Investigating the Scalability Limits of Distributed Erlang

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Abstract

With the advent of many-core architectures scalability is a key property for programming languages. Actor-based frameworks are fundamentally scalable, but in practice they have some scalability limitations. The RELEASE project aims to improve the scalability of Erlang on emergent commodity architectures with 10^5 cores. This paper investigates the scalability limits of distributed Erlang on up to 150 nodes by using *DE-Bench*. We discuss the design and implementation of DE-Bench, a P2P benchmarking tool for distributed Erlang. We demonstrate that frequency of global commands limit the scalability of distributed Erlang. Moreover, measuring the latency of commonly-used distributed Erlang commands reveals that the latency of RPC calls increase as cluster size grows. We show that distributed Erlang scales linearly up to 150 nodes with a relatively heavy data and computation loads when no global command is made.

Categories and Subject Descriptors C.2.4 [*Distributed Systems*]: Distributed applications

Keywords Scalability, Performance, Erlang

1. Introduction

The trend toward horizontally scalable architectures such as clusters, grids, and clouds will continue because they offer scalable hardware platform in a cost-effective way [1]. These scalable infrastructures typically consist of loosely-connected commodity servers in which node and network failures are common. To take full advantage of such architectures, the need for reliable scalable programming paradigms is obvious.

Recently, Erlang has become a popular platform to develop large-scale distributed applications, e.g. *Facebook chat backend*, *T-Mobile advanced call control services*, *Ericsson AXD301 ATM switch*, and *Riak DBMS* [2], [3]. This popularity is due to a combination of factors, including data immutability, share-nothing concurrency, asynchronous message passing based on the actor model, process's location transparency, and fault tolerance [4].

However, in practice the scalability of Erlang is constrained by aspects of the language and virtual machine [5]. For instance, our measurement shows that Riak1.1.1 does not scale beyond 60 nodes [6].

The RELEASE project aims to improve the scalability of Erlang on emergent commodity architectures with 10^5 cores [5]. The project plans to scale Erlang at the virtual machine, language level, infrastructure levels, and to supply profiling and refactoring tools. At the language level we aim to scale distributed Erlang, and so identifying the scalability bottlenecks of distributed Erlang is a key requirement.

We have designed and implemented DE-Bench to investigate the scalability limits of distributed Erlang [7]. DE-Bench, which stands for "Distribute Erlang benchmark", is a P2P benchmarking tool that measures the throughput and latency of distributed Erlang commands on a cluster of Erlang nodes. In the rest of the paper, we will explain how DE-Bench has been developed and employed to investigate the scalability of distributed Erlang.

2. How Does the Benchmark Work?

2.1 Platform

The benchmark was carried out on the Kalkyl cluster at UPPMAX (Kalkyl has now been decommissioned and replaced with Milou) [8]. The Kalkyl cluster consists of 348 nodes with 2784 64-bit processor cores which are connected via 4:1 oversubscribed DDR Infiniband fabric. Nodes have 24GB RAM memory and 250 GB hard disk. The Kalkyl cluster is running Scientific Linux 6.0, a Red Hat Enterprise Linux. Each node comprises Intel quad-core Xeon 5520 2.26 GHz processors with 8MB cache. In this report, to avoid confusion with Erlang nodes (Erlang VM), we use the term *host* to refer to the Kalkyl nodes (physical machines). Erlang version R16B has been used in all our experiments.

2.2 Hosts and Nodes Organization

The same as an ordinary distributed Erlang application, our benchmark consists of a number of Erlang Virtual Machines (Erlang VMs) communicating with each other over a network. The benchmark is run on a cluster of hosts and there can be multiple Erlang VMs on each host, however, each Erlang VM runs only one instance of DE-Bench. For example, Figure 1 depicts a cluster with 2 hosts and 2 Erlang nodes (Erlang VMs) per host. As shown, a node can communicate with all the other nodes in the cluster regardless of whether nodes are located on the same host or not. DE-Bench follows a P2P model in which all nodes perform the same role independently, and so there is no specific node for coordination or synchronisation. The P2P design of DE-Bench improves scalability and reliability by eliminating central coordination and single points of failure.

2.3 The Design and Implementation of DE-Bench

To evaluate the scalability of distributed Erlang, we measure how adding more nodes to a cluster of Erlang nodes would increase the

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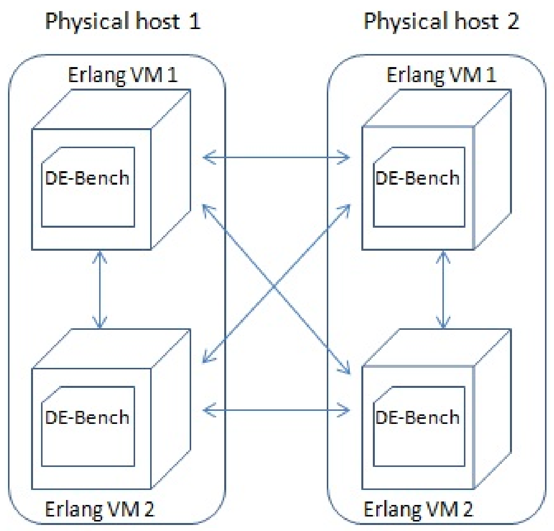

Figure 1: 2 hosts and 2 Erlang VMs per each host

throughput. By *throughput* we mean the total number of successfully executed distributed Erlang commands per second. DE-Bench is based on Basho Bench, an open source benchmarking tool for Riak NoSQL DBMS [9].

One interesting feature of Erlang is its support for failure recovery. Processes in an Erlang application can be organised into a hierarchical structure in which parent processes monitor failures of their children and are responsible for their restart [10]. DE-Bench uses this feature to provide a fault-tolerant service. Figure 2 represents the internal workflow of DE-Bench. Initially, a supervisor process runs a number of worker processes in parallel on a node. The number of worker processes on each node is definable through a configuration file. As each host in the Kalkyl cluster has 8 cores, we run 40 worker processes on each node to exploit available cores. The supervisor process supervises all the worker processes and keep them alive by restarting them in case of failure. A worker process randomly selects an Erlang node and a distributed Erlang command from the configuration file and runs that command on the selected node. There are three kinds of commands in DE-Bench:

- *Point-to-Point* (P2P): In P2P commands, a function with tunable argument size and computation time is run on a remote node. Figure 3 depicts the argument size and computation time for a P2P command. As the figure shows, firstly, a function with argument size *X* bytes is called. Then, a non-tail recursive function is run on the target node for *Y* microseconds. Finally, the argument is returned to the source node as result. P2P commands include *spawn*, *RPC*, and synchronous calls to server processes, i.e. *gen_server* or *gen_fsm*.
- *Global commands*: When a global command is run, all the nodes in a cluster get involved, and the result will be ready once the command runs successfully on all nodes. Global commands such as *global:register_name* and *global:unregister_name* are defined in the OTP *global* module.
- *Local commands*: In local commands such as *register_name*, *unregister_name* and *whereis_name*, just the local node gets involved and there is no need to communicate with other nodes in the cluster. The command *whereis_name* is a look up in the local name table regardless of whether it is from the global module or not.

After running a command, the latency and throughput of the command is measured and recorded in appropriate CSV files. The CSV files are stored on the local disk of each node to avoid disk access contention and network communication latency.

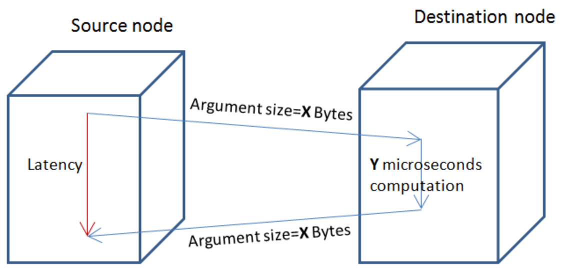

Figure 3: Argument size (X) and computation time (Y) in P2P commands

DE-Bench is extensible and one can easily add new commands into DE-Bench through the *de_commands.erl* module. At the time of writing this paper, the following commands are defined and measurable in DE-Bench:

1. P2P commands:
   (a) *spawn(Node, Fun)*: a function is called at a remote node with tunable argument size and computation time as depicted in Figure 3. Since spawn is an asynchronous call, the elapsed time is recorded after receiving an acknowledgment from the remote node.
   (b) *RPC(Node, Fun)*: synchronously calls a function at a remote node with tunable argument size and computation time.
   (c) *server process call*: makes a synchronous call to a generic server process (gen_server) or a finite state machine process (gen_fsm) by sending a request and waiting for the reply.
2. Local commands:
   (a) *register_name(Name, Pid)*: associates a name with a process identifier (pid).
   (b) *unregister_name(Name)*: removes a registered name, associated with a pid.
   (c) *whereis(Name)*: returns the pid registered with a specific name.
   (d) *global:whereis(Name)*: returns the pid associated with a specific name globally. Although, this command belongs to *global* module, it falls in local commands because it does a lookup in the local name table.
3. Global commands:
   (a) *global:register_name(Name, Pid)*: globally associates a name with a pid. The registered names are stored in name tables on every node in the cluster.
   (b) *global:unregister_name(Name)*: removes a globally registered name from all nodes in the cluster.

These commands are not used at the same rate in a typical distributed Erlang application. For instance, P2P commands such as *spawn* and *RPC* are the most commonly used ones and global commands like *register_name* and *unregister_name* are used much less than the others. Thus, to generate more realistic results, we can use each command with a different ratio.

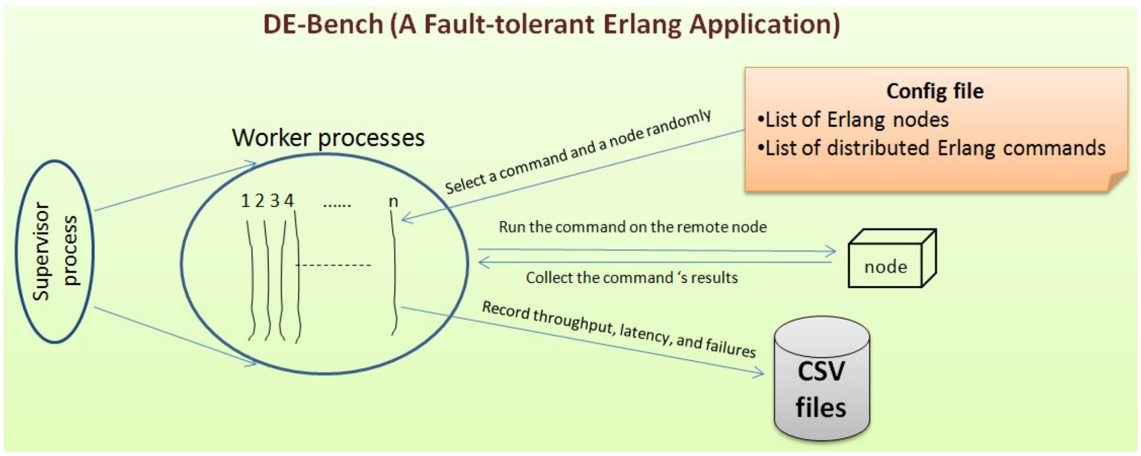
DE-Bench (A Fault-tolerant Erlang Application)
Config file
•List of Erlang nodes
•List of distributed Erlang commands
Worker processes
Select a command and a node randomly
Supervisor process
1 2 3 4 ...... n
Run the command on the remote node
Collect the command 's results
node
Record throughput, latency, and failures
CSV files

Figure 2: *DE-Bench* Internal Workflow

In Erlang, a process identifier (pid) only can be registered once, otherwise an exception is thrown. To prevent the exception, an internal state is defined in DE-Bench to ensure that after registering a process, all necessary commands like *whereis_name* and *unregister_name* will be executed afterward. Figure 4 shows three states that DE-Bench follows to avoid duplicate registration exception. As shown, P2P commands do not change the current state (*state1*). The commands *whereis_name(Name)* and *unregister_name(Name)* are ignored unless they come after *register_name(Name, Pid)*. After running a *register_name(Name, Pid)* command, both *whereis_name(Name)* and *unregister_name(Name)* will be run respectively. To avoid name clashes, a timestamp function is used to generate a globally unique name for processes.

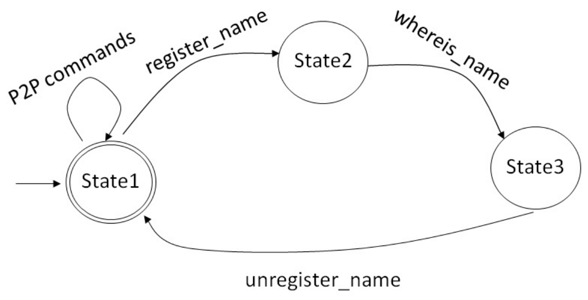

Figure 4: *DE-Bench* Internal States

3. Benchmarking Results

In this section, we employ DE-Bench to measure the scalability of distributed Erlang from different perspectives. In the scalability benchmark, we measure the throughput for different sizes of Erlang clusters and observe how adding more Erlang nodes to a cluster affects the throughput.

3.1 Scalability Aspects

The benchmark is conducted on 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100-node clusters and measures the throughput by counting successful operations per each experiment. There is one Erlang VM on each host and as always one DE-Bench instance on each VM. After the end of each experiment, the generated CSV files from all participating nodes are collected and aggregated to find out the total throughput and failures. For example, for benchmarking a 70-node cluster, 70 instances of DE-Bench are run simultaneously and consequently they will generate 70 CSV files which need to be aggregated to find the throughput of the 70-node cluster. To provide reliable results, all experiments are run three times and the middle values are represented in diagrams.

We will measure following aspects of the scalability of distributed Erlang:

1. **Global Commands**: As illustrated previously in Section 2.3, in global commands all nodes in the cluster get involved. This feature of global commands could make them a bottleneck for scalability. To find out the effects of global commands on the scalability of distributed Erlang, we run the measurements with different percentages of global commands.
2. **Data Size**: As shown in Figure 3, the argument size of P2P commands is tunable. To understand the effect of data size on the scalability and performance of an Erlang cluster, we run the benchmark with different argument sizes.
3. **Computation Time**: As with argument size, the computation time of P2P commands is also tunable in DE-Bench (Figure 3). We investigate the effect of computation time on both scalability and performance of distributed Erlang.
4. **Data Size & Computation Time**: It may be interesting for the Erlang community to know how distributed Erlang scales when both data and communication are relatively heavy. This benchmark tries to find an answer to this question.
5. **Server Process**: There are two popular types of server process in Erlang/OTP: generic server processes (*gen_server*) and finite state machine processes (*gen_fsm*). This section will inspect the scalability of these server processes, and try to find out whether the server processes are bottlenecks for the scalability of distributed Erlang.

3.2 Global Commands

To find out how global commands affect the scalability of distributed Erlang, we run the benchmark with different frequencies of global commands. The following commands are used in the measurement:

1. P2P commands: *spawn* and *RPC* with 10 bytes argument size and 10 microseconds computation time

2. Global commands: *global:register_name* and *global:unregister_name*
3. Local commands: *global:whereis(Name)*

Figure 5 shows how frequency of global commands limits the scalability of distributed Erlang. As we see from the diagram, scalability becomes more limited as more global commands are used. For example, when 0.01 percentage of global commands are used (the dark blue curve) , i.e. 1 global command per 10,000 P2P commands, distributed Erlang doesn't scale beyond ≈60 nodes.

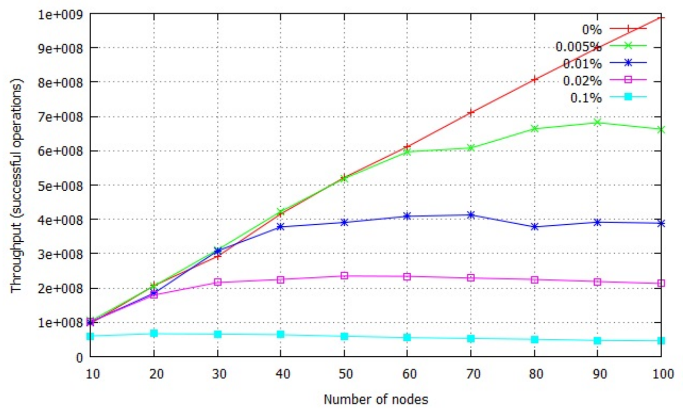

Figure 5: Scalability vs. Percentage of Global Commands

Figure 6 represents the latency of all commands that we used in this measurement. The diagram reveals that the latency of both global commands, i.e. *global:register_name* and *global:unregister_name*, increases dramatically when cluster size grows. For example, name registration on a 100-node cluster takes ≈20 seconds which is a considerably long time. The registered names are stored in name tables on every node [11] and these tables are strongly consistent, which means that an update is considered complete only when all nodes have acknowledged it. This lock mechanism for updating the replicated information becomes a bottleneck on large clusters. As we see from Figure 6, the other commands' latencies (i.e. *spawn*, *RPC*, and *whereis*) are very low and negligible in comparison with the global ones.

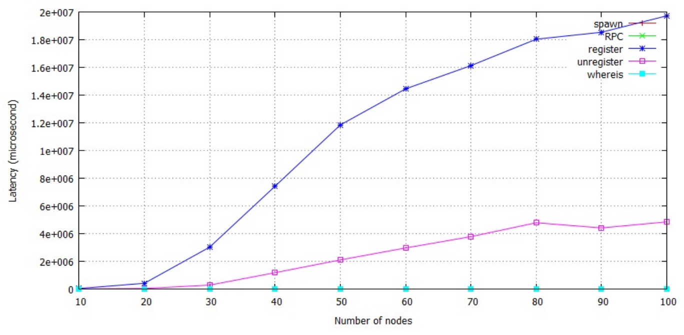

Figure 6: Latency of Commands

3.3 Data Size

This section studies the effect of data size on the scalability of distributed Erlang. As shown in Figure 3, P2P commands have two configurable parameters, i.e computation time and argument size. In this benchmark, the computation time is constant while argument sizes of P2P commands change for different experiments. The following commands are used in the benchmark:

- P2P commands, i.e. *spawn* and *RPC*, with 10, 100, 1,000, and 10,000 bytes argument size and 10 microseconds computation time

Figure 7 represents the scalability of distributed Erlang for different data sizes. The diagram shows that as argument size increases, the performance and scalability decrease. For example the best scalability belongs to 10 bytes data size (the red curve) and the worst scalability belongs to 10K bytes data size (the pink curve).

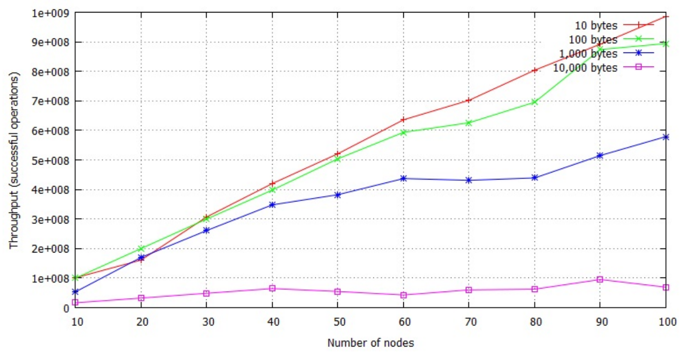

Figure 7: Scalability vs. Data Size

3.4 Computation Time

This section tries to find out how computation time affects the scalability of distributed Erlang. In this benchmark, the argument size of P2P commands is constant while the computation time changes for different experiments. The following commands are used in the benchmark:

- P2P commands, i.e.*spawn* and *RPC*, with 10 bytes argument size and 10, 1,000, and 1,000,000 microseconds computation time.

Figure 8 represents the scalability of distributed Erlang for different computation times. The diagram shows that as we increase the computation time, the performance and scalability degrade. The best scalability achieved for 10 microseconds computation time, and 1 second computation time shows the worst scalability. This is expected because for larger computation time, worker processes should wait longer for their response and consequently spend most of the time in idle mode.

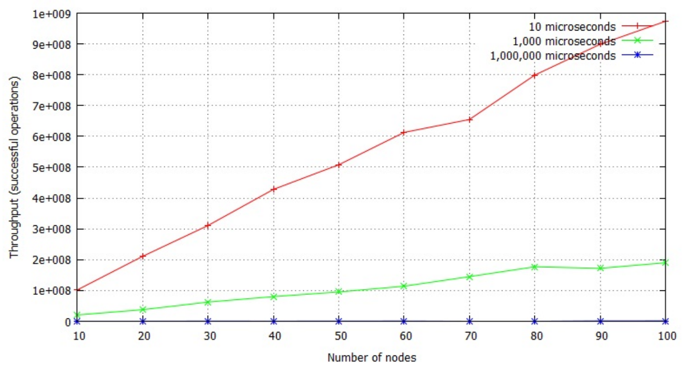

Figure 8: Scalability vs. Computation Time

3.5 Server Process

Our experiment with Riak shows how a server process could limit the scalability of a distributed Erlang application [6]. This section investigates the scalability of two common server processes in Erlang/OTP: generic server processes (*gen_server*) and finite state machine processes (*gen_fsm*). As mentioned in Section 2.3, a server process call is a P2P command. However, in this benchmark, we use all kinds of P2P commands, i.e. server process calls and non-server process calls such as *spawn* and *RPC*. Using all kinds of P2P commands makes us able to compare the scalability of server process calls with that of non-server process calls. The following commands are used in the benchmark:

- Non-server process P2P commands, i.e.*spawn* and *RPC*, with 10 bytes argument size and 1 microseconds computation time.
- Server process synchronous calls, i.e.*gen_server* and *gen_fsm*, with 10 bytes argument size and 1 microsecond computation time.

Figure 9 compares the scalability of distributed Erlang with different percentages of server process calls, i.e. 1% (red line), 50% (green line), and 100% (blue line). For example, when server process call is 1% (the red line), the other 99% of the calls are non-server process, i.e. *spawn* and *RPC*.

We see from the figure that as more server calls are used, the scalability improves. For instance, the best scalability is achieved when all calls are server processes (the blue line) and the worst scalability occurs when 1% of calls are server process calls (the red line).

We also depict the latency of each command individually to understand which commands' latencies increase when the cluster size grows. Figures 10 and 11 present the latency of commands that we used in the benchmark for 1% and 50% of server process calls. As the figures show, the latency of *RPC* calls rises when cluster size grows. However, the latency of the other commands such as *spawn*, *gen_server*, and *gen_fsm* do not increase as cluster size grows. We see that server processes scale well if they are used properly, i.e. not becoming overloaded as we experienced for Riak [6]. In the next section, we will discuss why RPC doesn't scale well.

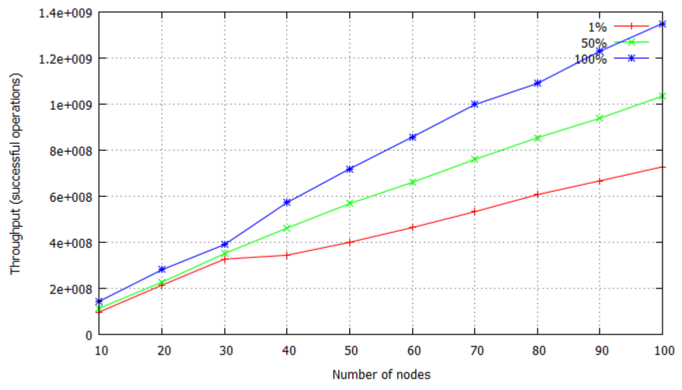

Figure 9: Scalability vs. Percentages of Server Process Calls

3.6 Data Size & Computation Time

Previously, we have seen the individual effects of data size and computation time on the scalability of distributed Erlang (Sections 3.3 and 3.4). In this section we aim to discover how distributed Erlang scales when both data size and computation time are relatively large.

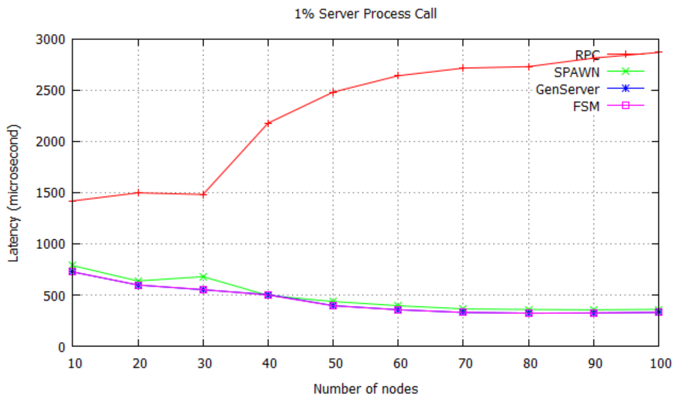

Figure 10: Latency of Commands for 1% Server Process Call

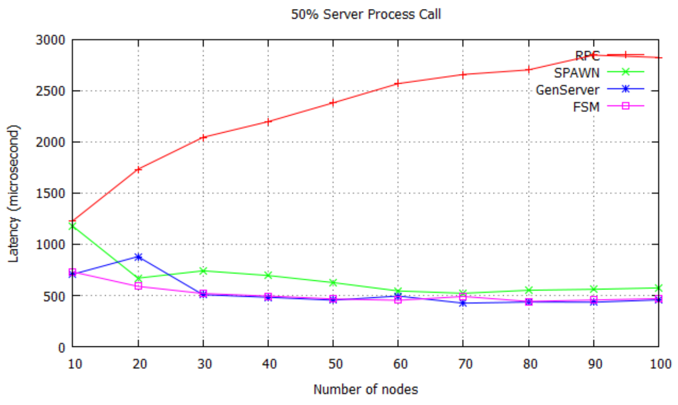

Figure 11: Latency of Commands for 50% Server Process Call

The following commands are used in the benchmark:

- P2P commands, i.e. *spawn* and *RPC*, with 1,000 bytes argument size and 1,000 microseconds computation time.

We chose 1,000 bytes for argument size because we think it is relatively large data size for inter-process communication. We also chose 1 millisecond computational time because it can be considered as a relatively computation-intensive function. Accessing more than 100 nodes on the Kalkyl cluster is difficult because it's a highly demanded and busy cluster. But we could run this benchmark up to 150 nodes to see how distributed Erlang scales on that size.

Figure 12 represents the scalability of distributed Erlang for 1,000 bytes argument size and 1000 microseconds computation time. As we see from the diagram, distributed Erlang scales linearly under relatively heavy data and computation load. But this doesn't mean that all P2P commands have the same scalability and performance. Figure 13 depicts the latency of *spawn* and *RPC* commands and it shows that latency of *spawn* is much less in comparison with *RPC*.

To find out why *RPC* latency increases when the cluster size grows, we need to know more about *RPC*. Figure 14 shows how an RPC call is handled in Erlang/OTP. There is a generic server process (gen_server) on each Erlang node which is named *rex*. This process is responsible for receiving and handling all RPC requests that come to an Erlang node. After handling the request, generated results will be returned to the source node. In addition to user applications, RPC is also used by many built-in OTP modules, and so it can be overloaded as a shared service. In contrast with RPC, *spawn* is an asynchronous call and the request is handled by a newly-generated process on the target node. This feature makes *spawn* more scalable in comparison with RPC.

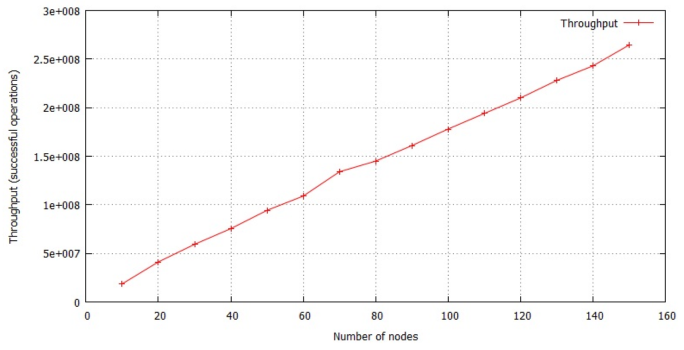

Figure 12: Scalability vs. Data Size & Computation Time

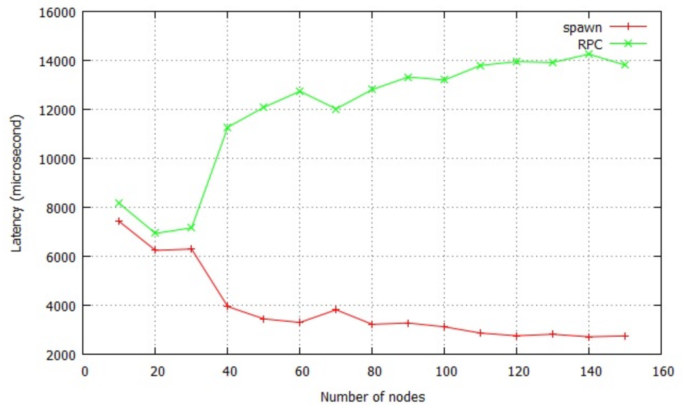

Figure 13: Latency of P2P commands

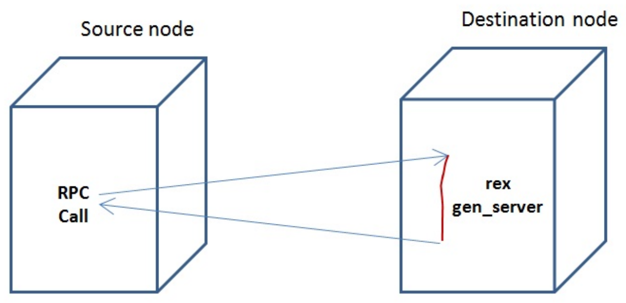

Figure 14: RPC call in Erlang/OTP

4. Conclusion and Future Work

We investigated the scalability limits of distributed Erlang from different perspectives. For global commands, we find that updating the global names table is a bottleneck for the scalability of distributed Erlang (Figure 5). In ongoing work we are developing techniques to improve this limitation [12].

We measured the scalability of distributed Erlang with a relatively large data and computation size. We observe that distributed Erlang scales linearly up to 150 nodes when no global command has been made (Figure 12). We also see from Figure 13 that the latency of RPC calls rises when the cluster size increases. This shows that *spawn* scales much better than *RPC* and using *spawn* instead of *RPC* in the sake of scalability is advised.

Finally, we see from Figure 9 that server processes scale well, and Figures 10 and 11 reveal that server process calls have the lowest latency among all P2P commands.

Acknowledgments

This work has been supported by the European Union grant IST-2011-287510 RELEASE.
The computations were performed on resources provided by SNIC through Uppsala Multidisciplinary Center for Advanced Computational Science (UPPMAX).
We thank Kenneth MacKenzie from Glasgow University for his insightful comments.

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