ScELA: Scalable and Extensible Launching Architecture for Clusters[⋆]

Jaidev K. Sridhar, Matthew J. Koop, Jonathan L. Perkins, and Dhabaleswar K. Panda

Network-Based Computing Laboratory
The Ohio State University
2015 Neil Ave., Columbus, OH 43210 USA
{ sridharj, koop, perkinjo, panda }@cse.ohio-state.edu

Abstract. As cluster sizes head into tens of thousands, current job launch mechanisms do not scale as they are limited by resource constraints as well as performance bottlenecks. The job launch process includes two phases – spawning of processes on processors and information exchange between processes for job initialization. Implementations of various programming models follow distinct protocols for the information exchange phase. We present the designs of a scalable, extensible and high-performance job launch architecture for very large scale parallel computing. We present implementations of this architecture which achieve a speedup of more than 700% in launching a simple *Hello World* MPI application on $10,240$ processor cores and also scale to more than 3 times the number of processor cores compared to prior solutions.

1 Introduction

Clusters continue to increase rapidly in size, fueled by the ever-increasing computing demands of applications. As an example of this trend we examine the Top500 list [1]. This list is a bi-annual list of the top 500 supercomputers in the World as ranked in performance on the Linpack benchmark. In 2000 the largest cluster, ASCI White, had $8,192$ cores. By comparison, last year the top-ranked BlueGene/L had over $200,000$ cores. Even as clusters increase in node counts, an emerging trend is increase in number of processing cores per node. For instance, the Sandia Thunderbird [2] cluster introduced in 2006 has $4K$ nodes – each with dual CPUs for a total of $8K$ processors, while the TACC Ranger cluster introduced in 2008 has $4K$ nodes – each with four quad-core CPUs for a total of $64K$ processors.

Programming models and their scalability have been a large focus as cluster size continue to increase. In addition to these concerns, other more basic concerns with regard to the system software must also be addressed. In particular, the mechanism by which jobs are launched on these large-scale clusters must also be examined. All programming models require some executable to be started on each node in the cluster. Others, such as the Message Passing Interface (MPI) [3], may have multiple processes per node – one per core. Our work shows that current designs for launching of MPI jobs can take more than 3 minutes for $10,000$ processes and have trouble scaling above that level.

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In this paper we present a scalable and extensible launching architecture (ScELA) for clusters to address this need. We note that the initialization phase of most programming models involve some form of communication to discover other processes in a parallel job and exchange initialization information. Our multi-core aware architecture provides two main components: a scalable spawning agent and a set of communication primitives. The first of these, the spawning agent, starts executables on target processors. The communication primitives are used within the executables to communicate necessary initialization information. We form an architecture to support a variety of launching needs.

We note that job initialization on most programming models involve exchange of redundant information as identical executables are launched on multiple cores. We design a hierarchical information cache to reduce the amount of communication over the network which inherently causes delays.

To demonstrate the scalability and extensibility of the framework we redesign the launch mechanisms for both MVAPICH [4], a popular MPI library, and the Process Management Interface (PMI). The PMI interface is a generic interface that is used by MPI libraries such as MPICH2 [5] and MVAPICH2 [6]. We show that ScELA is able to improve launch times at large cluster sizes by over 700%. We further demonstrate that our proposed framework is also able to scale to at least $32,000$ cores, more than three times the scalability of the previous design.

Although our case studies use MPI, ScELA is agnostic as to the programming model or program being launched. We expect other models such as Unified Parallel C (UPC) [7] and others to be able to use this architecture as well. In addition, ScELA can be used to run commands remotely on other nodes in parallel, such as simple commands like 'hostname' or maintenance tasks. It is a generic launching framework for large-scale systems.

The remaining parts of the paper are organized as follows: In Section 2 we describe the goals and design issues for our launch framework. We use our framework to redesign two job launch protocols and communication layers and present these case studies in Section 3. Section 4 contains our performance evaluation of the ScELA design. Related work is discussed in Section 5. We conclude in Section 6 sand give future directions in Section 7.

2 Proposed Design

In this section we describe the ScELA framework. The main goals of the design are scalability towards a large number of processing cores, ease of extensibility and elimination of bottlenecks such as network congestion and resource limits.

For ease of extensibility the various components of ScELA are divided into distinct layers. Figure 1 shows an overview of the framework. The following sections describe each of these layers in detail.

2.1 Launcher

The launcher is the central manager of the framework. The job-launch process starts with the launcher and it is the only layer that has user interaction. The main task of the launcher

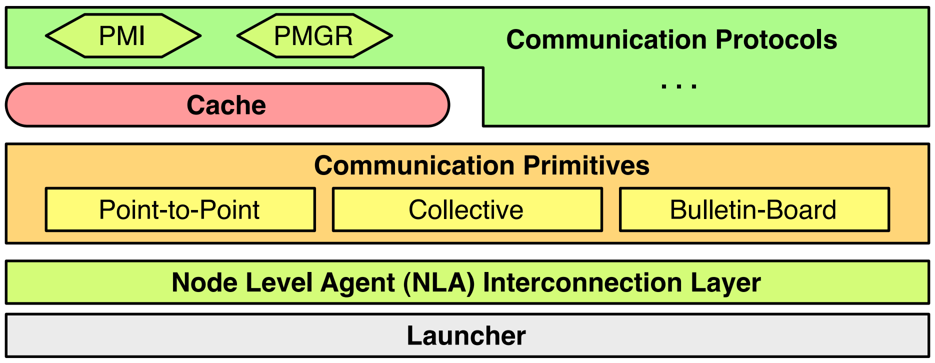


Fig. 1. ScELA Framework

is to identify target nodes, set up the runtime environment and launch processes on the target nodes.

Process Launching Modern clusters deploy multi-core compute nodes which enable multiple processes to be launched on a node. On such systems, the launcher would have to duplicate effort to launch multiple processes on a node. ScELA has a Node Launch Agent (NLA) which is used to launch all processes on a particular node. The launcher establishes a connection to target nodes and sets up a NLA on each of them. This mechanism allows the Launcher to make progress on launching processes on other nodes while the NLA handles node level process launching. The NLAs are active for the duration of the launched process after which they terminate.

Consider a cluster with n compute nodes and c processor cores per node. Table 1 shows a comparison of times taken to spawn $n \times c$ processes such a cluster. T_{conn} is the time taken to establish a connection to a node, T_{launch} is the time taken to spawn a single process and T_{nla} is the time taken to setup a NLA. We see that as the number of cores per node increases, the time taken to start the processes decreases with the NLA approach. Since the dominant factor on most clusters is T_{conn} (around 5 ms on our testbed), the use of NLAs on multi-core systems keeps the spawn time practically constant for a fixed number of nodes irrespective of the number of cores per node.

Table 1. Time Taken to Spawn Processes With and Without NLAs

With NLAs	Without NLAs
$n \times (T_{conn} + T_{nla}) + c \times T_{launch}$	$(n \times c) \times (T_{conn} + T_{launch})$

Process Health An important task of job launchers is to handle process termination. When a process fails, a job launcher must clean up other processes. Failure to do so would leave zombie processes which would impact performance of future processes. Having a node level agent allows ScELA to handle monitoring of process health in parallel. The NLAs monitor the health of the processes on a node and when a failure is observed the NLA sends a `PROCESS_FAIL` notification message to the central launcher. On receipt of such a message, the Launcher sends a `PROCESS_TERMINATE` message to all other NLAs which then terminate all processes. User signals are handled in an identical way.

2.2 NLA Interconnection Layer

After processes are spawned, many programming models require some form of information exchange and synchronization between processes before they complete initialization. For instance, MPI processes may need to discover other processes on the same node to utilize efficient shared memory communication channels or processes may need a barrier synchronization before they can enter a subsequent phase of initialization. Having a connection between every process does not scale for a large number of processes as the number of connections required is $O(n^2)$. Other approaches have all processes connect to a central controller which coordinates information exchange and synchronization. However, when a large number of processes initiate connections to a central controller, a bottleneck is created with the controller being overloaded. The resultant network congestion causes TCP SYN packets being dropped. Since SYN retransmission timeouts increase with every attempt on most TCP implementations [8], this introduces a large delay in the overall launch process. Some job launchers handle this problem by having processes initiate connections after a random intervals or by setting up connections in batches. This mechanism, however, can result in slower launch times. Also, most operating systems limit the number of connections that can be kept open which makes a central controller unfeasible.

We have designed a communication layer over the NLAs to facilitate communication and synchronization between processes. Each NLA aggregates initialization information from all processes on the node. This aggregation limits the total number of network connections needed per entity (process, NLA or the Launcher) on the system. NLAs from different nodes form a hierarchical k-ary tree [9] for communication of information between processes across nodes. The hierarchical tree improves overall parallelism in communication. A k-ary tree allows ScELA to launch processes over an arbitrary number of nodes while also keeping the number of steps required for synchronization and other collective operations such as broadcast or gather at a minimum at $log_k(n)$ where n is the number of nodes. An example of a 3-ary tree of depth 3 is given in Figure 2.

The degree k of the k-ary tree determines the scalability and the performance of ScELA. An NLA in the hierarchical tree should be able to handle connection setup and communication from all processes on a node as well as the parent and children in the NLA tree. If the degree of the tree is too high, each NLA would have to process too many connections which would create further bottlenecks. If the degree is too low, the depth of the tree would result in too many communication hops.

We determine the degree k of the tree as follows. If n is the number of nodes, we determine an ideal degree k such that the number of levels in the tree $log_k(n)$ is as follows: $log_k(n) \leq$

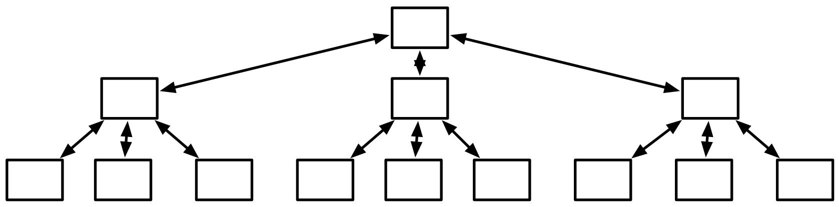


Fig. 2. Example 3-ary NLA Interconnection (with depth 3)

MAX_DEPTH. If c is the number of cores per node and $c + k \leq MAX\_CONN$, then we select k as the degree. If not, we select $k = MAX\_CONN - c$. The parameter MAX_CONN is the number of connections that an entity can process in parallel without performance degradation. From our experiments (Section 4.2) we have determined that a process can handle up to 128 connections with acceptable performance degradation on current generation systems.

2.3 Communication Primitives

The characteristics of the information exchange between processes depends on the programming model as well as specific implementations. The communication pattern could be point-to-point, collective communication such as broadcast, reduce, or a protocol such as a global bulletin board. We have designed the following communication primitives over the NLA Interconnection Layer for use by the processes for efficient communication.

Point-to-point Communication Primitives Some initialization protocols have processes communicating directly with each other. For such protocols, we have designed two point-to-point communication primitives – `NLA_Send` and `NLA_Recv`

Data from a sending process is forwarded to the NLA of the receiving process over the NLA tree. Each process is assigned a unique identifier. During the setup of the NLA Interconnection Layer, every NLA discovers the location of each process. A process is either on the same node as the NLA, or it can be found in specific lower branch of the NLA tree or higher up the NLA tree. These primitives can be used for point-to-point communication between processes.

Collective Communication Primitives In most programming models, all processes go through identical initialization phases with identical communication patterns. These communication protocols resemble MPI-style collective communication. To support such protocols, we have designed the following MPI-style collective communication primitives over ScELA.

- `NLA_Gather` – Gather data from all processes to a root process on the root NLA. At each level of the NLA tree, a NLA gathers data from all of its NLA children as well as all processes on its node. Once it has all the data, it forwards the gathered data to its parent NLA.

– `NLA_Broadcast` – Send data from a specified process on the root NLA to all processes. The root NLA sends data down the NLA tree and to all of the processes on the node. On receipt of broadcast data from a parent, each NLA forwards the data down the NLA tree and to all processes on the node.
– `NLA_AllGather` – Gather data from all processes at every process. This primitive is provided as a combination of `NLA_Gather` and `NLA_Broadcast`. The root NLA gathers data from all processes and performs a broadcast operation.
– `NLA_Scatter` – Send specific chunks of data from a process on the root NLA to every process. The root NLA sends data to be scattered down the tree, extracts data meant for processes on its node and sends them to the destination processes . On receipt of a scatter message each NLA forwards it down the NLA tree, extracts data meant for processes on its node and sends them to the destination processes.
– `NLA_AllToAll` – Send specific chunks of data from every processes to every process. The AllToAll primitive is provided as a combination of `NLA_Gather` and `NLA_Scatter`. The root NLA gathers data from all processes, re-organizes the data such that all data destined to a process is grouped together and does a scatter operation.

Bulletin Board Primitives Some communication protocols have processes publish information about themselves on a global bulletin board and processes needing that information read it off the bulletin board. To support such protocols over ScELA we have designed two primitives – `NLA_Put` and `NLA_Get`.

`NLA_Put` publishes data to all NLAs up the tree up to the root. When a process needs to read data, it invokes the `NLA_Get` primitive. When data is not available at a NLA, it forwards the request to the parent NLA. When data is found at a higher level NLA, it is sent down the tree to the requesting NLA.

Synchronization Primitive In some programming models, the information exchange phase consists of smaller sub-phases with synchronization of the processes at the end of each sub-phase. For instance, in MVAPICH, processes can not initiate InfiniBand [10] channels until all processes have pre-posted receive buffers on the NIC.

We have designed a synchronization primitive – `NLA_Barrier` which provides barrier synchronization over the NLA tree. Processes are released from an invocation of `NLA_Barrier` primitive only when all other processes have invoked the primitive. The `NLA_Barrier` primitive can be used in conjunction with `NLA_Send` and `NLA_Recv` to design other forms of communication required by a specific communication protocol.

2.4 Hierarchical Cache

On multi-core nodes, with communication patterns such as the use of a bulletin board, many processes on a node may request for the same information during initialization. To take advantage of such patterns, we have designed a NLA level cache for frequently accessed data. When a process posts information through `NLA_Put`, the data is sent up to the root of the NLA tree while also being cached at intermediate levels. When a process requests for information through NLA_Get, the request is forwarded up the NLA tree until it is found at a NLA. The response gets cached at all intermediate levels of the tree. Hence subsequent requests for the same piece of information are served from a nearer cache. This reduces network traffic and improves the overall responsiveness of the information exchange.

Our mechanism is advantageous even on non multi-core nodes or communication patterns with lack of repeated access to common information because the caching mechanism propagates information down the NLA tree. Thus subsequent requests from other sub-branches of the tree may be served from an intermediate NLA and would not have to go up to the root.

In Section 3.1 we describe an extension to the PMI_Put primitive that enables better utilization of the Hierarchical Cache.

2.5 Communication Protocols

As described in Section 2.3, the processes being launched may have their own protocol for communicating initialization information. We have designed the ScELA framework to be extensible so that various communication protocols can be developed over it by using the basic communication primitives provided. In Section 3 we describe two implementations of such protocols over the ScELA architecture.

3 Case Studies

In this section we describe implementations of two startup protocols on our architecture. We first describe an implementation of the Process Management Interface (PMI), an information exchange protocol used by popular MPI libraries such as MPICH2 and MVAPICH2 over the ScELA framework. We also describe an implementation of another startup protocol – PMGR used by MPI libraries such as MVICH [11] and MVAPICH.

3.1 Designing PMI Bulletin Board with ScELA

When MPI processes start up, they invoke MPI_Init to set up the parallel environment. This phase involves discovery of other processes in the parallel job and exchange of information with them. The PMI protocol defines a *bulletin board* mechanism for information exchange. Processes do a PMI_Put operation on a (key, value) pair to publish information followed by a PMI_Commit to make the published information visible to all other processes. When other processes need to read information, they perform a PMI_Get operation by specifying a key. The PMI protocol also defines a barrier synchronization primitive PMI_Barrier.

To implement PMI bulletin board over the ScELA framework, we utilized the NLA_Put and NLA_Get primitives designed over the NLA Interconnection Layer. A PMI_Put by a process invokes a corresponding NLA_Put to propagate information over the NLA tree. When a process does a PMI_Get, a corresponding NLA_Get is invoked to search for information in the Hierarchical Cache. Since the PMI_Puts are propagated immediately, we ignore PMI_Commit operations.

We have observed that with the PMI protocol, information reuse is high for some information. In such cases it is beneficial to populate the node level caches with information before the first `PMI_Get` request. We have designed an extension to the `NLA_Put` primitive that propagates information to all NLAs in the tree so that all `NLA_Get`s can be served from the cache. To reduce the number of `NLA_Put`s active in the tree, we aggregate puts from all processes on a node before propagating this information over the tree. We invoke the `NLA_Barrier` primitive when a process invokes `PMI_Barrier`. Processes are released from `NLA_Barrier` when the `NLA_Barrier` operation completes over the NLA tree.

We evaluate our design against the current startup mechanism in MVAPICH2 in Section 4.1.

3.2 Designing PMGR (Collective Startup) with ScELA

The PMGR protocol defines MPI style collectives for communication of initialization data. When MPI processes start execution, they call the `MPI_Init` function to initialize the MPI environment. When processes need to exchange information, they invoke a collective communication interface. When all processes have arrived at the interface, information exchange if facilitated by the job launcher. Thus these operations also act as implicit synchronization between processes.

The PMGR interface defines a set of collective operations – `PMGR_Gather`, `PMGR_Broadcast`, `PMGR_AlltoAll`, `PMGR_AllGather` and `PMGR_Scatter` and an explicit synchronization operation `PMGR_Barrier`. In our implementation when a process invokes a PMGR primitive, it is directly translated to an invocation of the corresponding collective communication primitive designed over the NLA tree.

We evaluate our design against the current startup mechanism in MVAPICH in Section 4.2.

4 Evaluation

In this section we evaluate the two case studies described in Section 3. We evaluate our designs against the previous launching mechanisms in MVAPICH2 and MVAPICH respectively. Our testbed is a 64 node InfiniBand Linux cluster. Each compute node has dual 2.33 GHz Intel Xeon “Clovertown” quad-core processors for a total of 8 cores per node. Overall, the cluster has 512 processing cores. The nodes have a Gigabit Ethernet adapter for all management traffic such as job launching. We evaluated the startup performance on various system sizes and configuration. We represent a system size as $n \times c$, where n is the number of nodes and c is the number of cores per node used in a test.

We have written a MPI microbenchmark to measure time taken to launch MPI processes and the time spent in `MPI_Init` which represents the information exchange phase. For the purpose of these microbenchmark level tests, we disable all optional features to keep the initialization time minimum.

4.1 PMI over ScELA

In this section we compare the performance of our design of PMI over ScELA (ScELA-PMI) against the default launch framework in MVAPICH2 (MVAPICH2-PMI). The default startup mechanism of MVAPICH2 utilizes a ring of daemons – `mpd` [12] on the target nodes. The launcher – `mpiexec` identifies target nodes and instructs the mpd ring to launch processes on them. PMI information exchange is done over the mpd ring. Figure 3 shows the time taken to establish the initial ring with various number of nodes. We observe a linear increase which is not scalable over larger number of nodes. We have also observed that the mpd ring can not be setup on larger sizes such as thousands of nodes. While a mpd ring can be reused for launching subsequent MPI jobs, most job schedulers elect to establish a separate ring as both target nodes and job sizes may be different.

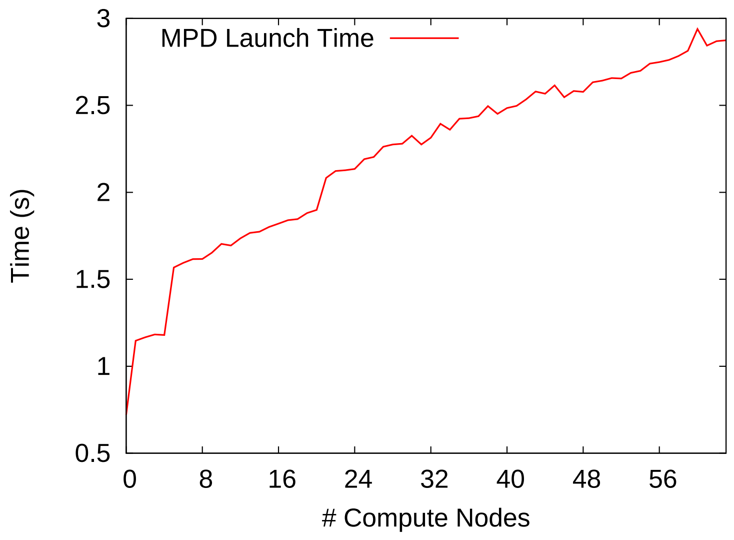
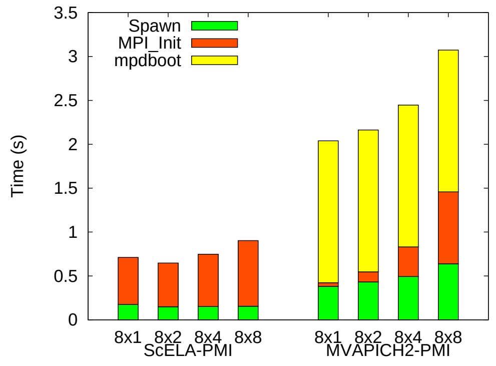


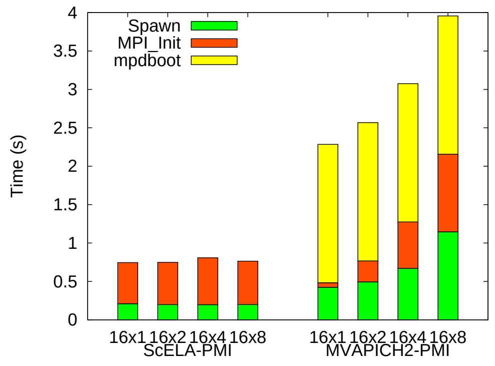
Fig. 3. Time to Setup MPD Ring with MVAPICH2

Figure 4 shows a comparison of the launch times for various system sizes and configurations. On ScELA-PMI, the spawn phase represents the time taken for the Launcher to setup NLAs on the target nodes and for the NLAs to launch the MPI processes. The MPI_Init phase represents the time taken to establish the NLA Interconnection Layer and for PMI information exchange. On MVAPICH2-PMI the mpdboot phase represents time taken to establish the ring of mpd daemons. The spawn phase represents the time needed to launch MPI processes over the mpd ring and the MPI_Init phase represents the time taken for information exchange.

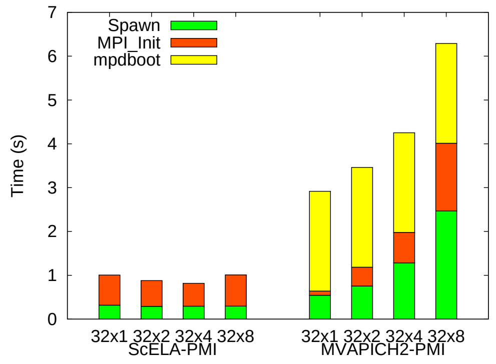
We observe that as we increase the number of processes per node, ScELA-PMI demonstrates better scalability characteristics. For a fixed node count, the duration of the spawn



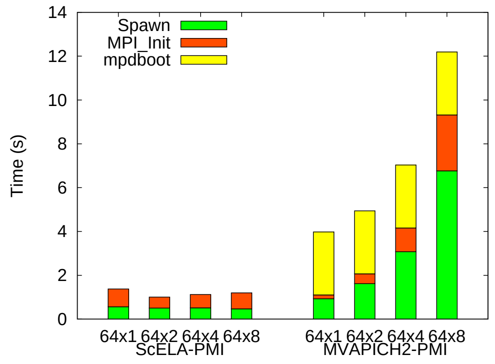
(a) 8 Compute Nodes



(b) 16 Compute Nodes



(c) 32 Compute Nodes



(d) 64 Compute Nodes

Fig. 4. Comparison of Startup Time on MVAPICH2

phase in ScELA-PMI is constant due to parallelism achieved through having NLAs. In Figure 4(d) we see the spawn time for MVAPICH2-PMI increase from around 1s to 6.7s when the number of cores used per node is increased from 1 to 8 but ScELA-PMI is able to keep spawn time constant at around 0.5s. At larger job sizes, for instance 512 processes on 64 nodes (64×8 in Figure 4(d)), we see an improvement in the MPI_Init phase from around 2.5s to 0.7s due to the better response times of communication over the NLA Interconnection Layer and due to reduced network communication due to NLA cache hits.

4.2 PMGR over ScELA

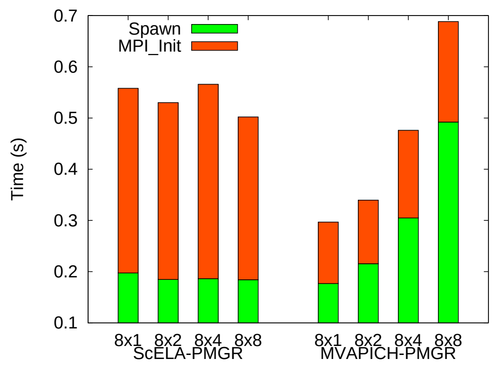
In this section we compare our design of PMGR over ScELA (ScELA-PMGR) against the default startup mechanism in MVAPICH (MVAPICH-PMGR). The default startup mechanism in MVAPICH has a central launcher which establishes a connection to target nodes and launches each process individually. On multi-core systems, this needs multiple connections to each node. Also, the MPI processes establish a connection to the central controller which facilitates the PMGR information exchange. As the number of processes increase, this causes a flood of incoming connections at the central controller which leads to delays due to serialization of handling these requests and network congestion. The number of MPI processes that can be handled simultaneously is also limited by resource constraints such as open file descriptor limits, which is typically 1024.

Figure 5 shows a comparison of the launch times. With ScELA-PMGR, the spawn phase represents the time taken to setup NLAs on the target nodes and for the NLAs to launch MPI processes on the node. The MPI_Init phase represents the time taken to setup the NLA Interconnection Layer and the PMGR information exchange between MPI processes. With the previous MVAPICH startup, the spawn phase represents the time taken for the central controller to launch each MPI processes on target nodes. In the MPI_Init phase, the MPI processes establish connections to the central controller and exchange information over the PMGR protocol.

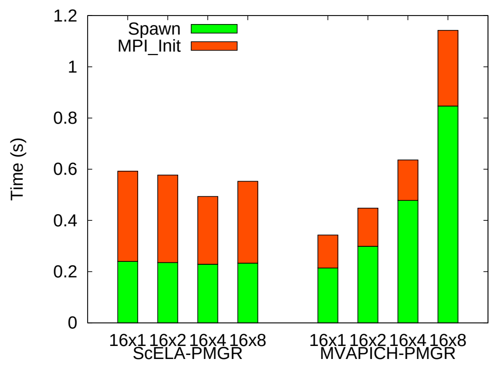
We see that for a fixed node count, ScELA-PMGR takes constant time for the spawn phase as it benefits from having NLAs while spawn phase with MVAPICH-PMGR grows with increase in number of processes per node. For instance in 5(d), we see that ScELA-PMGR is able to keep spawn time constant at $0.6s$, but on MVAPICH-PMGR the spawn phase increases from $0.5s$ to 3.6 as we increase the number of cores used per node from 1 to 8. Also, when the overall job size is small, the central controller in the MVAPICH startup mechanism is not inundated by a large number of connections. We see that the central controller is able to handle connections from up to 128 processes with little performance degradation in the MPI_Init phase. Hence the MVAPICH startup performs better at a small scale, but as the job sizes increases we observe larger delays in the MPI_Init phase. From Figure 5(d) we see that for 512 processes (64×8), the MPI_Init phase takes $4.3s$ on MVAPICH-PMGR, but on ScELA-PMGR it takes around $0.3s$. For 512 processes we see an improvement of 800% in the the overall launch time.

When only one process is launched per node, we introduce an additional overhead in the spawn phase as we first launch a NLA on a node and the NLA launches the sole process. However

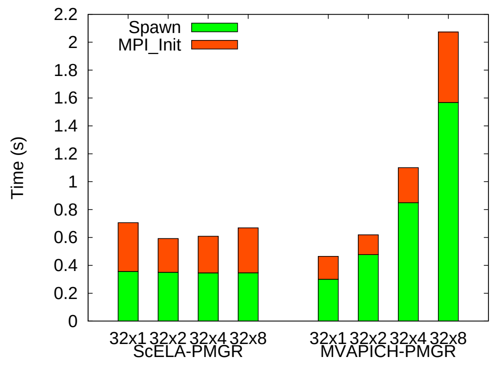
Figure 6 shows an evaluation of ScELA-PMGR and the previous MVAPICH startup mechanism on a large scale cluster – the TACC Ranger [13]. The TACC Ranger is an InfiniBand cluster with $3,936$ nodes with four 2.0 GHz Quad-Core AMD "Barcelona" Opteron processors making a total of 16 processing cores per node. The Figure shows the runtime of a simple *hello world* MPI program that initializes the MPI environment and terminates immediately. In terms of number of processing cores, ScELA-PMGR scales up to at least three times more than the previous MVAPICH startup mechanism. On $10,240$ cores, we observe that MVAPICH-PMGR takes around $185s$ while ScELA-PMGR takes around $25s$ which represents a speedup of more than 700%. We also see that MVAPICH-PMGR is not able to scale beyond $10,240$ cores, while ScELA-PMGR is able to scale to at least 3 times that number.



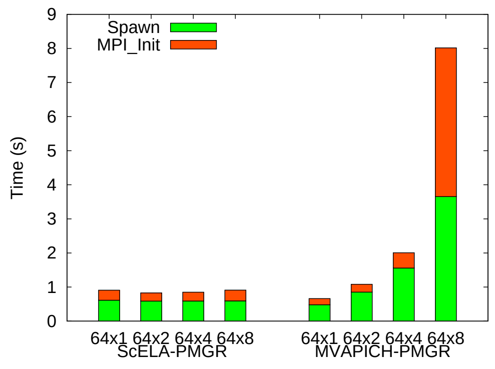
(a) 8 Compute Nodes



(b) 16 Compute Nodes



(c) 32 Compute Nodes



(d) 64 Compute Nodes

Fig. 5. Comparison of Startup Time on MVAPICH

5 Related Work

The scalability and performance of job startup mechanisms in clusters have been studied in depth before. Yu, et. al. [14] have previously explored reducing the volume of data exchanged during initialization of MPI programs in InfiniBand clusters.

In our work, we have assumed availability of executable files on target nodes through network based storage as this is a common model on modern clusters. Brightwell, et. al. [15] have proposed a job-startup mechanism where network storage is not available.

SLURM [16] is a resource manager for Linux clusters that implements various interfaces such as PMI and PMGR for starting and monitoring parallel jobs. Unlike ScELA, SLURM has persistent daemons on all nodes through which it starts and monitors processes.

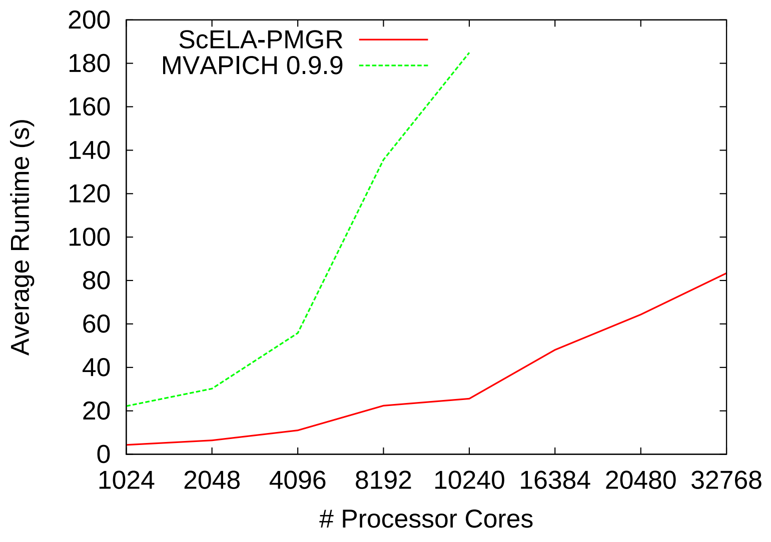


Fig. 6. Runtime of Hello World Program on a Large Scale Cluster (Courtesy TACC)

6 Conclusion

Clusters continue to scale in core counts. Node counts are increasing significantly, but much of the growth in core counts is coming from multi-core clusters.

In this paper we have demonstrated a scalable launching architecture that improves the launch performance on multi-core clusters by more than an order of magnitude than previous solutions. Although our case studies have been with two MPI libraries, we have presented an architecture extensible to any cluster launching requirements. For launching parallel jobs, we provide scalable and efficient communication primitives for job initialization.

With an implementation of our architecture, we have achieved a speedup of 700% in MPI job launch time on a very large scale cluster at $10,240$ processing cores by taking advantage of multi-core nodes. We have demonstrated scalability up to at least $32,768$ cores.

Our solutions are being used by several large scale clusters running MVAPICH such as the TACC Ranger – currently the largest computing system for open research.

Software Distribution Our implementation of PMGR over ScELA (ScELA-PMGR) is integrated with the 1.0 release of MVAPICH. The PMI implementation over ScELA (ScELA-PMI) will be available with the upcoming 1.1 release of MVAPICH2. More details on MVAPICH and MVAPICH2 are available at [17].

7 Future Work

In our solution, the Launcher launches Node Launch Agents serially. This could be a potential bottleneck with larger node counts. However, this is easily extended so that NLAs are launched hierarchically by other previously launched NLAs. We plan to explore this mechanism in the future.

Some of the collective communication primitives such as `NLA_Gather` can only gather data at a process on the root NLA. In future we plan to design collective communication primitives with a generic root process. With the recent demonstration of a 80 core processor by Intel, the number of cores per node on large scale clusters is projected to increase further. We can use more efficient communication channels such as UDP or shared memory for communication between processes and the NLA on a node so that the degree of the NLA tree can be decoupled from the number of cores on a node.

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References

1. TOP 500 Project: TOP 500 Supercomputer Sites. (http://www.top500.org)
2. Sandia National Laboratories: Thunderbird Linux Cluster. (http://www.cs.sandia.gov/platforms/ Thunderbird.html)
3. Message Passing Interface Forum: MPI: A Message-Passing Interface Standard. (1994)
4. Network-Based Computing Laboratory: MVAPICH: MPI-1 over InfiniBand and iWARP. (http://mvapich.cse.ohio-state.edu/overview/mvapich)
5. Argonne National Laboratory: MPICH2 : High-performance and Widely Portable MPI. (http://www.mcs.anl.gov/research/projects/mpich2/)
6. Huang, W. and Santhanaraman, G. and Jin, H.-W. and Gao, Q. and Panda, D.K.: Design of high performance mvapich2: Mpi2 over infiniband. Sixth IEEE International Symposium on Cluster Computing and the Grid (CCGRID 06). (2006)
7. Carlson, W., Draper, J., Culler, D., Yelick, K., Brooks, E., Warren, K.: Introduction to upc and language specification. CCS-TR-99-157, IDA Center for Computing Sciences (1999)
8. Shukla, A., Brecht, T.: Tcp connection management mechanisms for improving internet server performance. Hot Topics in Web Systems and Technologies, 2006. HOTWEB '06. 1st IEEE Workshop on (13-14 Nov. 2006) 1–12
9. Moody, A., Fernandez, J., Petrini, F., Panda, D.: Scalable nic-based reduction on large-scale clusters. Supercomputing, 2003 ACM/IEEE Conference (15-21 Nov. 2003)
10. InfiniBand Trade Association: InfiniBand Architecture Specification. (http://www.infinibandta.com)
11. Lawrence Berkeley National Laboratory: MVICH: MPI for Virtual Interface Architecture. http://www.nersc.gov/research/FTG/mvich/ index.html (2001)
12. R. Butler and W. Gropp and E. Lusk: Components and interfaces of a process management system for parallel programs. In: Parallel Computing. (2001)
13. Texas Advanced Computing Center: HPC Systems. (http://www.tacc.utexas.edu/resources/hpcsystems/)
14. W. Yu and J. Wu and D. K. Panda: Scalable startup of parallel programs over infiniband. In: International Conference on High Performance Computing (HiPC04), Bangalore, India (2004)
15. Brightwell, R., Fisk, L.: Scalable parallel application launch on cplant. Supercomputing, ACM/IEEE 2001 Conference (10-16 Nov. 2001)
16. Lawrence Livermore National Laboratory and Hewlett Packard and Bull and Linux NetworX: Simple Linux Utility for Resource Management. (https://computing.llnl.gov/linux/slurm/)
17. Network-based Computing Laboratory: MVAPICH: MPI over InfiniBband and iWARP. (http://mvapich.cse.ohio-state.edu)