN). In a distributed social network, nodes are homogeneous and runs the same software package – the solid circles. They use the same protocol – the solid lines. Most DSN proposals and implementations are actually DisSN, e.g. Diaspora [1].
Musubi [12] etc. In this sense, the DisSN approach is software-package oriented.

- Federated Social Network (FedSN). Nodes in a FedSN can adopt different software packages – the “solid” and “dashed” circles in Fig. 1(b) as long as they support a common protocol, a.k.a. the federation protocol represented by solid lines in Fig. 1(b). Email and OStatus [5] are two examples of this approach. In short, FedSN is protocol oriented.

- Meta Social Network (MetaSN) [14]. MetaSN is the network of different social networks: In this case, 1) there are many different software packages (server/client implementations) and 2) nodes may use different protocols – the solid or dashed lines in Fig. 1(c). Information diffusion on MetaSN does not rely on a single software package or a single protocol. Instead, it is done via multi-hop bilateral communications. There is a common object to hold information and it can have different representations on different links. In other words, MetaSN is object oriented. One can see that MetaSN is highly reminiscent of our real life social network in which different people may talk different languages. Socialization is not dependent on a single language but on multi-hop bilateral communications.

We have designed a cross-platform middleware, SNSAPI, to realize the MetaSN approach described above. Fig. 2 illustrates a MetaSN formed by SNSAPI and existing OSNs. Users running an SNSAPI-based App can socialize with users of mainstream OSNs, e.g. Twitter and Facebook, using the corresponding protocol. They can also conduct the same types of online social activities with each other in a transparent manner via other communication channels supported by SNSAPI, e.g. (E)mail and (R)SS. In contrast, the Twitter user and the Facebook user at bottom of the figure cannot communicate with each other due to the lack of a common protocol. SNSAPI users also have the ability to aggregate, filter and/or relay messages in this MetaSN. As such, the SNSAPI-based nodes can enable multi-hop social interactions among users who are originally locked into their own silo of existing OSNs. In short, the SNSAPI can help to jumpstart and then grow a DSN in an incremental, gradual manner.

### 4 SNSAPI Design and Implementation

Our cross-platform middleware, SNSAPI, is designed based on the following principles: 1) Focusing on solving the 80% problems; 2) Staying open to support future service evolution; 3) Trading execution performance for script development efficiency. In this section, we first introduce the overall architecture and the core abstractions. After that, we present some sample applications to show the flexibility and programmability of SNSAPI.

#### 4.1 Overall Architecture

Figure 3 depicts the architecture of SNSAPI, which consists of the following three layers:

- **Interface Layer (IL).** SNSBase is the base class for all kinds of SNS and can be derived to implement real logic that interfaces with those platforms. In SNSAPI terminology, the module containing derived classes is called “plugin”; the derived class from SNSBase is called “platform”; the instance of the class is called “channel.” Message and message list classes are also defined in this layer to provide the core abstraction to support MetaSN.

- **Physical Layer (PL).** There are many common operations when interfacing with different SNS, e.g. HTTP, OAuth, error definition, etc. We implement them in the PL so that plugins can reuse them. To enhance flexibility, we provide a wrapper class for most 3rd party modules so that users can substitute (all or part of) them with others without modifying the core of SNSAPI.

- **Application Layer (AL).** To reduce repeated works in batch operations, we developed a “Pocket” class in AL. It is a container to hold multiple channels. For most applications, Pocket should be the Service Access Point (SAP) to SNSAPI. In this way, end users can enable new channels by simple configurations and no intervention from App developer is needed.
4.2 Abstraction of Interfaces

We abstract the interfaces of different SNS platforms to support a set of common primitives. Since not all platforms have direct support for those primitives, we often have to translate the functions in order to provide a unified view to the upper layers. The three fundamental primitives and some examples are as follows:

- **auth** – This name is short for either “authorization” or “authentication”. For example, in order to access OSNs like Facebook, we need to go through the OAuth flow. In order to access email platform, the usual approach is to authenticate via username/password.

- **home_timeline** – This function gets the latest messages targeted to the user on a certain channel. For an OSN, it retrieves the home timeline. For Email platform, this function gets latest messages from INBOX, which resembles the home timeline of OSNs. home_timeline is the basic “read” function for a platform.

- **update** – It provides the basic “write” function for a platform. On an OSN, this can be a status update, blog update, or others, depending on the platform. On RSS platform, this function writes a new entry to the feed.

Although home_timeline and update can be named as “read” and “write” from a modeling viewpoint we stick to the OSN convention. This philosophy is adopted throughout SNSAPI: Instead of providing a unification scheme from scratch and requiring other existing/new OSN platforms to follow (as in the case of OpenSocial [4]), we adapt SNSAPI to existing platforms and work out a common divisor. From the basic primitives, two more “write” functions can be derived: reply and forward. The definition is different across OSNs due to differences in the positioning of each platform. The model of “write” operations observed on existing OSNs are further discussed in Section 5.2. Following are the definitions within the context of SNSAPI:

- **reply** – By replying a message, the user is able to add comments to the original message. If Bob replies a message posted by Alice, she will get a notification in some way. Where to post the comment is not regularized and can be different across platforms.

- **forward** – By forwarding a message, the user is also able to add comments to the original message. If Bob forwards a message posted by Alice, she may or may not get a notification, depending on the platform. However, the forward message together with the original message will appear in the message update list of Bob. Note that forward can be readily implemented via update and we have already included this cross-platform forwarding function in the base class. Plugins can implement platform-specific forwarding functions to enrich the functionalities.

4.3 Abstraction of Data Structures

As is discussed in Section 3, we need to design a common object to allow the formation of MetaSN. Message is the most important data structure SNS but comes in different forms, e.g. JSON object returned by the API of one OSN, RFC822 formatted texts of an email, or an XML entry of a RSS feed. Even if we only consider conventional OSNs, the JSON objects returned can still be quite different. In order to facilitate cross-platform operations, we abstract a Message object. It has the following four components:

- **MessageID** – It contains sufficient information for one to identify a Message across platforms. It is only designed to be used by SNSAPI plugins. Users are not supposed to tap into the fields of MessageID.

- **Mandatory fields** – This includes userid, username, text, time, and attachments. Those fields are actually the “Greatest Common Divisor” of different SNS platforms according to our year-long refactoring experience. The attachments field is used to convey non-text-based information like URL, image, and video files and can be an empty list.

- **Optional fields** – Although mandatory fields provide a common base to perform cross-platform socialization, we may sometimes expect a richer set of functionalities. Examples are like the “like count” and “share count” on some OSNs. Those fields are also unified via reformatting and re-assembling of the raw response from OSN providers. App developers should test the existence before using it since they are optional.

- **Raw data** – This is the original data obtained from an OSN service provider. It gives the largest amount of information. However, App developer should refer to the manual of specific platforms in order to use it.

4.4 Plugins

Plugin implements the logic to enable transaction with any specific SNS platform. A standard plugin implements the 5 interfaces defined in Section 4.2. It also performs essential data conversions from raw response to
the data structures regularized in Section 4.3. Following
is the list of plugins we have already developed:

- Renren, Sina Weibo, and Tencent Weibo – We
  started with these platforms, which are the three largest
  OSN services in mainland China. The plugins use REST-
  ful APIs of the corresponding OSN. Based on the experi-
  ence of developing these plugins, we have derived some
  common building blocks, e.g. HTTP, OAuth, and put
  them in the Physical Layer (PL).

- RSS, Email and SQLite – These three platforms are
  not regarded as social networking services in the tradi-
  tional sense. However, they are fundamentally the same
  as the OSNs mentioned above, i.e. a means to read/ write
  messages, so it is easy to make them SNSAPI-compliant.

- Twitter and Facebook – These two platforms are de-
  veloped based on existing 3rd-party wrappers. Their ex-
  istence shows that one can easily adapt existing wrappers
  to be SNSAPI-compliant, so as to enable seamless cross-
  platform operation on new platforms. Pros/ cons of using
  3rd-party wrappers are further discussed in Section 5.4.

4.5 Applications

The so-called SNSCLI, a Command-Line Interface in
form of a Python shell, has been developed as an appli-
cation (app) of SNSAPI. Some typical usages include: 1)
use SNSCLI to interface with programmes/scripts written
in other languages via STDIN/ STDOUT; 2) support interac-
tive debugging for a platform. Researchers have also
developed crawlers in SNSCLI using the Vertical
Interfaces (Section 5.1) to facilitate the collection of data
over large-scale OSNs.

After our third round of refactoring at the begin-
ing of 2013, an open-source contributor from GitHub,
Tommy Alex, built a Graphical User Interface (GUI)
called SNSGUI (Fig. 4(a)) which runs on major com-
puting platforms including Linux, Windows, and OS X.
Later Tommy also ported SNSAPI to Android with a
new UI (SNSDroid in Fig. 4(b)). It is noteworthy that
Tommy managed to develop SNSGUI and SNSDroid in
10 days and 7 days, respectively. Before developing
SNSGUI, he has no prior knowledge of SNSAPI. This
demonstrates the flexibility and portability of SNSAPI.

We have also developed another App called
SNSRouter [15] which provides a web UI and a
ranking framework for cross-platform socialization.
Based on the unified abstraction of SNSAPI, the UI was
developed in one week. User efficiency is improved
due to the convenient cross-platform operations plus
prioritization of incoming messages. Among all kinds
of benefits, it is worth to note that SNSRouter can
readily become a node in an ad hoc DSN by properly
configuring some channels supported by SNSAPI.

Due to space limit, we cannot present other existing
Apps that have been developed for SNSAPI, e.g. au-
tomatic forwarder, automatic replier, automatic backup
script. They can be found in our open-source repository.
They all share one distinguishing feature when compar-
ting to their traditional counterparts: these Apps all work
in a platform-independent fashion and are ready to oper-
ate on new platforms.

5 Discussions on Design Choices and Key
Observations

Since the initiation of SNSAPI project, we have gone
through three major rounds of refactoring. The project
is still under active development and there will be more
forthcoming features. In this section, we provide a com-
prehensive discussions of our experience in designing,
maintaining and refactoring SNSAPI. The philosophical
shifts and key observations extracted from our experi-
ence may shed light on future design of similar systems.

5.1 Vertical and Horizontal Interfaces

We categorize the functions provided by different social
platforms into three groups. As is described in Section
4.2 base functions include auth, home_timeline and
update; derived functions include reply and forward. Any
other OSN-specific functions are regarded as extra
functions, e.g. album list query and like. Extra func-
tions are not very common across platforms, so we do
not try to unify them. Fig. 5 illustrates the three types of
functions. Based on this categorization, we can deal the
aforementioned functions in a horizontal manner.

While providing Horizontal Interfaces is the original
goal of SNSAPI, we found that some users expected
SNSAPI to be a full-fledged wrapper for a given OSN platform. Such mis-matched perception roots from the fact that there exists many ad hoc wrappers in all kinds of languages for a wide range of OSN platforms. We realized that the support of the Horizontal Interfaces alone will not be adequate: in order to provide a unified set of horizontal interfaces, we are forced to trim down existing operations in some platforms which results in a loss of functionalities. To overcome this dilemma, we have to expose an additional set of Vertical Interfaces which support a richer set of functions but are allowed to be drastically different across various platforms.

The Horizontal Interfaces can be used to systematically stitch different social platforms together and they require a very mild learning curve. The Vertical Interfaces must be used with the assistance of documents from service providers. They are not the recommended way of using SNSAPI because Apps have to deal with upcoming changes from the OSN providers. Nevertheless, developers may find it useful when they are dealing with a specific platform, e.g. large-scale crawling as is used in Section 6.

5.2 The Model of “Write” on OSNs

Although SNSAPI tried to conform to existing services from the very beginning, the models provided by existing platforms may not be ultimately ideal. We observed different models of “write” operations, i.e. update, reply and forward, from existing OSNs. A summary of the write models is presented in Table 1 and we discuss the advantages/disadvantages as follows.

- Twitter: There is only one operation – update. Twitter has a “retweet” built-in (Official ReTweet, ORT) but users find it not very useful because they can not put comments while retweeting. Towards this end, many Twitter users are still using the old user-invented conventions (User-invented ReTweet, URT) by updating a status in the form: RT @user message. This user invented “RT” notation is closer to the “forward” operation defined in Section 4.2. If the “@user” appears at the beginning of a status update, it is regarded as a “reply”. In other words, the reply operation on Twitter is still an update operation in essence.

- Facebook: There are three operations regarding a status – update, share, and reply. Facebook’s reply is the same as our definition in Section 4.2. We will term this type of reply as Facebook-Style Reply (FBSR), in contrast to the above mentioned Twitter-Style Reply (TSR). FBSR is more privacy preserving but SNSAPI will lose track of those reply messages because they do not enter the timeline of the replier. When “share” one object on Facebook, users can add comments to it. At first glance, it appears as a forward operation in our context. However, all share operations go to the original status and are threaded there. Compared with our notion of “forward”, this “share” cannot track the forwarding traces. In this case, it is better to textually construct a “forward” message by the update method directly (i.e. a URT) on Facebook. In fact, the general forward method in SNSBase is designed to perform a URT if the platform does not have a built-in “forward” function in our sense.

- Renren, Sina Weibo, Tencent Weibo: There are three “write” operations – update, forward, and reply. In terms of product positioning, Renren is a Facebook-like service in China; Sina Weibo and Tencent Weibo are two Twitter-like ones. Interestingly, their write models are the same and partly differ from both Twitter and Facebook as presented in Table 1.

5.3 Pull Channel vs. Push Channel

We can abstract all SNS communications by directed graphs. For undirected graphs, we just add both directions of a connection. This graph encodes the potential message flow, i.e. the follower-followee relationships. One fundamental design choice for a social network is whether to let a follower pull messages from a followee or let a followee push messages to his/her followers. In the centralized scenario, this is only a matter of how database is synchronized. The service exposed to users does not have pull/push issues. In contrast, this design choice can result in very different resource usage under the decentralized scenario. In SNSAPI, both Pull-Channel models, e.g. RSS, and Push-Channel models, e.g. Email, are supported. Since they have different properties, it is desirable to choose the model on a per link basis, rather than pin down a global setting.

5.4 Use 3rd Party Wrappers for Plugins

Before the launch of SNSAPI, there were already many ad hoc wrappers for different OSN platforms. Those wrappers are easy to use as long as one only wants to deal with a specific platform. Whether to use 3rd party wrappers has been a design issue ever since the initiation of SNSAPI. When we tried to add Twitter support to SNSAPI, we found an already established 3rd party wrapper, python-twitter. By adapting its interfaces to follow the SNSAPI convention, we managed to support Twitter platform in half a day. This shows that 3rd party wrappers can enable rapid prototyping for new platforms and potentially make the upgrade process easier.

| Platform              | SNSAPI Model | Twitter Model |
|-----------------------|--------------|---------------|
| Facebook              | FBSR         | update (TSR)  |
| Renren                | FBSR         | update (URT)  |
| Sina Weibo            | FBSR         | URT           |
| Tencent Weibo         | FBSR         | URT           |
| SNSAPI                | FBSR         | URT           |

Table 1: Write models of different OSN platforms
There are also some disadvantages like being less flexible for modification. We have a qualitative comparison shown in Table 2. As we can see, there is no definite answer for this design issue at present. SNSAPI, together with the community, is still actively evolving and trying to test out those alternative solutions.

### 5.5 Friend-List Management

Friend-list management for OSNs is so far only available via platform-specific Vertical Interfaces (Section 5.1). As the designers of SNSAPI, we have two strong reasons not to horizontally abstract friend-list management functions. Firstly, friend-list management is not a common and frequent operation (so-called 80% problems), so Out-Of-Band (OOB) management is acceptable. Secondly, the Channel-list in SNSAPI is actually an implementation of friend-list under the fully decentralized scenario. Consider a social network formed using the RSS platform (Section 6). One user can update status to a RSS feed and publish it to some common location known by his/her friends. The other users can instantiate a RSS channel with the URL pointing to this location. In this way, the SNSAPI users form a DSN and the channel-list of SNSAPI is actually the friend-list. Instead of unifying friend-list management functions on different OSNs, a better way is to build a channel management application on SNSAPI to provide a more elegant abstraction.

### 5.6 Use Existing Services as Aggregators

Although our primary goal is to evolve towards a decentralized social networks structure, centralized OSN platforms are (and will remain to be) very important components under the bigger Meta Social Network paradigm. As discussed before, one reason is that those centralized OSN services are already established and we must avoid link loss during the migration process. Another reason is that centralized OSN platforms can actually serve as good message aggregators. Consider a special platform we built in SNSAPI – RenrenStatusDirect. With this platform, one can directly configure the list of users he/she wants to follow. Without explicitly adding the target parties as friends via the request/approval process, the SNSAPI user can readily get their public status updates. This approach gives us a clean model for friend-list management as is discussed in Section 5.5. However, more resource is used for querying those “friends” one by one. The alternative approach, adding those friends on an OSN first and configure only one normal channel in SNSAPI, is more resource saving because a single query is enough to retrieve an aggregated timeline.

### 6 Deployment of a 6000-node DSN on PlanetLab

This section describes our experimental deployment of a large-scale DSN on PlanetLab using SNSAPI. After instantiating a network of 6000 SNSAPI-based nodes on PlanetLab, we replay real-world update/forward activity traces collected from Sina Weibo, one of the top OSNs in China. To our best knowledge, this is not only the largest experimental validation and systematic evaluation of any DSN solutions in the literature but also the first one which involves the replaying of real OSN traces in this scale.

#### 6.1 Architecture of the Experiment

Our experiment platform has three major components:

- **SNSAPI**: The cross-platform middleware described in Section 1 – the basic building block for this DSN.
- **Bot**: When the experiment starts, a bot running on each instance of a SNSAPI-based node will continuously perform four actions: 1) Periodically query timeline from their friends (home_timeline); 2) Update SNS status according to a schedule (update); 3) Forward status according to a data-driven user behavior model to be described in Section 6.3 (forward); 4) Monitor nodal resource usage. We define an important system parameter called Query Gap (QG) which is the interval between two rounds of the timeline query action. In our experiment, we use a system-wide constant value for QG and show that this simple strategy suffices for the initial formation of a medium sized DSN (e.g. 6000 nodes). To avoid synchronization problems, every bot sleeps for a uniformly random duration between 0 and QG before the issuing its first timeline-query to its neighbours.
- **PlanetLab Manager (PLM)**: PlanetLab is a global research infrastructure widely used to evaluate new networking systems. PlanetLab nodes provide no guarantee on their service availability and can go online/offline at any time. This is ideal to evaluate the robustness and elasticity of our proposed DSN architecture. We have also developed a toolbox to manage our experiment on PlanetLab which includes modules for 1) base environment deployment such as the nodal installation of Python2.7 and virtualenv\(^3\) 2) Node-screening which help us to avoid

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\(^3\) Incidentally, the crawling of Sina Weibo for trace data is performed by another App of SNSAPI.

\(6\) http://www.virtualenv.org/
machines with large time-drift and those which are behind incompatible firewall; 3) Experiment workflow management like workspace cleaning, bot distribution, initialization/starting/terminating each experiment, and nodal log collection.

In principle, we can connect our bots through all kinds of platforms supported by SNSAPI. In reality, most OSN platforms require user’s intervention before SNSAPI can access it: App-key application, configuration on the OSN, and completion of an authorization flow. To allow automatic deployment of thousands of bots, we choose to use RSS in this experiment. For practical deployment in the wild, each pair of SNSAPI users can choose their preferred communication channel as our MetaSN model only requires bilateral communications.

6.2 Trace Collection from a Sina Weibo

We collected real data from Sina Weibo, the largest microblogging service in China, to evaluate the proposed ad hoc DSN based on SNSAPI. We leverage the Vertical Interface (Section 5.1) of SNSAPI to crawl the profile, status update, forwarding history, as well as the followee list of each user. In order to get a meaningful trace to evaluate our system, we need a tightly knitted group of active users with content frequently originated from and forwarded within the group. The following heuristic is used to identify such group of candidate users: 1) We use 60+ users categorized as “programmers” by Sina Weibo as our seed; 2) From the forwarding history of these seed users, we extract 6000+ more users. The overall development plus execution time of this SNSAPI-based Sina Weibo crawler is less than two days. This shows the remarkable development and execution efficiency provided by SNSAPI. In total, we collected 33GB of raw JSON data, which includes 12 million status update/forward actions, involving 480,000 users in the forwarding chain.

6.3 Data-Driven User Behavior Model

One of the primary reasons for users to use OSN is to identify and disseminate interesting messages. Using only passive measurements, it is impossible to determine what messages are seen and what messages are interesting to each user. As a surrogate, we consider the forwarding behaviors, which are strong indicators of user interest and message relevance. A key objective is to determine the additional forwarding latency caused by our SNSAPI-based DSN when comparing to that of a centralized OSN.

Consider the process illustrated in Fig. 6: User $u_o$ posts the original message $m_o$ at time $T(m_o)$; User $u_f$ forwards this message by posting $m_f$ at $T(m_f)$. The following factors will affect the end-to-end delay from $T(m_o)$ to $T(m_f)$:

- User online/offline pattern: From $T(1)$ to $T(2)$ the user is offline. The original message $m_o$ is posted during this period but cannot be forwarded by $u_f$.
- System delay: This is the time required by $m_o$ to go from $u_o$’s database to $u_f$’s database. For a centralized OSN, there is conceptually only one database so this delay component should be negligible. That is, as soon as $u_o$ post $m_o$, $u_f$ is able to get $m_o$ in his/her database. For DSN, it can take considerable time for $m_o$ to go to $u_f$’s database, which may cause a major increase in latency.
- Application delay: Users rely on certain application to retrieve their home timeline, e.g. the web UI or the mobile App of Facebook. Additional delay is added due to various reasons like refreshing frequency or message re-ranking strategy. Users rely on many different applications to access social networks, so this part of delay can be highly variant.
- User delay: After the above steps, $u_f$ already has $m_o$ in the home timeline. In order to identify the interesting messages, $u_f$ will spend time on reading the messages, watching attached videos, or even following the embedded links. Additional delay is added until $m_f$ is finally posted at time $T(m_f)$.

Our analysis of the user action cycle shows that: 1) System delay causes the major difference between centralized and decentralized social networks; 2) Factors like application delay and user delay are too complex to be characterised by simple models; 3) Precise user online/offline pattern is only available to the SNS providers; 4) The end-to-end delay, i.e. $T(m_f) - T(m_o)$, is observable via passive measurement. Towards this end, we adopt an overall data-driven model, established based on two assumptions: 1) A bot is always online, trying to identify and disseminate interesting messages; 2) There is an intrinsic delay for each message to be forwarded. We use $T(m_f) - T(m_o)$ to model the intrinsic delay for each message. Suppose one bot in our DSN see the message $m_o$ at time $t$, then the forward time $T(m_f)$ is determined by the two rules:

- 1) If $t < T(m_f)$, let $T(m_f) = T(m_o)$
- 2) If $t > T(m_f)$, let $T(m_f) = t$

The first rule is to respect the delay observed from real traces. If our DSN delivers messages quickly enough, then the bot waits until the intrinsic delay is passed.
The second rule comes from the bot assumption. Since the bot is always online and the message is seen after the intrinsic delay period, it forwards the message immediately. Fig. 7 depicts this data-driven user behavior model. Based on this model, our core performance metric is the Extra Forwarding Delay (EFD), defined as $T(m_f') - T(m_f)$.

6.4 Experiment Setup

To launch our experiment, we first distribute 6733 bots to 450 PlanetLab nodes randomly. The experiment lasts for one day wall-clock time. We filter out update and forward activities of those users from Aug 1, 2013 0:00:00 to Aug 1, 2013 23:59:59 (UTC). During this period, there are 1168 messages originated by the 6733 Sina Weibo users and are further forwarded within this group. The Query Gap (QG) is empirically set to 5 minutes. In real life, users can manually trigger the home timeline function if one wants to get the updates of his friends immediately.

After a replaying a 24-hour real trace, we collect 57GB of logs from the PlanetLab nodes. We then compute the average resources consumed by each bot. The histograms and summary statistics are presented from Fig. 8(a) to Fig. 8(f). Notice that the nodal memory usage includes both the bot and SNSAPI. Without the extra bot logic, the typical value is 10MB, i.e. for running the SNSCLI. There are two major disk-space consumption in this experiment. First is the RSS feed file: Each bot writes its feed to a directory which is then served by a lightweight HTTP server. Second is a SQLite database to support asynchronous operations via the buffering of incoming and outgoing messages. From Fig. 8(e) and Fig. 8(f), we see an exponential decay and the typical values are smaller enough to hold in the RAM so that disk storage and access can be avoided in real applications.

The c.d.f. and some percentiles of Extra Forwarding Delay (EFD) are shown Fig. 9. We see that 68%, 73%, 88% and 99% messages are forwarded with no EFD, $<1\text{min EFD}$, $<10\text{min EFD}$ and $<1\text{hour EFD}$, respectively. Since social networking is not a real-time service and there are already considerable delay other than system delay, we remark that this EFD is acceptable.

The mild resource consumption and small EFD shows that SNSAPI is a viable solution to enable rapid and incremental deployment of an ad hoc DSN. Furthermore, users can run SNSAPI not only on all major desktop operating systems (as demonstrated in Section 4.5) but also resource-constrained devices like smartphones.

6.5 Analytical Model for the Pull-based Backbone

Although SNSAPI supports both pull and push channels (Section 5.3), we only used pull channels, namely RSS, in our experiment. The major parameter for this pull-based DSN is the timeline Query Gap (QG) and we denote it by $h$. We want to characterise the relation between $h$ and the following random variables (r.v.):
• \(R\): An abstract notation for certain resource. It is an r.v. parameterized by \(h\). The expectation of \(R\) is inversely proportional to \(h\). Without loss of generality, we let \(E[R] = \frac{1}{h}\).

• \(C\): CPU usage. \(C = C_b + \beta_h R\). \(C_b\) is the CPU usage of the bot logic, i.e. checking and forwarding messages every second. It is constant w.r.t. the poll parameter \(h\). \(\beta_h R\) is the resource consumption of SNSAPI. \(\beta_h\) is the coefficient to be fit later. Taking expectation, we have:

\[\beta_h E[R] = E[C_b] + \frac{1}{h} EC\]

However, we already know from the system design that bot logic will take up the major portion of CPU usage. We expect \(\beta_h\) to be a near-zero coefficient.

• \(M\): Memory usage. As \(h\) varies, only query frequency is changed. Memory consumption is not affected by it. It is a r.v. independent of \(R\) and \(h\).

• \(D\): DISK I/O. \(D = \beta_h R\). There are two parts of major disk I/O as discussed in Section 6.4. The maximum size of RSS feed and SQLite DB are 20KB and 8MB, respectively. In real applications, they can be fully held in RAM, thus eliminating all disk I/O. Since this only adds a constant to \(M\), we do not build an individual model for disk I/O.

• \(H\): HTTP usage. In our experiment, the major network I/O is caused by HTTP. Others like domain name lookup only create very little network load. We measure HTTP usage from the followee’s point of view. \(H\) is the number of HTTP query one bot receives and \(H_k\) is the size of HTTP query it serves. Since the traces are from a micro-blogging service, the size of messages are upper bounded. Thus, we can assume \(H \approx H_k\) and formulate the following relationships: \(E[H] = \beta_m E[R] = \frac{1}{h} \beta_m\) and \(E[H_k] = \beta_{H_k} E[R] = \frac{1}{h} \beta_{H_k}\).

• \(\Delta\): The delay from the original message to the forwarding message in our DSN system. This depends on \(I\), the intrinsic delay.

Most of the relationships are clear and ready for model fitting. The end-to-end forwarding delay \(\Delta\) can be characterized based on the following additional assumptions:

• A1: \(h\) is the dominant delay component in this system so that other small delays can be neglected.

• A2: We assume an ideal Internet connection. Given current typical access rate and the size of RSS feeds in Fig. 8(e), one bot can finish the query to all its neighbors within seconds. This is also very small compared to typical values of \(h\) so that we can further assume one round of query can be completed immediately upon its issuing.

In reality, the forwarding traces form a tree. Since our target is \(E[\Delta]\), we can invoke the linearity of expectation, namely \(E[\Delta]\) is the summation of per-segment delay. In this way, we essentially decompose the tree into individual forwarding chains. Denote the length of forwarding sequence by \(L\), which will be fit later using data from real traces. Then the expectation of end-to-end delay can be expressed as: (total expectation)

\[E[\Delta] = \int E[\Delta|L = l] \Pr\{L = l\} dl\]

Next, we focus on the analysis of a chain of length \(l\). We denote the original message as \(m_0\) and the forward messages as \(m_1, \ldots, m_l\). We denote the absolute time when message \(m_k\) is posted as \(T(m_k)\). Let \(\Delta_k\) be the per-segment delay so that \(\Delta_k = T(m_k) - T(m_{k-1})\) according to definitions. The per-segment intrinsic delay is denoted as \(I_k\).

Denote the absolute time that a bot starts to pull messages by \(H\). Note that the bots sleep a uniformly random duration before the first pull. Then we have \((t - H) \mod h\sim U[0,h]\) for any fixed time \(t \in \mathbb{R}\). We use the deferred decision principle to study the forwarding behaviour of \(m_k\). That is, we first fix \(T(m_{k-1}) = T(m_0) + \sum_{j=1}^{k-1} \Delta_k\), and defer the realization of r.v. \(H\). \((T(m_{k-1}) - H\) is the duration from first pull to the post of \(m_{k-1}\). By modular \(h\), we get the time elapse from last pull to the post of \(m_{k-1}\). Then \(W = h - ((T(m_{k-1}) - H) \mod h)\) is the waiting time until next pull and we have a compact expression for \(\Delta_k\) according to the data-driven user behavior model described in Section 6.3.

\[\Delta_k = \max\{I_k, h - ((T(m_{k-1}) - H) \mod h)\}\]

If we fix \(T(m_{k-1})\), \((T(m_{k-1}) - H) \mod h\sim U[0,h]\) and further \(W = h - ((T(m_{k-1}) - H) \mod h)\sim U[0,h]\). Then the overall delay conditioned on the length being \(l\) is:

\[\Delta |_{L=l} = \sum_{k=1}^{l} \Delta_k = \sum_{k=1}^{l} \max\{I_k, W\}\]

We now calculate the Extra Forwarding Delay (EFD), denoted by \(\Delta_{\text{EFD}}\). This is to use end-to-end delay in our system minus intrinsic delay (the delay expected in a centralized system):

\[\langle \Delta_{\text{EFD}}\rangle |_{L=l} = \langle \Delta - I\rangle |_{L=l} = \sum_{k=1}^{l} \Delta_k - \sum_{k=1}^{l} I_k = \sum_{k=1}^{l} \Delta_k - I_k\]

Taking expectation, we have:

\[E[\Delta_{\text{EFD}}|L = l] = \sum_{k=1}^{l} E[\Delta_k - I_k] = \sum_{k=1}^{l} E[\max\{I_k, W\} - I_k]\]

where \(W\) is a uniform random variable in \([0,h]\). The overall EFD is:

\[E[\Delta_{\text{EFD}}] = \int E[\Delta_{\text{EFD}}|L = l] \Pr\{L = l\} dl\]

We assume \(I_k\) to be i.i.d. and use \(I\) for a shorthand. Then the expression is simplified to:

\[E[\Delta_{\text{EFD}}] = E[I] E[\max\{I_k, W\} - I_k]\]

We can fit \(I\) and \(L\) from real traces and give the final expression for EFD.
6.6 Model Evaluation using Experimental results

In this section, we run 20 experiments parameterized by \( h \) and compare the corresponding empirical measurement results with those predicted by the analytical model. We replay 5 days worth of traces from Aug 1, 2013 0:00:00 to Aug 5, 2013 23:59:59 (UTC) to drive the experiment in order to reduce diurnal variation. To make the experiment tractable and also reduce PlanetLab machine variance, we accelerate the experiment time by 12 times. That is, the 5-day traces are replayed in 10 real-life hours. We also trim the DSN topology to 4881 nodes by excluding those nodes having no update or forward activities during this period.

6.6.1 Fitting Intrinsic Delay and Forwarding Sequence Length

The empirical distribution of \( I \) and \( L \) are plotted in Figs. 10(a) and 10(b). Observe that the intrinsic delay of messages follows a power-law decay while exponential decay is exhibited by forwarding sequence length with their distributions given by:

\[
p(i) = \frac{1}{Z_i} \cdot 10^{ih} \quad , \quad p(l) = \frac{1}{Z_l} 10^{cl+d}
\]

where \( a = -1.03, b = 4.5, c = -0.7 \) and \( d = 4.2 \) based on fitting against experimental measurements. The normalization factors can be calculated as:

\[
Z_i = \int_1^{30265} r^i 10^h \, dr = 10^h \left[ \frac{1}{a+1} (i_{\text{max}})^{a+1} - \frac{1}{a+1} (i_{\text{min}})^{a+1} \right]
\]

and

\[
Z_l = \int_1^{\infty} 10^{c+d} \, dl = -1 \frac{1}{c \ln 10} e^{(c+d) \ln 10}
\]

where \( i_{\text{max}} = 30265 \) and \( i_{\text{min}} = 1 \) are the maximum and minimum intrinsic delay from observed from the trace data.

6.6.2 Closed Form expression for Extra Forwarding Delay

The expression for EFD, \( E[\Delta_{\text{EFD}}] = E[L] E[\max\{I, W\} - I] \), can be derived in two steps. Instead of going through the fitted parameters, we estimate \( E[L] \) directly by averaging over the forwarding sequence lengths and get

\[
E[L] = 1.14.
\]

This is to reduce possible errors in parameter fitting. The second part can be solved by double integral:

\[
E[\max\{I_{\text{max}}, W\} - I] = \int_1^{h} \int_0^{i_{\text{max}}} p(i, w) [\max\{i, w\} - i] \, dw \, di = \frac{1}{h Z_i} 10^h \left[ \frac{1}{a+1} (a+2)(a+3) \right] (\ln 10)^{a+3} - \frac{1}{2} h^2 \frac{1}{a+1} + \frac{h}{a+2} \frac{2 - a(a+3)}{a+1(a+2)(a+3)}
\]

6.6.3 Extra Forwarding Delay Evaluation

Fig. 11 depicts the scattered plots of the experiment results. The analytical prediction is plotted as a solid line. One can see that the analytical result matches experimental result when \( h \) is relatively large (> 10 mins). For smaller \( h \), the analytical result under estimates the EFD which can be explained by the following reasons: Firstly, we assume \( h \) is the only delay but there are other delays. Those small delays become dominating when \( h \) is small. Secondly, we assume the statuses are obtained immediately if one bot pulls its neighbour. However, given the fully decentralized construction of our DSN, one needs to pull RSS feeds from multiple friends. Since the network performance between PlanetLab nodes varies widely, some bots may take much longer time than QG to finish one round of pull. This also makes the experiment results deviate from analytical ones with small \( h \). One extreme case is when \( h = 0 \), the analytical model, which assumes \( h \) to be the only delay factor, will predict EFD=0. This is obviously not the case and we are working on the refinement of the model for EFD.
6.6.4 Resource Consumption

Various resource consumption is depicted from Fig. 12(a) to Fig. 12(d). The results align well with our analysis in Section 6.5, namely 1) CPU and memory usage are just a constant plus experimental variance; 2) HTTP query and size are reciprocal of Query Gap, \( h \).

![Graphs of Resource Consumption](image)

Figure 12: Consumption of Different Resources

7 Conclusions and Future Works

In this paper, we analyze the challenge towards a decentralized paradigm of Social Networking Services and proposed a meta social networking approach to solve the migration problem. We have built a cross-platform middleware, which is lightweight, programmable, and flexible, to support the transition from centralized OSNs to decentralized ones. We have presented the design and implementation of SNSAPI and discussed design choices and observations based on our year-long experience in maintaining and refactoring the corresponding open-source project. We deployed a 6000-node DSN on PlanetLab based on SNSAPI to demonstrate that it is a viable approach to form a DSN. Using real traces collected from a mainstream OSN, we show that with only mild resource consumption, we can achieve acceptable forwarding latency comparable to that of a centralized OSN. We have also developed an analytical model to characterize the tradeoffs between resource consumption and message forwarding delay in such a DSN. Via 20 parameterized experiments on PlanetLab, we have found that the empirical measurement results match reasonably well with performance predicted by our analytical model.

Future works include using non-uniform and even adaptive Query Gap, improving the analytical model, formation of a DSN using push channels (e.g. Email platform also supported by SNSAPI), developing a distributed back-off protocol to alleviate the congestion in the DSN. During the deployment of the 6000-node DSN and the series of parameterized experiments, we have also built a full set of tools for conducting and managing of similar large-scale DSN experiments. Like the SNSAPI and its Apps, this toolbox as well as the OSN activity traces we collected from Sina Weibo will be open-sourced in the near future. We hope they will provide a foundation to support large-scale experimental deployment and performance evaluation for DSN and the associated algorithms.

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