Monitoring as a Service of the cloud data centre: can SDNs help?

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**Abstract**—The recent rise of cloud applications, representing large complex modern distributed services, has made performance monitoring a major issue and a critical process for both cloud providers and cloud customers. Many different monitoring techniques are used for such applications, from simply measuring resource consumption, to application-specific measures which instrument the application or platform, to analyzing message exchanges. In all these cases, the information to be analyzed is logged at the host nodes on which the application is deployed, and from there either analyzed on site or forwarded to analyzing tools. Using new trends such as Software Defined Networking (SDN) shows promise to move some of the logging functionality into the network as a lot of information can be extracted from messages exchanged between application components. This raises the potential for the cloud infrastructure to provide a *Monitoring as a Service* to cloud applications in a transparent manner avoiding software instrumentation and allowing for a more flexible placement of logging functionality. To better understand the feasibility of this approach, this paper explores several approaches how application monitoring can be integrated into SDN. In particular, we combine port mirroring with tunneling to enable message filtering and reformating, and we propose a customized port sniffing approach. We provide their implementation based on OVS, analyze their advantages and disadvantages, and provide a comprehensive performance evaluation to understand the trade-offs and to show that moving application monitoring to the network is an attractive option.

**Index Terms**—Software defined networking, Application logging, Openflow, Network function virtualization

I. INTRODUCTION

Many application domains have started to move their services into the cloud, from e-commerce to health, sciences, gaming, and many more. The performance of such applications has a direct impact on business metrics such as revenue and customer satisfaction. Examples of this impact are well documented. For example, Google loses 20% traffic for additional delay of 0.5 second to their page-load time and Amazon loses 1% of revenue for every 100 ms in latency increase [1]. In a production environment, effective use of logging and monitoring is an important part of administrating the cloud applications, keeping track of their performance, and to detect, diagnose and resolve performance-related problems.

Cloud applications are often deployed as multi-tier or multi-component systems where the individual components and their replicas might run across tens, hundreds or even thousands of nodes and may communicate with other similarly distributed services to accomplish their goals. For example, user-facing components at Google comprise 100s to 1000s of nodes that interact with each other and with other services (e.g., a spell-checking service) to service user requests. Even simple web applications today consist of multiple distributed tiers that interact with each other and may be integrated with a third party such as Facebook, payment gateways, etc. to accomplish one transaction. This makes application performance monitoring a challenging task for system administrators who are in charge of identifying bottleneck components and resolving performance issues [2].

Both application and system layer measures need to be collected for cloud application performance monitoring in such multi-tiered and highly distributed architectures. System layer measures collect the state of hardware resources. For that purpose, cloud providers often use the virtual machine and hypervisor logs to observe the resource consumption of individual application components.

Application layer measures such as request service time, message size, or characteristics of service call distributions are also important to understand application performance issues. At the end host, relevant data can be collected either by instrumenting the application to generate log messages, or using the logs generated by the platform on which the application is deployed. For instance, the Tomcat Apache web server offers access log valve for logging purposes. The main disadvantage of these two logging approaches is that they are application and/or platform dependent.

To unify the logging and monitoring process for different application components and platforms, cloud administrators can use commercial logging tools at the components’ host to derive application-layer measures. Tshark is one example of a widely used commercial logging tool. It attaches to any software component or to the hypervisor and is able to observe all incoming and outgoing messages, using message content to derive performance measures.

What is common among all these approaches is that they generate the logging information on the end hosts. The logging
tools themselves can then either additionally perform the
analysis, write the logging information to a file for later
analysis, or send the logs to specialized analysis systems
that run on a different set of hosts. In any case, application
performance may be affected by sharing the host resources
with the logging and/or analysis tasks.

Contrary to an end-host approach, recent research work
has been exploring the feasibility of pushing the application
logging and analysis functionality down into the network layer
by utilizing Software Defined Networking (SDN). SDN is a
recent networking trend that introduces real-time network
programmability by decoupling network control logic from
the underlying hardware. Although the main goal of SDN
has been to provide real-time network traffic monitoring and
dynamic network flow reconfiguration, SDN can be utilized to
intercept network packets and infer application behavior from
this information [3].

The most basic approach to use SDN components such as
switches and routers for application monitoring is to instru-
ment them in such a way that they monitor application traffic
to specialized analysis systems. That is, application messages
are duplicated at the SDN component. The actual analysis takes
place somewhere else [3–6]. The approach is simple and does
not cause a big overhead at the switch/router, but the message
traffic overhead can be significant. Some recent research [7–
11] attempts to address this issue by extending the source
code of the SDN switch to have an inclusive analysis function.
However, the results show performance degradation in terms
of the modified SDN switch forwarding throughput. Thus, we
believe that approaches in between those two extremes, that
neither forward all messages to a remote analysis service nor
perform all analysis/monitoring locally within the switch path,
will be the most promising solutions. That is, some form of
pre-processing, filtering of messages or analysis is done at
the SDN component or close by, with more complex analysis
requiring to send some information to an analysis service. In
this paper we propose two different approaches that are in
this in-between category. The first only sends a subset of all
messages to the analysis service but does not perform analysis
at the switch. The second decouples message observation and
analysis from the forwarding mechanism at the switch.

In our first approach we exploit SDN’s feature of supporting
the specification of filtering conditions allowing us to mirror
only packets that fulfill certain conditions leading to less
application traffic being mirrored to the analysis tool. As in
its default implementation, such selective mirroring overwrites
some of the original packet routing information, which might
be a concern if this information is importing for the analysis,
we employ a tunneling protocol to encapsulate the original
packets before forwarding them to the analysis service. We
can use selective mirroring with tunneling on both hardware
and software-based SDN switches.

In the second approach, we decouple the monitoring func-
tion from the switch forwarding path by developing a separate
process that is only loosely coupled with the switch functional-
ity, and runs on the host of the software switch. This approach
works for software switches that run on general purpose
hardware that also allows other processes to execute (which
is often the case for software switches deployed at rack-level
and/or for the VMs/containers hosted on the same machine).
We can exploit such loosely coupled approach to integrate a
flexible and adjustable amount of application monitoring and
analysis.

In summary, the contribution of this paper is as follows:

- We provide a characterization of various application
monitoring approaches, both at the end host as well as in
the network.
- We propose two monitoring SDN-based approaches that
allow filtering, and to some degree analysis, of the
relevant data at the node of the SDN switch. One of them
integrates the functionality within the switch exploiting
its programmability, and thus can be deployed on both
hardware and software switches. The other relies on
software switch deployment.
- We evaluate and compare a variety of logging approaches
using a benchmark based on YCSB, and analyze the
corresponding trade-offs in terms of impact on the applica-
tion that is monitored, general resource consumption,
and switching speed.

II. BACKGROUND: SOFTWARE DEFINED NETWORKING

Using SDN, the SDN controller represents the control
plane that decides on how messages are routed and SDN
switches represent the forwarding plane (data plane) that guide
messages through the network. The controller provides each
switch with a set of rules indicating how to forward the
different flows of messages they receive from end hosts or
other switches. A flow is typically identified by a set of IP
header fields. Forwarding rules can change over time as the
controller can dynamically customize how to route individual
flows. OpenFlow – the de facto standard of SDN – is an API
used for exchanging control messages between controller and
switches.

A SDN switch has one or more flow tables, configured by
the SDN controller through the OpenFlow API, which contain
rules to match incoming flows and/or packets with certain
actions such as prioritization, queuing, packet forwarding and
dropping. The following is an example of a flow table rule,
consisting of a set of conditions and actions to execute should
the conditions be true:

Conditions:

\[
\begin{align*}
TCP-\text{protocol} &= \text{TCP}, \\
Source-\text{IP} &= A.A.A.A, \\
Source-\text{Port} &= X, \\
Destination-\text{IP} &= B.B.B.B, \\
Destination-\text{port} &= Y, \\
TCP-\text{Flags} &= \text{ACK}
\end{align*}
\]

Actions: output to out1, out2.

Where A.A.A.A and B.B.B.B. are the IP addresses of the
source and destination, respectively, and out1 and out2 are the
switch port numbers connected to the targeted destinations.

Network Function Virtualization (NFV) and Software
Switches: Network functions such as packet switching but
also more complex tasks such as intrusion detection, load bal-
ancers and firewalls are traditionally implemented as custom
Cloud network architecture: A typical cloud data center network architecture today consists of a 2-3 layer tree of switches and/or routers (e.g., Fat Tree [12]), such as shown in Figure 1. Hardware packet switches are being used in the core network where higher speed is a must. In contrast, optimized software switches [13]-[16] (e.g., OVS integrated with DPDK that accelerates packet processing workloads running on general-purpose CPU), are largely deployed as top-of-rack (TOR) switches. OVS is also used within high-end server machines that host many virtual machines and/or containers. There, the OVS instance routes the messages exchanged between the VMs/containers running within this same machine.

Having a switch implemented as a NFV provides considerable flexibility for integration of logging and analysis functionality, either within the switch or as an additional NFV.

III. APPLICATION LOGGING APPROACHES

A. Architecture and classification

A distributed cloud application within the data center might be spread across multiple network hops as illustrated in Figure 1 where the client request flows from one hop to the next, each performing a different task to complete the request. Performance analysis of distributed applications is complex as there are many possible causes for performance anomalies, and so many possible things to measure. However, over time, a set of measures have been shown to be useful and are provided by many logging tools. Obviously hardware resource consumption (CPU, memory, I/O, etc.) is an important indicator. More high-level measures are request service times for a client request or for the sub-requests executed by a particular component. Error rates, i.e., the percentage of problem requests compared to all requests, throughput rates that measure the popularity of individual components and their services, or response sizes (e.g., in terms of KB or returned data items) also provide interesting insights and help in deciding on proper provisioning of resources. Changes in these times, rates and sizes are of interest to determine bottlenecks and anomalies.

To retrieve and analyze these measures, a comprehensive application logging framework typically consists of two phases:

1) The collection phase captures and collects performance related data from the different hosts/components of a cloud application. This phase is concerned about where, and how to capture and collect performance related data and in which format according to the type of performance measures needed to be executed.

2) In the storage and analysis phase the collected performance data is aggregated and stored for further processing and analysis. Many of the application performance measurements are calculated in this phase and performance issues are reported such as exceeding set thresholds or detecting specific patterns. Analysis can take place at the hosts that run the components, at specific analysis nodes, or in the network. If at the hosts, it might have a negative affect on the resources available for the application itself. Dedicated nodes will cause logging-related network traffic. If in the network it might affect the other tasks the network has to do.

The main focus of this paper is the design of the collection phase and its linkage to the analysis. We have already shortly outlined the options in the introduction. They can be categorized as depicted in Figure 2.

A common first step to get insight into the performance and potential bottlenecks is to measure the hardware resource consumption of the component in terms of CPU, memory, I/O and network. Many logging tools offered by cloud providers use the unit of a virtual machine on a hypervisor, the unit of a docker or of a process to observe the behavior of individual application components [17]. Obviously, except of the network load, all these hardware measures need to be taken at the end host. However, performance issues are not always caused by hardware bottlenecks. For instance, [2] showed that a cache misconfiguration causing unnecessary long delays was not detectable by looking at resource consumption unless the database was overloaded but could easily be detected when looking at component throughput.

In the remainder of the paper, we do not consider hardware resource measurements any further but rather look how more high-level measures can be collected. To better illustrate and compare the approaches, we use as an ongoing example request service times, especially for HTTP requests. Given the ubiquity and amount of HTTP traffic (TCP ports 80 and 8080) in many cloud data centers [18], [19], providing transparently and on-demand request service times to web applications would be a crucial feature of any monitoring service [20].

As can be seen in Figure 2 data relevant to such high-level measures can be collected at the end host through software.
Instrumentation or through port sniffing. In the network, SDN switches can be instrumented to perform port mirroring or selective forwarding; for software switches, we can also use a port sniffing approach similarly to the one used on end hosts.

B. Log collection (and analysis) at the end-host

Software Instrumentation: Software instrumentation typically creates explicit application and/or platform specific log entries. Application-specific measures such as request service time can be obtained by instrumenting the application and/or platform to generate related performance information [21]–[24]. For instance in [22], Twitter shows how they instrument their code to generate structured “client event” log messages keeping track of various type of session information. This information can be later used to derive application-performance measures such as request service time.

Alternatively, a software platform can incorporate a logging mechanism that can deliver the necessary measurements for the applications deployed on the platform. For example, Apache Tomcat uses its proprietary “Access Log Valve” to create log files for monitoring client access information. Any request arriving at a Tomcat web application is passed to the access log valve process as well, where information about both the request and its response (such as request service time) is saved into access log files.

Software instrumentation is an application and/or platform dependent logging process. Obviously, neither Twitter structured logs nor Tomcat valves can be used in a different application or servlet/JSP container. Thus, software instrumentation is likely not the appropriate approach when attempting to offer Monitoring as a Service, as it would require support from the application/platform developers.

Message Analysis: Interestingly, a considerable number of high-level application specific measurements can be obtained by only looking at the application messages exchanged between the client and the components of the application. In here, it is more relevant which message exchange protocol is used, and HTTP covers a huge range of applications. HTTP, as many other client/server protocols, sends messages in form of a request/reply pair. In most cases a client connection to the server can have at most one outstanding request; that is a client can only send a new request once it has received a response for the outstanding request. With this, by having access to the flows from client to server and from server to client, one can take the time difference between observing the request and observing the response as request service time. If a client is allowed to have multiple outstanding requests (as shown in Figure 3), then one can simply assume that the first response refers to the first request, the second response to the second request, etc. Thus, by matching request/response message pairs over time, average request service times can be observed.

Information about message exchange can be extracted in an application independent manner at the end hosts by sniffing the relevant ports of the components and analyzing the message content. Several commercial sniffer tools use this approach, such as Tshark and tcpdump. For example, Tshark can be configured to sniff and parse all the messages designated to a user-defined application (such as port 80 for a web application). In addition, Tshark contains an analysis engine that can produce some application performance measures such as HTTP request service time.

While monitoring tools like Tshark and tcpdump are application independent, they collect the necessary information at the end hosts, and either also do the analysis locally, log the data to a file for offline analysis, or send relevant logging information from the end host to an external analysis tool. All this puts an extra burden on the hosts and potentially reduces the resources available for the components themselves.

C. Log collection (and analysis) in the network

The interesting thing about using messages exchanged between components to derive performance measures, is that this can be done not only at end hosts but also in the network, allowing for more flexibility and decoupling. As messages travel through the network and are processed and forwarded by SDN switches, the switches can potentially be programmed to perform work relevant to log collection and analysis.

There are several ways how the network can contribute to log collection and potentially log analysis. Figure 4 shows some of them.

Port mirroring: Using port mirroring, the switch forwards all messages of a flow not only to the indicated destination

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4In fact, as also the client needs to know to which request to match a response, some servers guarantee that they will send responses only in the order they received requests even if they execute the requests concurrently.

5Tcpdump [http://www.tcpdump.org/](http://www.tcpdump.org/)
but to a second destination. The application-performance monitoring framework developed in [2] uses port mirroring to forward a copy of all packets of a flow of interest to a monitor agent that then extracts relevant information from messages of interest. Figure 4(a) shows an example of port mirroring of all network traffic between application component A1 and B1. The port mirroring runs with lower priority compared to the normal forwarding. When a switch becomes busy, then switching the normal traffic flow takes high priority and the performance of mirroring may be degraded or in extreme circumstances be temporarily suspended. A big advantage of this approach is that the switch sends an exact copy of the packets to the analysis tool without overwriting any of the mirrored packet header fields. It is also very fast as no copy process takes place. However, port mirroring might have a significant communication overhead as it mirrors all packages of a flow.

**Selective mirroring:** The filtering capability of OpenFlow compatible switches can be utilized to copy and forward only those network packets to the analysis tool that match a predefined criteria. This will forwarding unnecessary packets and reduces the message overhead compared to port mirroring. This selective mirroring is defined in the switch through the flow rules.

An issue with basic selective mirroring is that the switch has to overwrite the routing information of the original destination of packets as the copy sent to the analysis tool has a different destination. This is an issue, if the destination routing information is necessary for analysis. In the next section, that presents a more detailed implementation, we show how basic selective mirroring can be enhanced with tunneling to overcome such restriction.

Using selective mirroring is coupled with the switch forwarding path. The only way to define the needed filtering and mirroring is through (OpenFlow) rules. This may lead to a processing overhead (for making a copy and forwarding it to a second destination) and delay in routing the message.

An interesting aspect of selective mirroring (and port mirroring) is that it can be supported by any SDN switch, whether it’s a hardware or a software switch. Therefore, we believe it’s an approach that needs further investigation.

**Switch enhancements:** The switch software can potentially be extended to include application analysis functionality. However, results so far have shown considerable overhead and impact on the performance of the switch’s main task – message forwarding. The reason is that many analysis tasks require an often costly deep inspection of the packages beyond the packet header, which is time consuming. Also, this requires extensions to the switch’s code base. Thus, it is not quite clear how quickly any such approaches would be adapted in production systems. We present some of the systems in the related work. But as the code is not publicly available, we do not include such mechanisms in our evaluation.

**Port sniffer:** In the case of software switches, e.g., the ones based on OVS, these switches receive messages through ports. Thus, a sniffer process can be deployed at the port inspecting all incoming and outgoing messages. This mechanism is depicted in Figure 4(b). For instance, assuming that all ToRs in Figure 4 are virtualized on computing nodes, a sniffer process can be deployed on B1’s ToR switch host and instructed to sniff all web traffic traversing the virtual switch port connected to B1. This is similar to port sniffing of the application components such as Tshark. In fact, one could deploy Tshark or similar tools at the host of the software switch to sniff and analyze application traffic traversing predefined switch ports. Again, a port sniffer might be either responsible to create more dense logging information to be forwarded to a remote analysis tool, or perform analysis itself. In our case, we explore a customized port sniffer, presented in the next section, to better understand the performance overheads.

**IV. IMPLEMENTATION DETAILS**

In this section, we look at the implementation of selective mirroring as well as discuss options for a port sniffing process.

**Tunneled selective mirroring**

Using selective mirroring, the decision to mirror a packet is determined through flow rules. For example, suppose that A1 in Figure 4(b) is a frontend server, B1 is the web server and we want to monitor the request service time of B1. Two OpenFlow rules are added to the B1’s TOR switch to forward the network packets that match the selection criteria and send
them to the analysis tool one for each flow direction (A1 to B1 and B1 to A1). The one that captures the message flow from A1 to B1 looks roughly like:

**Conditions:**
TCP-protocol,
Source IP = A1’s IP, Source Port = A1’s port,
Dest. IP = B1’s IP, Dest. port = 8080,
TCP-Flags = ACK and PUSH

**Actions:** Forward to B1 and Analysis Tool.

In this scenario, the TCP-Flags ACK and Push are used to distinguish data packets from TCP control messages that are of no relevance for monitoring. When the analysis tool receives messages, it extracts and analyzes the packet data in order to match the response packets with their requests and calculate the service time.

As mentioned before, the problem with forwarding a copy of the message to the analysis tool is that the switch has to replace the original destination information (IP address and port number of B1), with the destination address of the analysis tool. Thus, the original destination address is lost. This is an issue if this destination information is necessary for analysis. For example, to measure request service time, we have to have the IP address and port number for the communicating entities to be able to match request and response packet pairs, and hence, calculating request service time. The loss of such destination information can be avoided through tunneling.

Tunnels, in conjunction with OpenFlow, can be used to create a virtual overlay network with its own addressing scheme and topology [4]. Figure 5 shows an example where the switch of B1 is programmed to tunnel messages to the analysis tool. Tunneling protocols such as GRE [25] or VXLAN [26] encapsulate network data and protocol information in other network packet payload. An outer header is added to allow the encapsulated packets to arrive at their proper destination. At the final destination, decapsulation occurs and the original packet data is extracted. Figure 5 illustrates this process, where the outer header contains the Ethernet and IP headers of the sending switch and tunnel destination, and the payload contains the original packet (starting from the L2 header). EverFlow [4] employs GRE to encapsulate mirrored network packets to network monitoring application. We propose using the same strategy for application performance monitoring. First, the switch will be configured through the OpenFlow rules to set up a tunnel between itself and the host where the monitoring and analysis tool resides (see Figure 5). Then, OpenFlow rules similar to the one above are added to the switch that define the selection criteria and encapsulate the network packets to send them through the tunnel to the analysis tool. This happens for request messages sent from A1 to B1 and for response messages from B1 to A1. At the endpoint of the tunnel, i.e., the analysis tool, first a decapsulation has to take place before analysis can be started on the original data packets.

Note that also this tunneled selective mirroring approach can be used by OpenFlow capable hardware switches as the tunneling semantics can be implemented in OpenFlow rules.

![Fig. 5: Tunneled selective mirroring](image1)

![Fig. 6: Customized port sniffer overview](image2)

### Customized port sniffer

Virtual switches implemented in software, such as OVS, use standard ports for incoming and outgoing traffic. Thus, we are able to sniff the packets going through these ports just as we can do this for end-host ports. The sniffer is an independent process on the node running the software switch. In principle, the sniffer can implement any kind of semantics, e.g., simply forwarding selective messages to a analysis tool, or aggregating and reformattting logging messages that only contain information relevant for the analysis (as depicted in Figure 6), or performing the analysis by itself. For the latter case, tools such as Tshark and tcpdump could be deployed on the switch node. In our implementation, we follow a flexible approach that allows for the entire range of possibilities.

Our port sniffer separates the actual sniffing from any additional tasks. The listener process keeps sniffing on pre-defined switch ports, filters relevant messages, and saves the needed traffic packets into a shared memory space. From there, further extraction, analysis and forwarding is performed by extra process(es) as needed. We implemented the listener in a separate process as it has to work at the speed of the OVS ports. Thus, we wanted to make its task as simple as possible, allow for straightforward multi-threading and avoid interference.

For measuring HTTP service request times, the listener process sniffs the OVS port that is connected to the web server and filters for the relevant traffic between client and server (i.e., network packets with port 80 or 8080) to be analyzed. From there, we have implemented two versions for further processing.
In the first version, the analysis process of our OVS sniffer performs the analysis itself. For that it extracts the relevant information from the messages deposited by the listener. It distinguishes the different client connections and captures the arrival time of messages. In order to detect requests and responses, it performs a deep inspection of the TCP packets, as the http headers are embedded in the payload of the TCP messages. It then matches requests/responses for each client connection and calculates service times from there. For that it maintains a few light-weight data structures.

In the second version the extract and forward process of the OVS sniffer extracts again the relevant information, determines timestamps and data packets, but does not do the matching itself. Instead this time the information is forwarded to a remote analysis tool, similar in concept to what the selective tunneling is doing. It uses UDP for that purpose.

V. EVALUATION

We evaluate the different logging approaches discussed in the previous sections using a multi-tier cloud application based on a modified version of the YCSB benchmark [27]. The architecture is illustrated in Figure 7. The testbed consists of modified YCSB clients that send their requests not to a data store but to a web-server, an Apache Tomcat web server, a MySQL database and a Memcache server. The clients submit a predefined workload of HTTP requests to the web server whereby each request retrieves data from either the database or the memory cache. Recent results are cached in the Memcache server. The database schema and the query requests follow the YCSB benchmark. A separate analysis tool component is used for some of the evaluated approaches. All components are connected by an OVS switch configured via Openflow.

The experiments are performed using DELL hosts with dual Intel(R) Xeon(R) CPU E3-1220 v5 @ 3.00GHz CPUs (4 cores per socket), a Broadcom NetXtreme BCM5720 Gigabit Ethernet Dual Port NIC, and 32.8GB memory, with the clients on one machine and all server components on another machine together with the OVS software switch. This resembles the scenario where the cloud provider has large end-host machines that host many components. Each server component runs in its own docker container (docker-ce version 18.03.1). All docker containers are connected by 10 Gigabit Ethernet OVS ports. We used OVS version 2.9.90. 16GB of RAM are assigned to the cache and the backend database system is MySQL 5.7.24.

In order to compare the performance of different monitoring approaches, we run our YCSB benchmark with and without monitoring HTTP request service times. We then measure the overhead for each of the monitoring approaches by analyzing the client perceived performance. That is, we look how they affected the throughput and the latency observed at the clients. To understand the results, we look at CPU utilization for each monitoring approach and how OVS forwarding performance is affected in case of the network-based approaches.

For our experiments, we chose the YCSB read only workload with 3 million scan requests and zipfian distribution for records selection over a 10GB database (10 million records). Each test scenario runs that workload for two minutes and the results are averaged for 5 runs. We tested with up to 40 client threads (after which the web-server was saturated even without monitoring enabled).

A. Monitoring Approaches

Table I provides characteristics of each evaluated monitoring approach such as application dependency, online analysis, deployment location and whether the analysis is done locally or remote.

For a platform-specific software instrumentation at the end host, we enabled the access log valve in Apache tomcat server to log HTTP request service times. We refer to this as Tomcat in the performance figures. For application-independent tools deployed at the end host, we used Tshark and tcpdump. Tshark sniffs the messages, analyzes request times (and other things) and either visualizes them or logs them to a file. Visualization was considerably more expensive. Thus, our evaluations show the overhead when results are dumped to a file. Tcpdump does not have an analysis engine, so we only instructed it to dump all the packets to/from the web-server port to a disk file, which can be fed into any offline analysis tool.

For monitoring in the network, port mirroring, tunneling using GRE/VXLAN and our customized OVS port sniffer are evaluated. As both tunneling approaches have very similar performance results, we only show VXLAN in the figures for better readability. For port mirroring and the tunneling approaches, the mirrored packets are sent to the analysis tool. For our customized OVS sniffer, we show the results when the OVS sniffer performs the request service time analysis itself and when it sends relevant data to the analysis tool. The remote analysis tool used for mirroring and by our OVS

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Footnote: 6The test scenario with rack switches as shown in Figures 5 and 6, where the web server under observation and the analysis tool are on different nodes, is still under development. A bare OVS switch does not provide a large message throughput when the endpoints are on different nodes. We mentioned in Section I that integrating OVS with DPDK can achieve line rate switching performance. We are currently working on this setup.
sniffer actually only dumps all the message it receives to a file without further analysis. We do so because in our setup it resides on the same physical machine as the web server. To not indirectly influence the web-server we wanted to keep the overhead as small as possible.

B. Application throughput and latency

Here we examine the impact of monitoring on the throughput and latency at the YCSB client. Ideally, monitoring has little to no impact on the performance observed at the client side. Figure 8 shows the end-to-end throughput and latency observed by the YCSB client without and with the various monitoring approaches while increasing the workload, i.e., adding more and more client threads.

Of all approaches, Tomcat works the best having nearly no impact on performance compared to no logging. This is because the access log valve does not need to perform any sophisticated message analysis; instead, likely through interception, it only records the time before the web-server starts processing a request and once it has completed, and then logs the time difference as service. This is only possible because the valve is tightly integrated into Tomcat’s software. The other two end-host mechanisms, both application independent, negatively affect performance. Tcpdump has a much lower impact than Tshark, though. This might be due because tcpdump does not perform any analysis but it could also just be that Tshark has generally not an efficient implementation.

All the network-based logging approaches perform relatively similar in terms of client perceived performance as tcpdump. Port-mirroring is slightly worse than tcpdump and the others are yet a bit worse than port mirroring. The reasons for it are different and better explained by looking at the resource consumption and the delay induced in OVS using mirroring approaches as discussed in the next sections.

C. CPU consumption

Figure 9(a) shows the CPU overhead of the analysis tool process and Figure 9(b) shows the CPU consumption of the docker containing the web-server. For Tshark and Tcpdump the CPU overhead for analysis shown in Figure 9(a) is part of the consumption shown in Figure 9(b) as the tools reside within the same docker as the web-server. With OVS sniffer, it resides within the OVS, and for port mirroring and tunneling, the tool resides in its own docker.

Tshark has serious performance problems and often crashed during experiments. It increases the CPU utilization of the web-server docker considerably and the Tshark process itself needs 100%, thus a full core. This is the reason for the poor client-perceived performance. Note that it also missed messages at higher throughputs as it could not handle the high speeds.

For our OVS sniffer with analysis, it performs the analysis locally and writes it to a local file. It performs this much more efficiently than Tshark (possibly because it does overall less analysis than Tshark which also has other features\(^7\) using considerably less CPU resources, but requires more CPU than those approaches that only dump all data (tcpdump and the separate analysis tool used for mirroring and tunneling).

Interesting, when the OVS sniffer only reformats messages and sends them to a remote analysis tool it is not more efficient. With analysis, the sniffer performs request-service measurements for which it has to maintain some internal data structures. Without analysis it has to create messages and send them to a remote tool. This also causes considerable CPU overhead. As the switch and the OVS sniffer are on the same machine as the web-server, the CPU needs of the sniffer compete now with the CPU needs of the web-server and we observe a decreased CPU utilization for the web server. We believe that this is the reason why the OVS sniffer results in a lower client-perceived performance than no monitoring. Our assumption is that if the OVS switch and sniffer are on a different machine, there would be no impact on web-server performance. Of course, the machine on which the OVS switch resides must have the CPU capacity to actually perform the OVS sniffer tasks.

Tcpdump and the separate analysis tool require the least CPU resources as they actually do not do matching but just dump the data. Analysis with tcpdump and port mirroring is more expensive than with tunneling as ALL messages are processed and dumped, while with tunneling the analysis tool only receives a selected set of messages. This was 25% of all packets in our case. Given that the CPU overhead with tcpdump is quite small, the web-server CPU consumption remained the same as without logging.

D. Switch overhead

In this section we compare the performance of port mirroring and tunneling in terms of their impact on the OVS

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\(^7\)However, in our evaluation tests, we enabled only the Tshark analysis features that are corresponding to the ones performed in our OVS sniffer.
forwarding performance. To do that, we use Iperf to measure core link performance. We deploy the Iperf server, the Iperf client and an analysis tool process, each in a separate docker container, all connected through 10 Gigabit Ethernet OVS ports. We work within a single host as the focus is on the performance of the OVS software. We run experiments with up to 10 concurrent client connections.

Figure 10 shows forwarding latency (a) when 10 clients are directly connected with the server (no OVS), (b) using OVS without any mirroring or tunneling, (c) using OVS with port mirroring to the analysis tool process, and (d) using OVS with tunneling (VXLAN) to the analysis tool. As expected, direct connections perform best. OVS adds around 0.4 microseconds latency overhead, port mirroring is only slightly worse than OVS. Tunneling is the slowest.

Tunneling incurs a higher delay because it has to reformat messages and requires more flow rules. The simple OVS switch has only two flow rules that forward the packets between Iperf client and server in both directions. Enabling port mirroring in OVS does not require more flow rules but only different configuration rules to mirror the packets to the analysis tool. For tunneling, we have to define two additional flow rules to selectively mirror the data packets to also the analysis process. There is also the need for reformatting (i.e. encapsulation).

We believe that the client-perceived performance impact observed in Figure 8 for mirroring and tunneling is partially due to this forwarding delay.

E. Summary

Application-independent complex analysis, as done by Tshark, can have a considerable negative impact on application performance. Network-based approaches decouple log collection and analysis from the end components and allow for flexible placement of log collection somewhere in the network (as long as the messages flow through the switch that performs log collection).

While port mirroring has shown better performance than tunneling in our experiments as it introduces less overhead in the switch, it produces more traffic, which might have an affect on overall cloud performance should the analysis tool reside on a different node than the switch. It also increases the load on the analysis tool that has to process more messages as we have seen when we looked at CPU consumption. Compared to mirroring and tunneling, the OVS sniffer has the advantages that (a) it does not introduce any delay into the switch, and (b) it can perform some analysis locally or decide to send selective information for remote analysis, i.e., a whole spectrum of work distribution can be implemented. The disadvantage of the OVS

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8Iperf [https://iperf.fr/](https://iperf.fr/)
sniffer is that it can be only implemented in software and not on SDN-enabled hardware switches.

All the end-host approaches dumped the data they collected into a local file. If one wants to perform global analysis the data needs to be instead send somewhere else. We have seen with our OVS sniffer without analysis that this can lead to significant overhead for sending the messages to remote. For the sniffer process this overhead occurs on the network node. With end-host collection, this overhead is added to the end-hosts.

Thus, we believe that a network approach provides us considerably more flexibility in the placement of logging, monitoring and analysis functionality, and the mechanisms to do so, selective mirroring and port sniffing on OVS ports, are an attractive implementation to integrate the functionality into the network.

VI. RELATED WORK

There exist vast literature regarding logging and monitoring frameworks. Many of them include application instrumentation [21]–[24], [28]–[30]. We already described the Twitter framework previously. Another example is SAAD [21], which uses log statements as trace points to track the execution flow of the tasks during the run-time and exploits the statistical similarity of tasks to detect performance anomalies. However, the use of application-dependent logs for analysis needs to rely on experts with deep knowledge of the system, which is less practical in large deployments.

Recent years have seen efforts to have the network support tasks necessary for application logging. AS SDNs already perform a considerable amount of traffic monitoring and analysis, the question was whether the SDN components could also be used for application monitoring and analysis.

We ourselves were inspired by NetAlytics [3], [5] which is an application-independent performance monitoring approach which deploys monitors across the cloud network. SDN switches mirror packet flows to these monitors for real-time analysis. We moved this idea forward by using tunneling to mirror less packets or by putting some of the analysis into the switch. Specifically for HTTP request service time monitoring, NetAlytics performs it for individual clients. Our customized client can be deployed for multiple concurrent clients. EverFlow [4] utilizes match and mirror capability in commodity switches to capture certain packets and debug DCN faults. Our tunnelled selective mirroring adapts the same idea for application layer measures such as HTTP request service time. Other, mainly network-relevant monitoring that exploits mirroring are [5], [6], [31], [32].

NefPerf [33] sniffs packets on all communication paths between application components of the running application to compute per-hop throughput and delays, and uses these measurements to identify both hardware and software performance bottlenecks. We have the same goals but with more focus on monitoring more finer application metrics. Other approaches that use sniffing are [3], [9], [34]–[36]. Similar to NetAlytics, [37] and [38] place in-network monitoring agents. For example, in [37], in-network monitors are deployed to mark and tag network packet for monitoring purposes. When arriving its egress monitoring agent, The packet tags are forwarded to the SDN controller for further analysis. This interferes the basic operation of the SDN controller which led to communication and processing overheads.

As we have mentioned in Section III.C, several projects have worked on extending switch software, usually by extending the OpenFlow protocol. In particular, they often provide deep packet inspection [7], [8], [10], [11], [39], [40]. The authors in [7] extend the OpenFlow architecture to inspect not only the packet header but also the payload information in the packets by inserting a set of predefined string patterns into the switch at the time of the switch initialization. Logs of matched packets are generated and sent to a log server for further analysis. In contrast, [11] augmented SDN switches with application processing logic defined in a table called application table. This enables customized packet handling in the SDN data plane switch. As the switch now needs to scan every packet in [7], [11], it can handle significant less packets per time unit than without application-specific functionality.

Both [8] and [10] modify the OVS source code to decouple the monitoring functions from the forwarding path of OVS in two different ways. UMON [8] decouples monitoring from forwarding by defining a monitoring flow table in the OpenFlow switch user space to separate monitoring rules from forwarding rules. [10] extends the kernel space of OVS to buffer the monitored packets into the ring buffering to be picked up by the monitoring process. However, these both approaches are meant for network layer measures and do not include monitoring of any application level measures.

VII. CONCLUSIONS AND FUTURE WORK

In this paper, we have empirically explored the various trade-offs of different host and network based logging approaches. In addition, we proposed and implemented two network-based logging approaches and provided a quantitative comparison. The results show that sniffer tools on end-hosts can create considerable overhead. In contrast network-based approaches provide for a flexible deployment of log collection and analysis functionality. The use of SDN features keeps the overhead induced by the collection process at reasonable levels. Virtualized switches further enhance the possibilities of what can be done at the network components.

In a next step, we will evaluate architectures with top-rack OVS based switches that build on fast packet processing libraries. Furthermore, we will explore further high-level application monitoring functions to build a complete Monitoring-as-a-Service of the network.

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