Coflow Scheduling in data center networks

Stas Mushits, Amit Borase, Ruby Pai, Sreejith Unnikrishnan, Ritvik Jaiswal

***Abstract*—Current coflow schedulers require coflows to be explicitly identified by the programmer to the scheduler via an API. This is not ideal as it depends on the programmer manually identifying all coflows completely and accurately, which is not a reasonable assumption. This paper attempts to evaluate the performance of existing coflow schedulers in the case where coflows are incompletely identified.**

***Index Terms*—Coflow scheduling, Data center networks**

I. Introduction

The main bottleneck for data parallel applications arises from slow network connections. Traditional network scheduling techniques do not take advantage of the rich semantics available from such applications. Therefore, the *coflow abstraction* [1] was introduced, for the applications to easily convey their communication semantics so the network can better optimize common communication patterns. Coflow scheduling uses this abstraction to schedule flows in such a way as to decrease communication time of data-intensive jobs and guarantee predictable communication time.

Current coflow schedulers include Varys [3] and Aalo [2]. Varys is based on heuristics that draw on insights about characteristics of an optimal coflow scheduler that minimises the coflow completion time (CCT) or ensures that flows meet their deadlines. This approach requires prior knowledge about the coflows in the system thus limiting Varys' applicability. Aalo, on the other hand, efficiently schedules coflow without this prior knowledge.

One major drawback of these schedulers is that they require coflows in the system to be identified manually. Therefore, in this paper, we attempt to evaluate the performance of these schedulers when coflows are incompletely identified.

II. Related work

Our primary work was to study the coflow scheduler work in detail. Network scheduling mostly ignores application level requirements, especially in intensive data parallel applications. At the application layer flow completion time would be the most important metric. Coflow abstraction represents collection of related flows in data network, and improving the coflow completion time is equivalent to improving the application performance. Improving application performance by minimizing coflow completion time (CCT), and ensuring that individual flows meet deadlines is a NP hard problem. Varys[3] is a coflow scheduling algorithm that uses heuristic approach to minimize coflow completion time of the system. The algorithm uses Smallest-Effective-Bottleneck-First (SEBF) heuristic, that schedules coflow based on bottleneck flow's completion time. Minimum-Allocation-for-Desired-Duration (MADD) algorithm is used to allocate rate for individual flows. MADD slows down all the flows in a coflow to match the completion time of the flow that will take the longest to finish. Working together, these algorithm effectively implements a heuristic that reduces the coflow completion time. Varys coflow scheduler works based on the aformentioned principles. Varys scheduler is designed to be clairvoyant scheduler, meaning it knows the flows and flow structure in advance. However the authors proposed a new scheduling algorithm called Aalo[2], which is non clairvoyant, which in turn translates to a more pragmatic approach in coflow scheudling. Aalo uses multi-level queue structure with a threshold value to effectively reduce flow completion time. The aalo scheduler uses a predefined threshold X for highest priority queue, and subsequent lower priority queues each multiplied by a factor of E^N. All coflows enter the higher priority queue first. When the flow crosses the threshold it gets de prioritized into lower level queues. This ensures that shorter coflows will get effective bandwidth and is not greatly affected by larger flows. Within a queue, scheduler follows a First In First Out (FIFO) principle.

One of the preliminary task was to create a suitable environment to simulate and run the network. We did a survey of possible network simulators carefully looking for the features it provided and its suitability for our objective. For the baseline network simulation we decided to go for mininet[4]. There are other options like NS2 simulator etc. Support for python programming coupled with integration support with many VMs made our choice of picking up mininet easier. Moreover there is a huge community involvement and documentation for the tool.

The second decision was to decide on a network topology over which we should be running the simulation. Our aim was to ensure that rather than sticking to naive network topologies, we should rather read up on production quality network topologies, that is actually useful in real world scenario. Keeping that in mind and considering the pragmatic implications, we used fat-tree based network topology. Fat tree topology ensures that the end hosts receive full bisection bandwidth and there would be multiple path from a host to core server, ensuring higher bandwidth and reliability. Most of the fat tree implementation requires some method of hashing, usually ECMP to ensure that the multiple paths are effectively utilized. Our search for an SDN controller with ECMP support did not bear the fruit. The next best option was to find a controller that learns MAC addresses for efficient switching. Openflow Floodlight[5] controller was selected for this purpose. Firstly floodlight supports learning based data forwarding and secondly provides Java based API. We were able to successfully create and deploy a fat tree topology with

parameter K = 4, ensuring that we have 16 hosts connected to each other.

We ran the network in our allotted UCSD cluster machines. However we came across a problem when we tried to assign individual IP addresses to each mininet hosts. Mininet host will take IP's based on the host name, which while running on a single VM is the same. To resolve this, we had to look for other means. After quite a bit of research, we decided to use Docker[6] containers for deploying mininet hosts. Docker containers are essentially virtual machines without hypervisor. This essentially means that we were able to create Docker based software containers for individual mininet hosts and was deployed on our cluster virtual machines. Docket provide APIs that enables us to monitor, trigger and execute process in individual containers from the host machine. We used python based API for our interaction with docker containers.

Next step was to create software architecture that is efficient and flexible enough to create the simulation framework. Since the Varys and Aalo scheduler code runs on Scala, we decided to use Java as our main language. Given the legacy of socket programming and multi-threaded capability of Java, our choice proved effective in the long run. Our control traffic was handled in-band, with a master node. The system takes a hosts file that contains the list of hosts and their IP addresses as its input and a task file descibing the frame size, mapper reducer configuration etc. We also provide a simulation file in JSON format which the program uses to identify the Master URL, the URL where the Varys or Aalo scheduler listens to for scheduling the tasks. The Program then runs the simulation in accordance with the tasks file and produce relevant log files as the output. We created a small program in MATLAB, that would analyze the log files to generate graphs and results out of it.

III. Design

At the beginning of our research we decided to built a simulation system which would allow us to simulate data center traffic patterns on a small scale. As a network abstraction we chose Mininet. For host behaviour we tried decentralized and centralized system and chose centralized one because of it more predictable behaviour and easiness of deployment. Because of a dependency for a host name of a machine we chose Docker containers to run our hosts in.

A. Simulating a network

1) Mininet: Mininet is network emulation orchestration system, which creates a network of virtual hosts, switches, controllers, and links, that run on single Linux kernel underneath and share host file-system and other components. It uses lightweight virtualization to make a single system look like a complete network, running the same kernel, system, and user code. In short, mininet simulates all the hardware entities of network using software. Mininet exports powerful python APIs that could be used readily to design complex network topologies along with the required routing solution. We chose mininet to simulate network, mainly because of its fast deployability and customizability.

2) Topology: Fat-tree topologies are widely prevalent in todays data center network environments. Since the Coflow scheduling is largely effective in the isolated network environments such as data-centers, we decided to use fat-tree topology to simulate the data-center network. One of the many advantages posed by fat-tree topology is the availability of multiple equal cost paths, but that meant we needed to write our own routing solution based loosely on the 2-level routing table solution described in. The strict time-constraint of the project meant we had to yield to a more ineffective routing solution such as learning switch, which does not take full advantage of all equal cost paths available and instead routes traffic through learnt paths only.

Additionally, we tried to have an out-of-band and fast control network, but that meant we introduce loops in the topology and disturb the existing routing solution. Hence we decided to have an in-band control network by assigning the first host the sole role of scheduler and simulator controller. All our experiments were done on fat-tree topology with k-value of , that meant we had 16 hosts in the network.

B. Simulation framework

The next step was to create a program which could approximate the behaviour of the host in a datacenter. As we wanted to particularly inspect coflow behaviour our system should be very time sensitive, meaning that each flow should start in a specific point in time in order to give us ground for reasoning about its completion time and completion time of a coflow to which it belongs. We tried two approaches: decentralized and centralized system. For a network behaviour to simulate we chose MapReduce pattern since it is very common and very suitable for coflow usage.

C. Decentralized system

At first, we tried to build a decentralized system for simulation since it seemed more easy and faster to implement and should have been sufficient for our needs. It had one entity, we call it Actor since it plays a role assigned to it by simulation. Actors accepted configuration of simulation and tasks they need to accomplish and behaved based on that information. The task represented one flow and had starting time, sender, receiver and amount of data to transfer. Synchronization of timing among hosts wasnt an issue because as programs deployed within mininet hosts they share kernel and use the same timer.

Although this first system could behave using TCP sockets it we realized that it wasnt very suitable for simulation of coflows since coflow should be registered by one host before other hosts can send traffic using this coflow. The situation was worsen by the need for generating of tasks for a simulation. As we wanted to simulate MapReduce we had to generate concrete tasks for each host so that part of the hosts in one specific moment would start behave as mappers and another part would start to behave as reducers. All of that required

precise timing and generating task files for each host with this timing in mind which is as complex as a system itself.

D. Centralized system

Our second attempt was a centralized system with one Controller, which had all the tasks and knew about all other hosts in a network. It was deployed on a separate host in a network. With it we neglected the need to generate tasks for each host in the network separately, synchronize hosts by timing and could concentrate on the creating one task file which would allow us to easily coordinate behaviour of all Actors from the Controller.

The coordination and interaction between Controller and Actors as well as between Actors is the follows. On start of simulation Controller accept a task file which has the following format:

```
Line 1: <Number of ports in the fabric>
    <Number of coflows below (one per line)>
Line i: <Coflow ID> <Arrival time (ms)>
    <Number of mappers> <Location of map-m>
    <Number of reducers>
    <Location of reduce-r:Shuffle
    megabytes of reduce-r>
```

Task scheduler on the Controller then iterate through the tasks and send each task in appropriate time to all hosts which participate in execution of this task. Also, it register coflow for each task during the start of the task and unregister it when this task is finished.

Upon receiving the the task, Actor creates a mapper or reducer thread depending on a role given in a task. Using task mappers send specified amount of data to appropriate reducers using Aalo API which schedules sending using information on local Aalo slave and global Aalo master located on the Controller host. When reducer finishes receiving data from all mappers it report to Controller. When all reducers report to Controller about completion of the task Controller unregister coflow and measure its completion time. Using this system we could vary the tasks, number of mappers and reducers, specify unlabeled flows in a coflow and orchestrate the whole system from one host. Also, the timing was simplified because only master knew when and which host should start sending or receiving and could activate all Actors in an appropriate order.

E. Docker containers as a mininet hosts

During the initial phase of deployment with the coflow scheduler, we found out that the coflow scheduler heavily uses the hostname of the system to frame various control messages. Since the mininet hosts shared the file-system with the host, this posed a problem as the mininet hosts could not be configured to have a unique hostname across the virtual network, they merely had the same hostname as the underlying system. We tried to get-around this roadblock by designing a wrapper around the hostname APIs in java to return hostname that did not match with that of underlying host and were

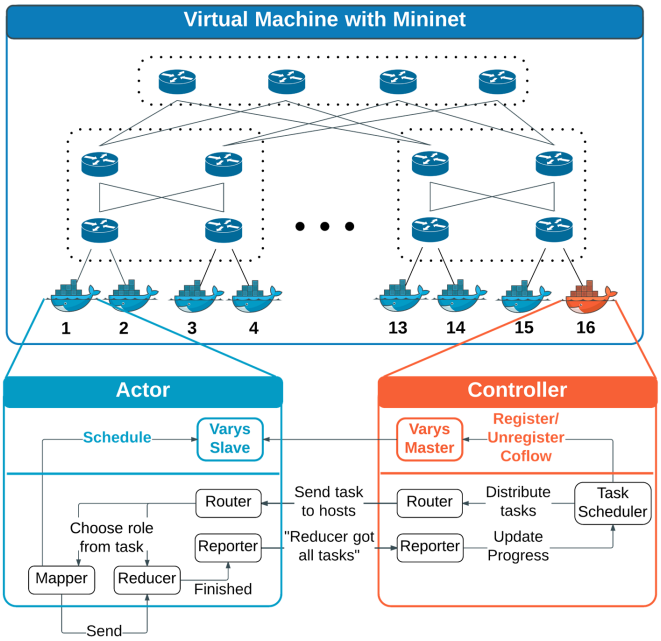

Fig. 1. System Setup

unique across mininet network. This approach did not prove to be fruitful as it required hard-coded hostname framing at multiple places in both coflow scheduler code and the hosts system. To get around this issue, we decide to have mininet hosts as docker containers.

Docker is an upcoming technology that allows packaging of an application with all of its dependencies into a single container, that works out-of-box and can be readily deployed on any docker environment regardless of the underlying hardware. Docker container thus built wrap up a piece of software along with a complete filesystem that contains everything it needs to run: code, runtime, system tools, system libraries.

This meant that each docker container instance gets assigned an unique hostname, which made sure that we were not needed to make to any cosmetic changes to the coflow-scheduler code. Additionally docker container allowed us to package both, coflow scheduler and simulator into a single image that could be readily uploaded and deployed on any machine as long as it ran Ubuntu system. This allowed us to carry out some of our experimentation on faster amazon EC2 instances without any additional setup requirements.

We used publicly available fork package of mininet *https://github.com/mpeuster/dockernet*[7] that replaces mininet hosts with docker containers.

IV. Evaluation

V. Conclusion

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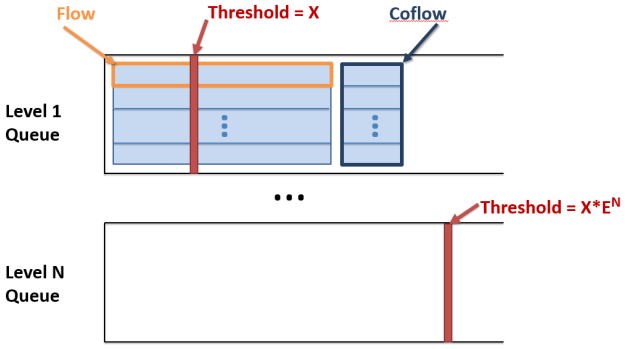
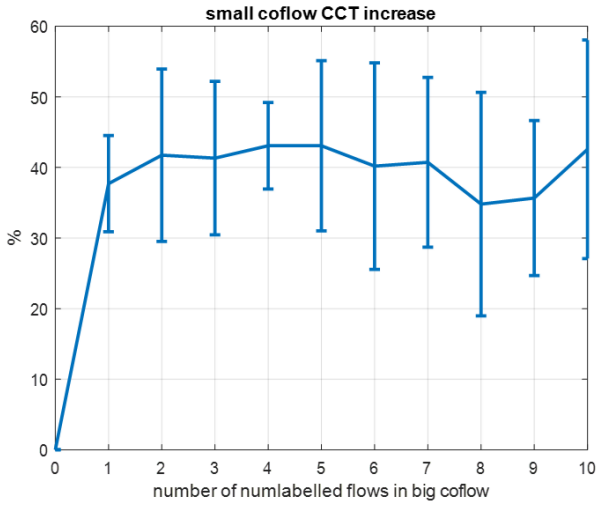
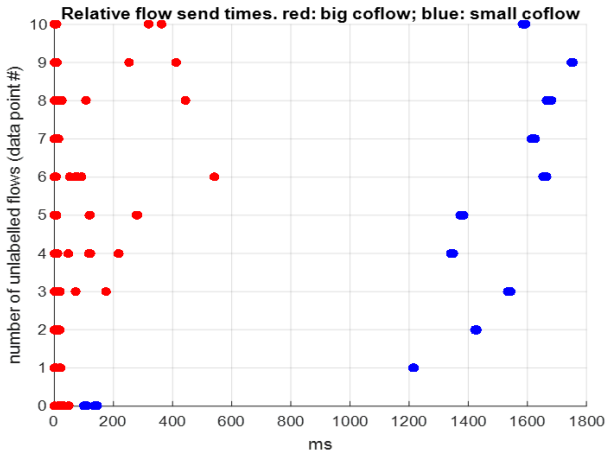
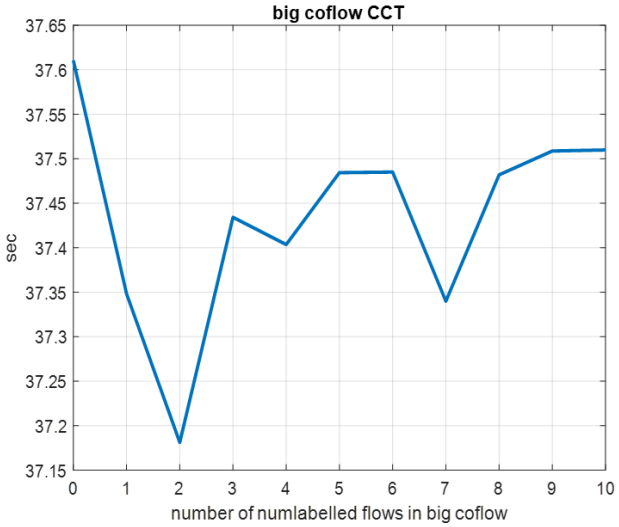


Fig. 2. Scheduler Queues







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References

[1] Coflow: A Networking Abstraction for Cluster Applications *Mosharaf Chowdhury, Ion Stoica, SIGCOMM, 2012*

[2] Efficient Coflow Scheduling Without Prior Knowledge, *Mosharaf Chowdhury, Ion Stoica, SIGCOMM, 2015.*

[3] Efficient Coflow Scheduling with Varys, *Mosharaf Chowdhury, Yuan Zhong, Ion Stoica, ACM SIGCOMM, 2014.*

[4] Mininet - rapid prototyping for SDN *https://github.com/mininet/mininet*

[5] Flood light SDN controller *https://github.com/floodlight/floodlight*

[6] Docker *https://www.docker.com/*

[7] Dockernet *https://github.com/mpeuster/dockernet*