Towards Software-Friendly Networks

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ABSTRACT

There has usually been a clean separation between networks and the applications that use them. Applications send packets over a simple socket API; the network delivers them. However, there are many occasions when applications can benefit from more direct interaction with the network: to observe more of the current network state and to obtain more control over the network behavior. This paper explores some of the potential benefits of closer interaction between applications and the network. Exploiting the emergence of so-called "software-defined networks" (SDN) built above network-wide control planes, we explore how to build a more "software-friendly network". We present results from a preliminary exploration that aims to provide network services to applications via an explicit communication channel.

Categories and Subject Descriptors

C.2.4 [**Computer Systems Organization**]: Computer-Communication Networks—*Distributed Systems; Network operating systems*

General Terms

Design, Management

Keywords

Software-Defined Networks, OpenFlow, Network OS, Network Services

1. INTRODUCTION

Part of the success of the Internet undoubtedly comes from the simple and consistent interface between applications and the network. Most applications use the socket API to request a connection to a remote computer, then simply send data into and out of the socket. The application needs no knowledge of the topology or current state of the network, and needs no control over how packets are delivered. The network is a set of dumb pipes.

However, many applications can benefit from a richer interface to the network with more visibility of its state, and more control over its behavior. In general, past efforts to increase the richness of the API have not been very successful (e.g. RSVP [11]). While many applications could benefit from the QoS control RSVP offers, few applications find RSVP optimized for their needs. For example, Skype employs a number of its own proprietary tricks to figure out the current quality and state of the network, and then uses multiple paths and rates to optimize its behavior [12]. This may be feasible for Skype, but is beyond the reach of many smaller applications.

One extreme approach to increasing the richness of the interface would be to put application-specific support directly into the network, as proposed in Active Networking [14]. Active networks exploit the fact that the network knows its own state, and attempts to expose state and control to user applications. However, the particular approach proved unpopular for several reasons, most notably because of security (preventing malicious use of the network), isolation (protecting one application's behavior from another) and performance (programmable elements slow-down the forwarding path).

Software defined networks (SDN) are emerging as a new (but backwardly compatible) way for networks to be architected. SDNs are being deployed in data centers now, and we expect them to be deployed in enterprise, campus and WAN networks in the next few years. It is therefore interesting to think about how, in light of this trend, the interface between applications and the network may change.

An SDN has the following elements (see Fig. 1):

1. A packet-forwarding datapath controlled by a narrow open vendor-independent API (e.g. OpenFlow [8]). These are the switches, routers and access points through which packets pass.

2. A network-wide operating system to control the datapath. The network OS (e.g. NOX [4]) has a global view of the network state, and has full programmatic control of the forwarding.

3. "Network features" are hosted on the network OS, to implement various network services such as routing

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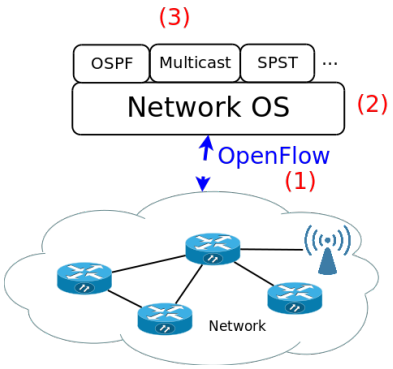


Figure 1: Components of SDN

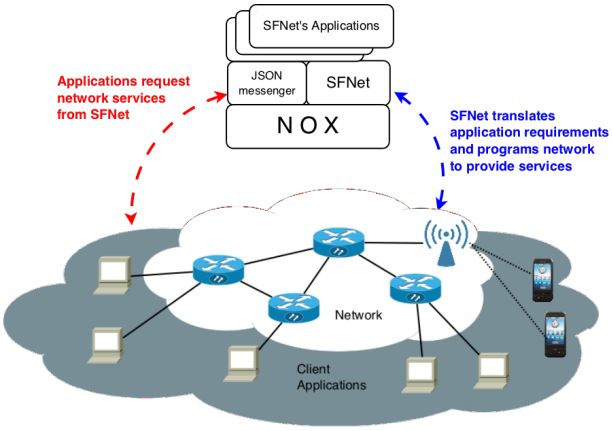


Figure 2: Architecture of SFNet

(e.g. OSPF, BGP, multicast, multipath), mobility management, QoS control, etc.

An SDN is simply a repartitioning of the way networks are built. Initially, we expect them to support many of the features in today's networks. The key difference is that it is much easier to add *new* features to an SDN; the owners and operators of networks can improve their networks without having to wait for vendors and standards bodies. We can therefore expect SDNs to evolve and improve at a much faster pace than today's networks.

Current SDN (and NOX in particular) do not specify how applications should interact with the network. An application may continue to use the minimal socket API, and continue to view the network merely as a means for interconnection. The question we are most interested in answering is: *How will applications interact with the network in a world where owners and operators are free to add new functionality to the control plane?* Because SDN is still in its infancy, our work is just a first step towards answering this question.

One possible outcome is that every application will provide its own "plugin" to the network OS to view and control the network, and to also define its own application-specific communication protocol to the plugin. For example, a plugin optimized for Skype might interface directly with the network OS to set up paths, reserve bandwidth, and create access control rules. Alternatively, over time, a relatively small number of "*de facto* standard" plugins might emerge for common tasks (e.g. a plugin for multicast, another for multipath routing, and yet another for bandwidth reservations). A third scenario is where plugins emerge to suit certain classes of applications (e.g. a plugin for chat applications, another for real-time video, and a third for low-latency applications). Of course, all three models can coexist: Many applications may choose to use common feature plugins, whereas others can create their own. Our goal here is not to propose, or mandate, that any particular model will emerge. We merely make the observation that SDN allows all three models, and for each application to choose its own path. The "winning features" will be picked by adoption, rather than by standards bodies.

In this short paper we explore one possible path to more "software-friendly networks". We propose creating a plugin for the network control plane that allows applications to query the network state and issue network service requests directly. Motivated to support applications like multi-way high-definition peer-to-peer video conferencing application for mobile users, we experimented with a novel query to request the congestion state of the network, as well as classical services like bandwidth reservation and multicast.

To the best of our knowledge, this is the first paper to propose creating "software-friendly networks" using SDN. The paper is distinctive in that it allows applications to communicate with the network directly.

In the rest of the paper, we present our design in Section 2. Sections 3, 4, and 5 discuss congestion query, bandwidth reservation, and multicast respectively. We describe related work in Section 6 and conclude in Section 7.

2. DESIGN

The key role of a software-friendly network is to bridge the semantic gap between applications and the software-defined network. While exposing network services to application writers can potentially improve application performance, low-level operations required, such as route calculation or discovering network topology, are forbidding for most programmers. By presenting high-level APIs to the program and hiding the details of the implementation, software-friendly networks reduce the barrier to entry and increase uptake of network services.

To help with the exploration of software-friendly network designs, we have created a prototype called SFNet on top of NOX, as shown in Fig. 2. SFNet allows the applications to directly interact with the network using a high-level API. By exploiting the global view provided by NOX, SFNet supports high-level primitives, such as network status requests and resource reservation, easily. Data exchanges between applications and SFNet are represented in JSON (JavaScript Object Notation), which is a simple and concise data format supported by most modern programming languages.

As an example, let us describe how an application can discover the location of SFNet's controller, an pre-requisite to using SFNet. The application first sends a discovery request using an UDP packet addressed to a predefined IP address and port (e.g., 224.0.0.3:2209 in our case), and the response is returned directly using another JSON message (Fig. 3). This avoids any broadcast in the discovery process. Using the response, the application can set up a TCP socket with the controller which forms the communication channel for subsequent JSON messages.

Network controller discovery message

```
{"type": whereisnox"}
```

Network controller discovery reply

```
{"type": "whereisnox",
"tcp port": 2703,
"ssl port": 2703,
"ip": [10.79.1.105,192.168.0.1,172.24.74.198]}
```

Figure 3: A discovery message sent from a user and the reply message from SFNet

3. BACKING-OFF DURING TIMES OF CONGESTION

SFNet provides network congestion status to applications, allowing them to backoff if they choose. The application composes a query as a JSON message to inquire about the congestion state of the path between two hosts. SFNet would then determine the switch and port on which the hosts are connected and the shortest path between them. The congestion state (i.e., percentage of link bandwidth in use) of the links, including of those between switches and hosts, are then determined.

Congestion state information is useful for a variety of purposes. For example, delay-tolerant backups can be programmed to back off when the network is congested to increase the performance of delay-sensitive traffic. Today, an administrator typically schedules backups at night so as not to interfere with network activities during the day. This can backfire, however, as it can create congestion for users pulling an all-nighter for an impending deadline.

To validate our congestion enquiry implementation, we perform the following experiment. We wrote two applications, both to transfer a 10 MB file. The first sends it right away. The second inquires the state of congestion from SFNet at 10 s interval and transmits the data only if there is no congestion. To create congestion, we create a background task using TCP iperf to generate a continuous traffic load on the network.

Without congestion, the 10 MB file can be transferred in an average of 18.7 s with standard deviation 0.2 s (Fig. 4). With congestion, the first program took an average of 38.4 s with standard deviation 1.9 s. The second program, with the help of SFNet, completed the transfer in an average of 18.5 s with standard deviation of 0.3 s, showing similar performance to an uncongested network.

The key takeaway is not how much faster the file transfer went, but the ability to determine the congestion state of routes and its utility to enable an application to back off during congestion.

4. BANDWIDTH RESERVATION

Our SFNet prototype supports bandwidth reservation. The application can send to SFNet a request for guaranteed bandwidth. SFNet determines the route, and provisions the required bandwidth along the route for the application. SFNet will grant or deny the request depending on the availability of the requested bandwidth.

Many interactive applications, such as video on demand and VoIP calls, are delay intolerant and have a strict bandwidth requirement. Even with traffic classification tools, to-

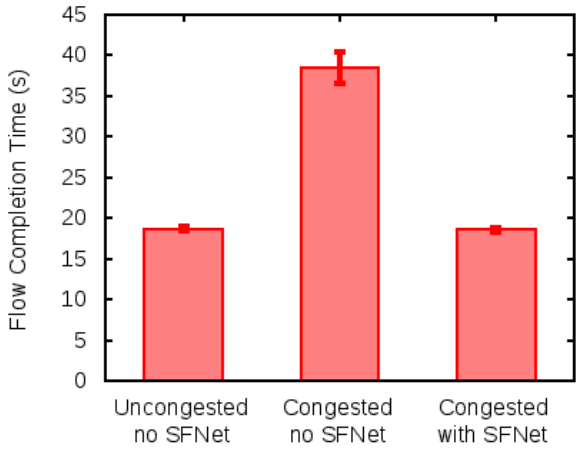


Figure 4: Flow completion time with(out) SFNet's congestion enquiry

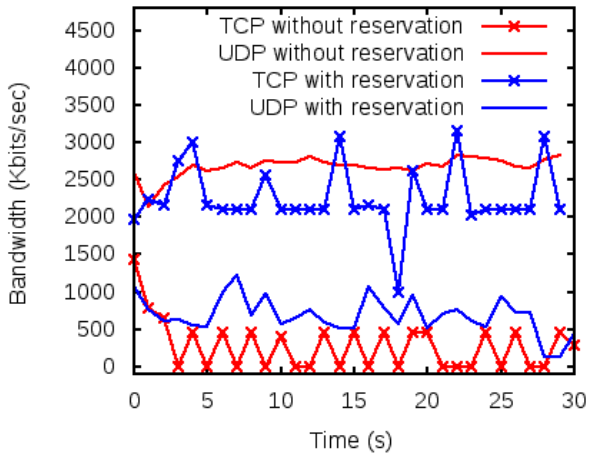


Figure 5: Available TCP bandwidth with(out) SFNet's reservation

day's network cannot differentiate between a user watching a random video clip from the web and an important customer being presented a demonstration video. With SFNet, high-priority applications can directly indicate the bandwidth required, so the network can make the bandwidth available.

To validate our implementation, we perform an experiment where a high-priority application (using TCP) runs in the presence of a low-priority UDP flow that is overwhelming the link. We create both flows using iperf, where the UDP flow is specified with a sending rate of 3 Mbps. The high-priority TCP flow submits a request for a bandwidth of 3 Mbps to SFNet.

Our results (Fig. 5) show that the TCP flow achieves an average rate of 280 Kbits/sec without reservation. By reserving bandwidth over SFNet, the TCP flow achieves 2.24 Mbits/sec—about 8 times more throughput. We also observe that the low priority UDP flow is appropriately throttled (Fig. 5). We also observe that this has a dramatic effect on the quality of the playback of a streamed video. Such bandwidth reservation allows applications to express

the tacit importance of each flow by explicitly reserving the appropriate network resources.

5. MULTICAST

SFNet can support a multicast session for an application. Here, the application indicates to SFNet a set of IP addresses participating in the multicast with a selected multicast IP address; SFNet then returns a response (success or failure). Subsequently, messages sent to that multicast address will be delivered to the participants. SFNet finds the shortest network paths between the participants. Each message sent to the multicast IP address is duplicated where necessary in-network. To deliver packets among n participants, SFNet installs n multicast trees—from a host to the other $n-1$ hosts. Each multicast message is carried only once on each link of the multicast tree. This efficiency is critical for increasingly important telepresence applications such as high-definition multi-user video conferencing.

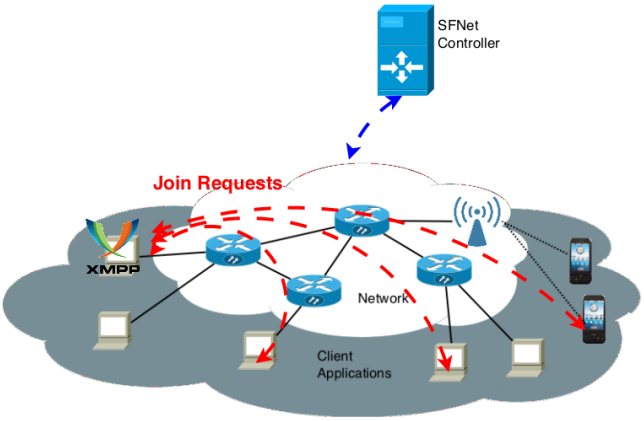
We next describe how we can use this multicasting in SFNet to improve the implementation of a chat service that uses XMPP as a rendezvous point to set up chat sessions, hereafter referred to as P2PChat. Fig. 6 describes a use scenario of P2PChat. To join the service, each user will submit a join request to P2PChat using the XMPP protocol (Fig. 6(a)). P2PChat aggregates requests for a chat session and submits the IP addresses of the participants in a request to SFNet, which installs the appropriate multicast routes for the session (Fig. 6(b)). The participant can then communicate with each other by sending messages to the multicast IP address. The chat messages are forwarded directly in-network, instead of going through the server (Fig. 6(c)).

Once a chat session is set up, the participants can communicate directly with each other using multicast sessions. This translates to reduced traffic as well as lower latency. Our results show that by having participants communicate directly, we can reduce delay from 21 ms to 3 ms compared to communicating through the XMPP server residing in the same LAN. In the meantime, relieved of its message routing duty, the P2PChat server can scale to serve more users. Moreover, failures of the chat server will not affect any of the ongoing chat sessions. This opens up interesting possibilities, such as using a transient client in the network as the chat server.

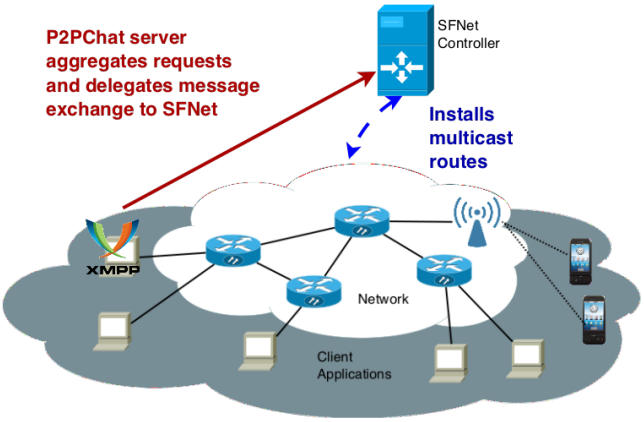
6. RELATED WORK

Previous work, such as Resource ReSerVation Protocol (RSVP) [11] and Darwin [2], provided a means for applications to request service from the network. RSVP allows applications piggyback QoS request in their packets and request resources from routers the packets traverse. Although RSVP is widely implemented in switches and routers, it is not generally used—perhaps because its service is not easily tailored to the needs of an application. Darwin uses a global resource scheduler to handle requests from applications, and allocates network resources through "active networking", i.e., embedding code into application packets and executing the code in routers en route.

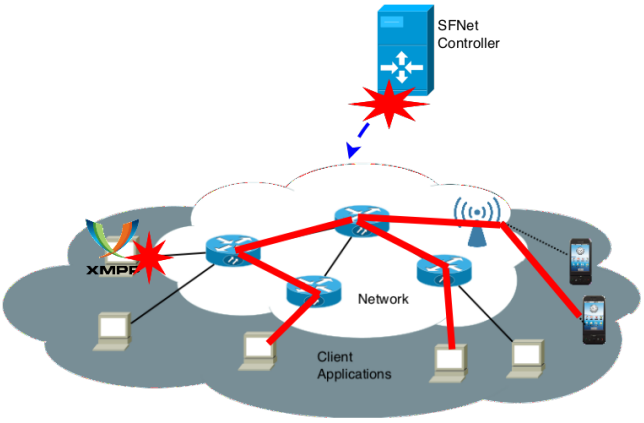
Application developers have also developed solutions at the application layer. Numerous methods have been developed to estimate the end-to-end network capacity and route quality. Available bandwidth (ABW) estimation is one of the most well-studied techniques [6, 9, 10, 13]. Real-time



(a) Chat clients issues join requests to P2PChat server. This is how the chat will be carried out today, i.e., via the server at all times.



(b) P2PChat server delegates message exchange to the network through SFNet's request and SFNet installs n-multicast routes.



(c) Clients switch to P2P chat where the malfunction of the XMPP server and/or SFNet controller will not affect the chat session.

Figure 6: P2P chat via in-network mesh-casting (n-multicast)

multimedia applications often use the estimation to choose encoding rate [12]. Peer-to-peer applications uses ABW estimation for route selection, QoS verification, and traffic engineering over the overlay network [7]. However, due to the dynamic nature of Internet traffic, it is difficult to accurately estimate end-to-end available bandwidth [5]. Other than ABW, applications would also monitor the packet loss rate and apply different forward error correction mechanism. However, these techniques can only help applications remedy their performance loss, and not proactively improve it.

On the other hand, network operators are also trying very hard to understand the traffic from the applications. Traffic classification mechanisms are widely used to help network operators deploy appropriate QoS mechanisms, prevent network congestion, or to defend against network attacks. Many techniques can be used to classify application traffic from aggregated flows. Some are based on statistical properties of network traffic, such as packet size, inter-packet gap and flow duration [1, 3], while others are based on protocol signatures and deep packet inspection. None of these would be able to determine the importance of a flow with certainty.

With software-friendly networks, we aim for applications to directly request the service they need. The central controller can also authenticate users and tell the network to encrypt traffic.

7. CONCLUSION

In this short paper, we have presented our preliminary exploratory foray of how to provide software friendly network in the context of SDN. A first prototype of SFNet has been deployed in our production network [15], thus allowing applications to make better use of our network. We are encouraged by how easy it is to provide conventional API like bandwidth reservation and multicasting, while supporting interesting new API like congestion enquiry.

What we presented is but a small step in the direction of creating software-friendly networks, using a particular approach in an early prototype system. There is much more work to be done.

8. REFERENCES

[1] D. Bonfiglio, M. Mellia, M. Meo, D. Rossi, and P. Tofanelli. Revealing skype traffic: when randomness plays with you. In *SIGCOMM '07: Proceedings of the 2007 conference on Applications, technologies, architectures, and protocols for computer communications*, pages 37–48, New York, NY, USA, 2007. ACM.

[2] P. Chandra, Y.-H. Chu, A. Fisher, J. Gao, C. Kosak, T. Ng, P. Steenkiste, E. Takahashi, and H. Zhang. Darwin: customizable resource management for value-added network services. volume 15, pages 22 –35, jan/feb 2001.

[3] M. Crotti, M. Dusi, F. Gringoli, and L. Salgarelli. Traffic classification through simple statistical fingerprinting. volume 37, pages 5–16, New York, NY, USA, 2007. ACM.

[4] N. Gude, T. Koponen, J. Pettit, B. Pfaff, M. Casado, N. McKeown, and S. Shenker. NOX: Towards and operating system for networks. In *ACM SIGCOMM CCR*, July 2008.

[5] C. D. Guerrero and M. A. Labrador. On the applicability of available bandwidth estimation techniques and tools. In *Computer Communications*, January 2010.

[6] M. Jain and C. Dovrolis. Pathload: A measurement tool for end-to-end available bandwidth. In *Passive and Active Measurement Workshop*, April 2002.

[7] M. Jain and C. Dovrolis. Path selection using available bandwidth estimation in overlay-based video streaming. *Comput. Netw.*, 52(12):2411–2418, 2008.

[8] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner. Openflow: enabling innovation in campus networks. *SIGCOMM Comput. Commun. Rev.*, 38(2):69–74, 2008.

[9] B. Melander, M. Bjorkman, and P. Gunningberg. A new end-to-end probing and analysis method for estimating bandwidth bottlenecks. In *Global Telecommunications Conference, 2000. GLOBECOM '00. IEEE*, volume 1, pages 415 –420 vol.1, 2000.

[10] V. J. Ribeiro, R. H. Riedi, R. G. Baraniuk, J. Navratil, and L. Cottrell. pathchirp: Efficient available bandwidth estimation for network paths. In *Passive and Active Measurement Workshop*, April 2003.

[11] RFC 2205: The resource reservation protocol (rsvp). `http://tools.ietf.org/html/rfc2205`.

[12] Skype and network management. `http://share.skype.com/sites/en/2009/12/skype_and_network_management.html`.

[13] J. Strauss, D. Katabi, and F. Kaashoek. A measurement study of available bandwidth estimation tools. In *ACM IMC*, October 2003.

[14] D. L. Tennenhouse and D. J. Wetherall. Towards an active network architecture. *SIGCOMM Comput. Commun. Rev.*, 37(5):81–94, 2007.

[15] K.-K. Yap, M. Kobayashi, D. Underhill, S. Seetharaman, P. Kazemian, and N. McKeown. The stanford openroads deployment. In *WINTECH '09: Proceedings of the 4th ACM international workshop on Experimental evaluation and characterization*, pages 59–66, New York, NY, USA, 2009. ACM.