PROJECT UPDATE

Energy Characterization and Optimization in Heartbeat Failure Detection Systems

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1. Introduction

Fault Tolerance (FT) is a common concern in various scenarios, for example, in High-Performance Computing (HPC), environments containing a large number of nodes, which ultimately leads to an increased number of failures, making the Mean Time Between Failures (MTBF) as low as a few hours [3], and also in Internet of Things (IoT) applications, like the ones using Wireless Sensor Networks (WSNs), which is good to know failures and detected faulty sensors [9].

One important component of FT is the failure detection mechanism. There a few ways to detect failures, for example, in HPC systems, one can use daemon processes to monitor other processes [5], or use heartbeat monitoring systems, where each process monitors its neighbor, if the process observed stops sending alive beats, it will be considered faulty and the failure will be propagated to the other processes [1]. In WSNs, usually a voting system or a comparing system is employed, where the sensing information of different devices are compared to define if a sensor is faulty or not and other approaches like sending test messages or messages right before battery depletion to take account of permanent failures [9].

This work leverages the library OCFTL [8], an improved heartbeat-based FT library for MPI. Although this library is focused on HPC systems, the same failure detection could be employed in IoT systems to detect permanent failures. The objective of this work is to first characterize the library in terms of energy, and compare with other HPC failure detection implementations and mechanisms, as well as proposing changes to the algorithm and the communication back-end to evaluate if the library can be more energy efficient. Finally we want to discuss whether option would be the better to employ in IoT systems considering their restrictions.

2. Related Work

Failure detection can be divided in two procedures, the detection mechanism and the propagation mechanism.

For the detection mechanism in HPC, some monitoring system is employed. Like using daemon processes (one per node) to monitor the other processes using signals from the Operating System. Further, these daemon processes are monitored either by the root

process [5] or by heartbeat messages exchanged between the daemons [10]. Others rely on the `slurmd` daemon to detect process failures via exit codes [2]. Finally, the heartbeat ring approach works by distributing processes throughout a ring and exchanging messages between neighbors [1]. This paper evaluates a library that is based on the heartbeat approach. For the propagation mechanism, usually a fault-tolerant broadcast is employed. These type of broadcast usually employ redundant messages, for this work, we will be using the broadcast proposed in the evaluated library, a chord-based broadcast that has reduced overload of messages still providing redundant messages [8].

For the mechanisms in IoT applications, a survey on the fault tolerant approaches for WSNs was made [9]. This survey shows different approaches for fault detection, some employed to detect permanent failures (like the OCFTL library) and some employed to detect errors in the sensing system (malfunction of the sensors). The survey shows that the mechanisms are probabilistic based, or employ message exchange with a central devices, or employ a exchange of messages in a group, neighbors or cluster to detect failures in the proximity [9]. Looking at the proposals, a heartbeat failure detection system could be an approach for detection the permanent and transient failures in such systems.

In respect to energy efficiency, the HPC works usually does not evaluate the energy cost of the applications, since they are usually coupled with high performance applications which would consume much more energy than the monitoring system. This works aims to evaluate this proportion by evaluating some monitoring systems in HPC running them with distributed HPC applications. For the WSNs, the survey [9] discusses the energy-efficiency of the approaches, not by measuring them, but by pointing the main focus of energy consumption (what to send in messages, how to exchange messages, and who receives messages). In this work we also want to compared different proposal of the library algorithm to see whether would be the better option if we would port the library to an IoT system.

3. The Heartbeat

OCFTL's heartbeat system consists in a ring-topology process distribution, like in Figure 1. In this topology, each process will have two neighbors (Figure 1-a)). In this representation, each process will be an `emitter` to the following process, periodically sending alive beats, also being an `observer` to the previous process, receiving its alive beats. If the observer does not receive alive beat in a given `timeout`, it will state the its emitter failed and will rearrange the ring to remove the failed process (Figure 1-b)), then, it will propagate the failure using the FT broadcast. In this broadcast, a process will send the failure message to other processes following the power of two (1, 2, 4, ...) starting at the first neighbor, and each time a process receives the first message of a broadcast it will replicate the same way, like the example of Figure 2.

To implement that mechanism, OCFTL proposes the Algorithm 1, as we will be referring as `OCFTL-std`. Given the neighbors of a process, the `emitter`, the `observer` and the heartbeat parameters `period` and `timeout`, the main loop is described in the Algorithm 1.

It is good to note that this main loop iteration occurs every `timestep`, this time step is a value much lower than the `period` and `timeout`, to guarantee we will receive and parse any message as soon as possible, and, because of that, it will be responsible for

Figure 1. Heartbeat ring topology

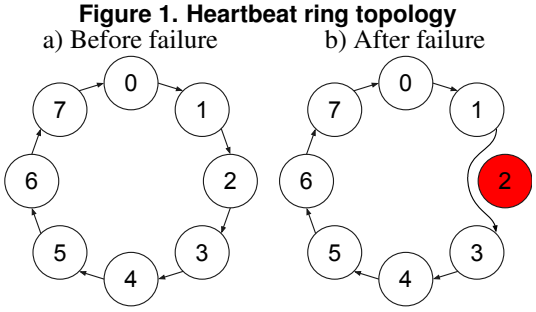
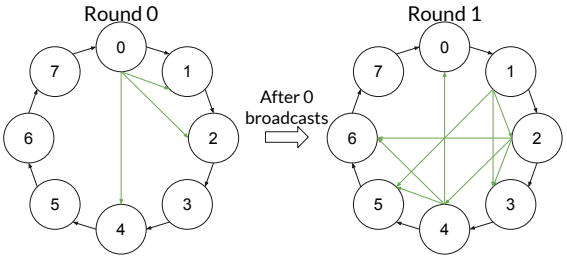


Figure 2. Chord-like Broadcast



Algorithm 1: Standard OCFTL heartbeat algorithm

```
1  while (!hb_done) do
2      if (timeout expires) then
3          broadcast(emitter);
4          find new emitter ;
5          rearrange the ring;
6      end
7      if (period achieved) then
8          alive_beat(observer);
9      end
10     if (alive msg received) then
11         resets timeout;
12     end
13     if (new_observer msg received) then
14         observer ← new_observer;
15     end
16     if (broadcast received) then
17         do related procedure;
18         if (first time this broadcast) then
19             broadcast(bc_message;
20         end
21     end
22     sleep_for(timestep)
23 end
```

determining how much computation is done. Higher values oh the `timestep` means we are doing less iterations per second, then less computation, lower value of the `timestep` means we are doing more computation.

4. Proposals

We have two proposals to evaluate for this work, the first proposals to change the way the main loop of the Algorithm 1 works but still uses MPI as back-end, and the second proposes using the NNG library, which is a light-weight messaging library.

4.1. Standard Algorithm Change

For this proposal we will work on the computation made at each step of the loop. The goal is to do less computation as possible. In the Algorithm 1, we check for several conditions and based on each one we will do a procedure. Taking a more closer look, we are requesting for the MPI back-end three times if a message was received, if the `timeout` does not expires, we decrease a counter and if the period is not achieved we also decrease a counter.

For this new proposal (Algorithm 2) which we will refer as `OCFTL-new`, we propose to check one time per iteration if a message was receive and parse it accordingly to the tag of the message received, for the `timeout` checking we kept the same way as before, and for the `alive` beat, we create a new thread specialized for sending the beats, where we can eliminate the associated counter and wake-up only at each defined `period`.

4.2. Back-end Change Proposal

MPI is widely used in HPC applications, but here we want to see when using another library, such as NNG messaging library, first if the library is capable of what the MPI version of the library is (in terms of heartbeat parameters) and if takes less or more energy. The implementation of this version (which we will refer as `OCFTL-nng`) follows the Algorithm 3, which is similar to the algorithm presented in Section 4.1. For this proposal, we setup a web-socket between each pair of processes, which would make the process of implementing the library simpler and each process would communicate direct with another. This might not be the best option in terms of scalability, since the the number of sockets can increase exponentially. Another factor of this implementation is that each iteration, we need to verify if a message was received in each one of the sockets (line 8 in the algorithm), excluding the own socket, this can increase the computation time, but comparing to the MPI back-end a likely approach has to be done depending on the communication back-end used.

5. Characterization

Following our methodology, we will be characterizing energy in a distributed system. We will be using the Sorgan mini cluster, composed by three worker nodes. To characterize, we will be using three benchmark applications and two developed applications. The first three applications are used to evaluate the library with a high computation load applications while the other two are to evaluate to library with a non-intense application and with an application that injects failures, these two developed applications will be called

Algorithm 2: New OCFTL heartbeat algorithm

```
1  Main-Thread:
2  while (!hb_done) do
3      if (timeout expires) then
4          find new emitter ;
5          broadcasts the failure;
6          rearrange the ring;
7      end
8      if (any message received) then
9          if (type == alive) then
10             resets timeout;
11         end
12         if (type == new_observer) then
13             observer ← new_observer;
14         end
15         if (type == broadcast) then
16             do related procedure;
17             if (first time this broadcast) then
18                 replicates the broadcast;
19             end
20         end
21     end
22     sleep_for(timestep)
23 end
24 ---------------------------------------------------------------
25 Alive-Thread:
26 while (!hb_done) do
27     alive_beat(observer);
28     sleep_for(period)
29 end
```

Algorithm 3: NNG-OCFTL heartbeat algorithm

```
1  Main-Thread:
2  while (!hb_done) do
3      if (timeout expires) then
4          find new emitter ;
5          broadcasts the failure;
6          rearrange the ring;
7      end
8      for ( i = 0; i < size; i = i + 1 ) {
9          if (any message received in socket[i]) then
10             if (type == alive) then
11                 resets timeout;
12             end
13             if (type == new_observer) then
14                 observer ← new_observer;
15             end
16             if (type == broadcast) then
17                 do related procedure;
18                 if (first time this broadcast) then
19                     replicates the broadcast;
20                 end
21             end
22         end
23     }
24     sleep_for(timestep)
25 end
26 ---------------------------------------------------------------
27 Alive-Thread:
28 while (!hb_done) do
29     alive_beat(observer);
30     sleep_for(period)
31 end
```

`libonly` and `failure` respectively, which consists in a sleeping loop application, for first one, and a sleeping loop application that kills a process each 20 seconds, for the second one.

Table 1 shows the resume of the applications used to characterize the library until this point of this work. These application where selected from previous works and related works.

Table 1. Applications evaluated

Application	Input	# Processors	# Nodes
LULESH [7]	$-i$ 20 $-s$ 60	27	3
MiniMD [6]	$-i$ mini-input	36	3
HPCCG [6]	150 150 150	36	3
Libonly		36	3
Failure		36	3

Finally, all the information, scripts, programs, tools used in this project are available in the repository of the project: https://github.com/PedrooHR/eec-project.

5.1. Data Collection

To collect the results of each application, we first run each application 10 times in the following scenarios: without FT library, using `OCFTL-std`, using `OCFTL-new` and using `OCFTL-nng`. All applications are MPI based, so we used the Open MPI version 4.0.0 [4], and for the last case, we used the NNG messaging library in addition. To collect the data about energy, we used the `perf` tool, with certain privileges, the tool permits us to collect information about the counter related to power.

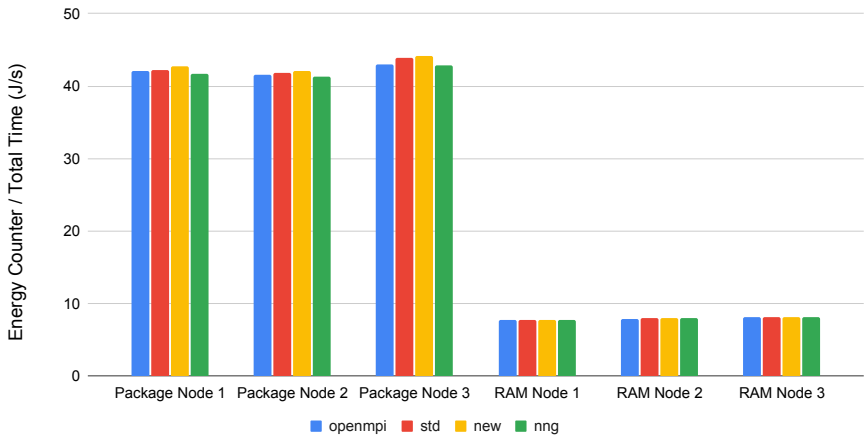
Unfortunately, in the cluster, there are only three counters available, and one that not gives any results. So, for this work, we will be measuring the counter `power/energy-pkg/`, which measures the energy of the components in the CPU package, and the `power/energy-ram/` counter, which measures the energy related to the RAM. Since we are working with 3 nodes, and the `perf` tool collects the energy for each process, we will be measuring multiple times the counters related to one node. To solve that, in the results we will be showing the average value of the measurements in the same node, for example, if we measure energy from 8 processes in the first node, the average measure of these 8 processes will be our final measure for that node. This way, at the end, we will have the energy consumption for the three nodes for each application, for each scenario.

5.2. Results

Following the methodology described before, we can evaluate the energy consumption of each scenario. Here we will be comparing each scenario for all the applications. We present the results we have until the deadline of this report. For 4 of the 5 applications. The reason for the `Failure` application being not listed is discussed in Section 5.3.

These results shows were obtained using the `period` equal to 1 second, `timeout` equal to 10 seconds and the `timestep` equal to 20 milliseconds. For the

Figure 3. Results for the application LULESH



final report, we will evaluate lower values for these parameters, which will lead to more computation, then more energy consumed. For this report, the metric we adopted is the counter per time, meaning we will divide the total energy by the time spent, to know how much energy is being dissipated per second, this will make the results easier to evaluate. In the final report we will also evaluate the total time, to see if different proposals imposed more overhead to the applications, then consuming more energy. The sheets containing all results is available at: https://docs.google.com/spreadsheets/d/1_eE7A2Sec9yr_Lgw2S8y6P_XHrKNkpO8Y9X3_-GafR4/edit?usp=sharing

5.2.1. LULESH

Figure 3 shows the results for the LULESH application, for this application, the result for RAM energy is about the same for each scenario, and marginally better for Open MPI and `nng` option. Comparing the values, there are not a large difference, so we can say the consumption is about the same. Important to say that some tests of the `nng` failed and were not taken into account.

5.2.2. MiniMD

Figure 4 shows the results for the MiniMD application. Similar to the LULESH test, the energy consumption is practically the same for the scenarios, where we can see a marginally difference for OpenMPI being the lowest package energy consumption. Concerning the new strategies, the results were marginally worse than the standard approach, this is discussed in Section 5.3. Important to say that mostly of the `nng` tests failed and were not taken into account.

5.2.3. HPCCG

Figure 5 shows the results for the HPCCG application. Similar to the LULESH and MiniMD tests, the energy consumption is practically the same for the scenarios, Here the

Figure 4. Results for the application MiniMD

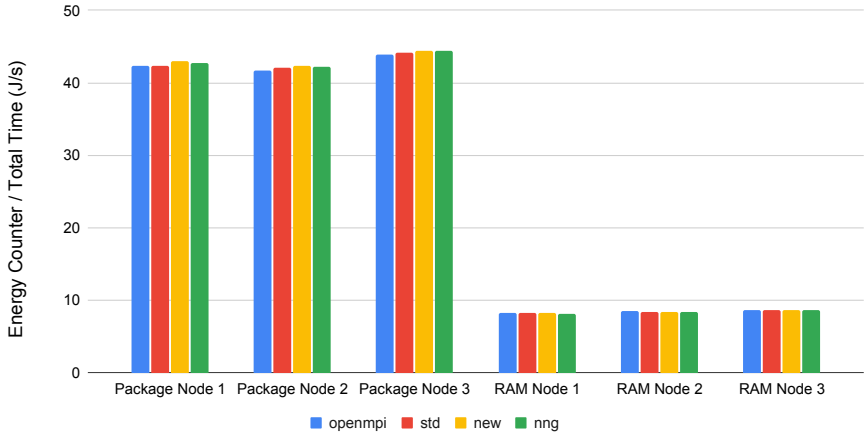
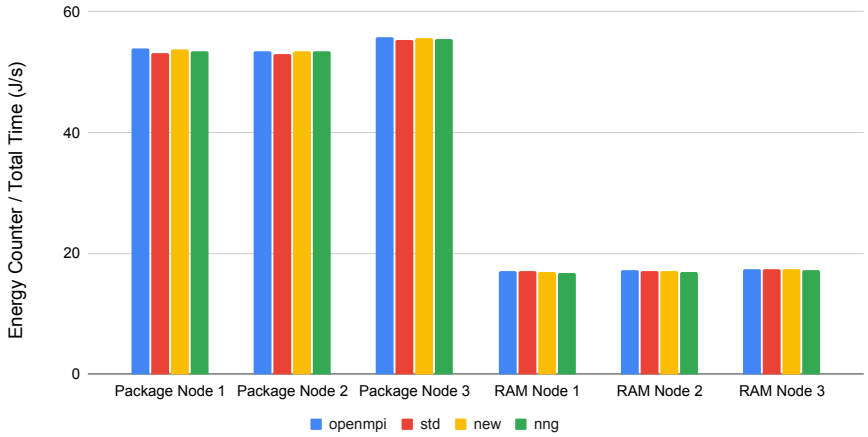


Figure 5. Results for the application HPCCG



standard option consumes a bit less package energy than the other options. Important to say that some tests of the `nng` test failed and were not taken into account.

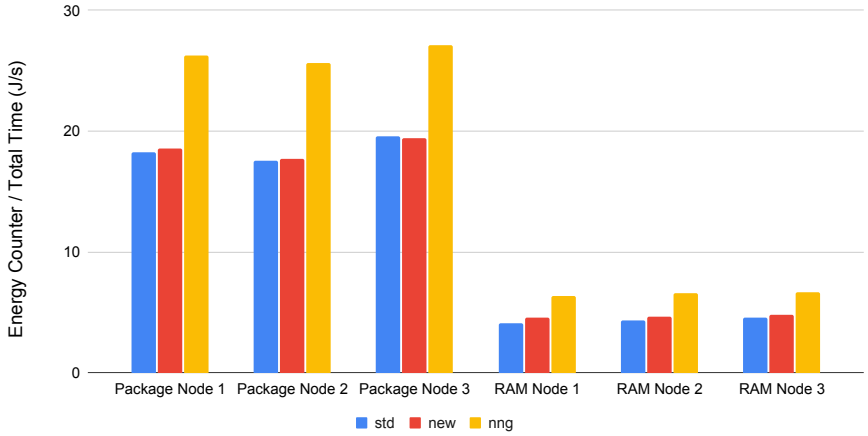
5.2.4. Libonly

Figure 6 shows the results for the Libonly application. For this application, we can see the most difference, when executing only the fault tolerance libraries, the `nng` library showed much more consumption than the other options, where the `std` and `new` options consumed about the same energy. Important to say that some tests of the `nng` test failed and were not taken into account.

5.3. Discussions

The data collected in previous section do not show good results. After a short inspection of the library source code, we observed that both the `new` and `nng` library had a error in code, making it send much more alive messages than the necessary (when transferring the code to a new thread, the variable determining the time to sleep was incorrect when

Figure 6. Results for the application Libonly



we determine the period via environment variables). We re-executed the tests with these new modifications, and when evaluating the results was observed that, different from the first time, the MPI bound processes by filling the first nodes instead of equally dividing then into the nodes (probably the policy was changed when we included the `exclusive` option in the job script). This made the first nodes to do much more computation and be much more overloaded than the third one, and for the LULESH application, which run with less processes (it has to be a power of 3, for our case, 27 processes), to use only 2 of the three nodes. The same problem occurred for the `Failure` application in all tests, which was the reason the results for that application were not exhibited.

As, for the deadline of this report, we are unable to re-execute this test and report here. We will be re-executing these tests to the final version of this report. The tests presented in this report shows the first experiment we did, which validates our experimenting methodology.

Observing the results, we can see that for those relaxed parameters set in the experiment, the results for energy consumption where about the same, even when comparing with the execution without the library. Although this option does not cause over energy consumption, the higher values, especially leading to a higher `timeout` leads to a less efficient heartbeat, taking a long delay to detect failures.

6. Future Activities and Schedule

We have characterized the use of the library and the proposals with different applications, intensive and non-intensive which was our first objective of this work. For the final report, we plan to re-execute the tests to evaluate the last modifications we did in the two proposals (discussed in Section 5.3) and get the failed experiment results.

To the final version of this report, we plan to evaluate different heartbeat parameters observing the approaches limits and energy-consumption, to achieve our second, third, and fourth objectives. Finally, establish a relation between the efficiency in terms of algorithm and energy.

We also plan to compare the energy consumption of the OCFTL with the ULFM's proposal, a likely heartbeat implemented in the source code of OpenMPI [1] and Reinit++,

which uses daemon processes to monitor and detect failures [5].

Some of these future tests are already in execution, but the results are not available for this report. We maintain our initial schedule with a new update. One week of the activity A6 will be transferred to the activity A5, to give more time the make the experiments and get better results.

Table 2. Schedule of the project activities

Activity	W0	W1	W2	W3	W4	W5	W6	W7	W8	W9
A1										
A2										
A3										
A4										
A5										
A6										
A7										

A1. *Proposal Definition:* define the final version of this proposal.
A2. *Project Set up:* set up the git repository and every other project requisite.
A3. *Energy Characterization:* characterize the monitoring system in terms of energy, evaluating different type of applications and how the monitoring system affects the energy consumption.
A4. *Modifications proposal:* propose and evaluate changes in the algorithm and communication backend.
A5. *Results Comparison:* compare the results of the initial characterization and the results after modifications.
A6. *Another Cases of Use:* elaborate other uses of this monitoring system and point how the energy characterization would help concerning energy consumption, specially for IoT applications.
A7. *Final Presentation:* evaluate the results of the project and make presentation of them.

References

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