Idle Injection Mechanism Implemented in the BFS scheduler

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***Abstract*—In these days the problems of power consumpion and temperature management have become two of the most studied fields in computer architecture. Lots of applications are built with different methods and different levels of abstraction to try to manage them. Various techniques are implemented at the hardware level, others are at software level either in the kernel or in userspace.**

In this paper we want to discuss about the concepts, implementation and results of a system based on the BFS scheduler of Linux that uses the idle injection method to reduce the workload and therefore the temperature of a stressed system. This kind of solution, as you will undestand, has already been used and implemented on other schedules, but there's nothing similar for that kind of scheduler.

***Index Terms*—Operative System, Linux Kernel, Power Consumption, Temperature, Scheduling, Idle Injection**

I. INTRODUCTION

In modern computer architecture, developers are obliged to consider the problems caused by high temperature and power consumpion. These can really have a bad impact on the performance of a system, in terms of throughput and overheating of components.

To avoid this situation, we can work at hardware level using more parallelized cores, processor with multithreading support, "do nothing well" technique, lower power state for DRAM or disks and dynamic voltage frequency scaling.

However, we can also work at software level using idle injection or frequency scaling techniques. Today, more or less all modern CPUs have the Frequency Scaling Support, which is used by the operative system to control the power consumpion (they have policy like powersave, ondemand etc), whereas there are only few implementations of idle injection technique.

In this paper we will present our own solution for the linux kernel 3.2.6 patched with the BFS scheduler by Con Kolivas. The background chapter is an overview on the situation of the modern schedulers in the linux kernel. The following chapter (the heat problem) describes the temperature problem and the possible consequences. The fourth chapter talks about the aims of our project and the theoric concept of our solution. The fifth chapter describes the implementation details and then there is a chapter about the results we obtained, with a short description of our three tests. In the end, we make an overview of possible future works related to our project.

II. BACKGROUND

In today linux boxes, we can find two main versions of the scheduler. One is in the mainline of linux kernel, created by Ingo Molnar and called CFS; the other is an unofficial version, developed autonomously by Con Kolivas, after an argue with Molnar[1], and called BFS.

CFS[2], which stands for Completely Fair Scheduler, is in the mainline since 2007. The idea behind is based on the Fair-Share Scheduling policy, which divides the CPU time among entities, such as users, groups, or tasks. CFS can support all this levels, but was originally created for scheduling at task level. Each one of these tasks should have a fair share of the CPU, but this is an ideal case. CFS keeps track of how much time is given to a task respect the others, so it can schedule the one with the highest level of unfairness. To easily know which task it should choose, CFS organizes them in a red-black tree, descending ordered by their total unfairness. The chosen task is the leftmost and the total time required to schedule it is $O(\log n)$, where n is the number of tasks present in the system. When the current task has finished running on the CPU, just before selecting the new one, the scheduler increments the task's *vruntime* field, which saves the amount of time that the CPU has dedicated to it. Then the scheduler chooses the most unfairly treated task by selecting the one with the lowest vruntime. At its creation, a new task is given the minumum value of current vruntime, which is stored and mantained in a variable in order to speed up the whole process. So, there is no concept of timeslice, but a task runs until it's no longer the most unfairly treated. In order to reduce the context switching overhead (the time used for sending a content switch signal), CFS introduces a minimum granulrity of time (a minimum time that a chosen task must at least run), used to control the tradeoff between latency and content switching's overhead. In case of multiprocessor architectures, CFS keeps separate data structures for each CPU, reducing lock contention but requiring some sort of load balancing to spread tasks across processors.

BFS[3], which stands for Brain Fuck Scheduler, was written by Kolivas as an alternative to CFS. It doesn't adopt the modular framework of CFS; instead it uses one single system-wide runqueue, containing all non-running tasks. In this way, it's able to determine the next scheduled task without using some sort of special and complicated heuristic. BFS implements an earliest effective virtual deadline policy. A virtual deadline is the ideal time that any two tasks with the same niceness will have to wait before running on the CPU; when a task asks for CPU usage, it is assigned a deadline. Even if the deadline is virtual, because there is no assurance that a task will be scheduled by that time, however tasks will be scheduled from earlier to later virtual deadlines. Because of this approach, earlier virtual deadlines are given to tasks with higher priority. If a task blocks, it keeps the remainder of its timeslice and virtual deadline, so it gains higher priority when is rescheduled. Because of there is no order of tasks in the runqueue, they cannot be placed in a tree like in CFS' solution and the lookup for the next scheduled task takes an $O(n)$ scan over the whole queue. As a consequence, BFS scales poorly with large amounts of tasks. Furthermore, a share data structure among all CPUs increases lock contention, but tasks can be quickly scheduled on different CPUs without problems as soon as they become available. This results in a lower latency. On the net it is possible to find several stress tests, even if only few of them really explanatory[4], made using benchmarking programs, like latt.c a tool specific for schedulers's benchmarking, or just using gcc instruction, make for example, or playing a video. All tests can be done on netbook, laptop and desktop, too. Results generally demonstrate that BFS scheduler has a lower latency, which is not a surprise indeed as it was written with this aim. However CFS scheduler results have a better performance in terms of turnaround time (which is the total time taken between the submission of a task for execution and the return of the output) under different load conditions, especially with multicore machines. Finally, another result is that BFS scheduler, playing a video, drops much less frames than CFS, under large amounts of load.

As a conclusion, we can say that, generally, CFS is better in terms of turnaround time, and so for batch processing, while BFS has a less latency, more indicated for interactive tasks.

III. THE HEAT PROBLEM

More than in the past years, heat is a main problem that must be taken into account while building systems. Components are susceptible to malfunction or even break if overheated, especially integrated circuits like CPUs. Because of these problems, components are often designed to generate as little heat as possible and operating systems try to reduce power consumption which generates heat. In modern computers, integrated circuits are the prime source of heat, due to the fact that they work at high frequency and voltage. Increasing CPUs workload in order to exploit better performance in term of thrughput and speed up, with i.e. ILP, results, as a drowback, in an increasing amount of warmth produced by components.

Nowadays all CPUs and GPUs must use dedicated Heat Sinks or they will reach high temperatures in few time of work. But there is the possibility to reduce it also via software, by writing programs properly, using specific software or solutions that involve idle injection, as well.

Because it's the mainline kernel, proposals in this last way are already provided for CFS scheduler. One, for example, is Kidled by Google, which scope is to realize a power capping through idle cycle injection[5]. It consists in a module for the CFS scheduler, patched by Google developer Salman Qazi[6], which allows the system administrator to set the percentage of time that a specific CPU should be idle and an interval over which that percentage is calculated. To avoid important processes to be stalled, there is the special notation "interactive" with which a process can be marked and, when running, idle cycles will be forced only when necessary. Kidled code also allows system administrator to select a process that should be idled, so he can chooses if he wants to affect all the system or just a single process. The result is a reduction of power consumption and, as a consequence, a reduction of heating.

IV. SYSTEM GOAL AND APPROACH

The goal of our system is to provide an injection control mechanism of idle cycles for the linux BFS kernel which is able to reduce the power consumpion and the average temperature. The aim of doing that is to try to maintain the best condition of work, in terms of heating, also when a system is overloaded. To garantee the flexibility and the usability, our system has no policy hardcoded inside, whereas there are two interfaces where external monitors can plug in and control them specifing their own policies.

Another use that can be done with this system is to control a process or thread's throughput, injecting more or less idle cycles during its specific execution, to keep its performance in a defined range.

Our approch is based on the behaviour of the scheduler. We mainly worked on the *schedule()* function, the one that chooses the earliest deadline task. The idea behind our system is to inject idle every X calls of the *schedule()* function, or Y times that a specific process is scheduled. We faked the condition inside the BFS to force it to schedule an idle cycle, instead of the elected process. The way is to change, if needed, the next process with the idle process before that the *context_switch function* is called. Actually, our system doesn't consider realtime processes because it has no much sense to work on a process that needs all the resources given to it.

Our implementation provides two main functions, one which works globally on the machine and the other one on a specific process or thread (via its identifier, pid or tid).

The global function can be used to keep under control the temperature of the machine when it's rising.

The second function works on a specific identifier that can be used to control a single process or a thread (even more than one at a time), maybe because it's requiring more CPU time respect to the amount that we want to give it (ex. updates manager).

Our system has two interfaces, working through procfs, which either the user directly or a monitor program as well can use to control the injection (see the Implementation Chapter below).

We realized a monitor program as a test that uses a simple heuristic to control the quantity of idle cycles injected, based on current heat (the higher is the temperature, the greater is the number of cycles injected), but other monitors can be attached.

On the other hand, if an user wants to administrate the number by him or herself, he or she can do it freely.

V. IMPLEMENTATION

In this section we want to present some more detailed aspects of our own implementation.

A. IDLE PROCESS

Our mechanism is an injector of idle, but what is an idle process? Actually it can be different things.

In some cases it is a process with pid=0 that executes a sequence of NOP instructions and it is scheduled if and only if there isn't any other process that can execute (it's the process with the lowest priority). In other cases it indicates a turned off cpu, switched off to save power when it has nothing to execute.

Inside the linux kernel, an idle is like a normal process that does nothing; it's the only process where the *task_struct* isn't dynamically allocated, but is statically defined at kernel build time and is called init_task.

We decide to use this special process because it's already defined for the kernel and makes the processor doing exactly what we want it to do, that is nothing.

B. CHANGES TO THE OPERATING SYSTEM

The linux version's choice is totally arbitrary for using our system. In our own implementation we choose Gentoo, with a standard *kernel 3.2.6*[1].

That kernel was patched with a Kovalis' patch porting made by us. We also performed another patch with the HRM system, used to get details about the impact on the thoughput of our application. Finally, we had to install the lm_sensors module to get information from the temperature sensors.

C. GLOBAL INJECTION

The global injection is realized to take under control the global scheduling machanism. The point where we modified the schedule to achive this kind of injection is just inside the *schedule()* function.

The number of calls to this function that can be done before an idle is executed is variable and can be modified via procfs, using a file which can be found in */proc/schedidle/sched_global*. The monitor does it automatically, trying to keep the temperature at about 60°C, while an user, to insert a specific new value, can simply use an echo into this file, overwriting the current X quantity[2].

Using this kind of injection it's possible to apply different type of policy, starting from a simple one that only checks the global heat (calculating the average temperature of the cores) and ending with a more complex policy that takes into account also other metrics like the cpu's workload.

We tested it with the simple metric that takes into account only the average temperature of the testing machine (see Results Chapter).

D. PID/TID CONTROL

The second implementation is a finer mechanism used to control processes or threads. As before, the point where we modified the schedule to achieve this kind of injection is just inside the *schedule()* function.

The system uses a file in procfs whose path is */proc/schedidle/sched_pid.* As in the Global Injection, either an user or the monitor program can access to it and control the injection's frequency. Managing this file, a list inside the kernel space is updated, where tuples with the following information are stored:

1) Identifier: number that tells to the kernel which process/thread to control.
2) Y: this value means "put an idle process every Y times that the process with pid/tid = identifier is executed".
3) Type: this field says if the identifier refers to either a process or a thread. Its value can be equal to p or t.

Also there the user can add a specific process or thread manually, using an echo on the file above[3].

VI. RESULTS

We tested our own implementation in three different ways which are made to cover and verify the main goals of our injector.

The first is realized in order to show how we can control the temperature of the machine under stress.

The second shows how the throughtput decrease unsing the control on threads.

The third is done to control the maximum throughtput of the system injecting, when needed, some idle cycles.

The testing enviroment is a Dell Laptop xps m1330 version with an Intel Core2 Duo T7100. As said before we installed a Gentoo linux with our own patched kernel version. Our tests use the HRM monitor to see which is the throughput of our groups of threads and they use the lm_sensors to monitor the temperatures.

Now let's get a more deeply look on each test.

A. Global Temperature Management

The idea behind this test is to show how a simple monitor can manage the temperature of an overloaded laptop.

To do so, we modified the "sensors" tool available in lm_sensors so now it computes the average temperature of the cores and, depending on the result, it changes the rate inside the sched_global file in procfs that says how much idle the system has to inject.

The figure below shows our results:

[1]Actually the system works for sure only on this version but maybe it can also works with previous version of the kernel.

[2]Ex. If an user writes on terminal "echo 200 >/proc/schedidle/sched_global", it means that every 200 calls of schedule() an idle cycle is executed.

Keep in mind that, for doing so, Monitor program must be stopped or it will overwrite user's value with the one prefixed.

[3]Ex. If an user writes on terminal "echo 1000,6,p >/proc/schedidle/sched_pid", it means that an idle cycle is executed instead of the process with pid equal to 1000 every 6 times that that process is scheduled.

This graph shows the effectiveness of using the system for managing the whole temperature of a machine on which both processes and threads are running indistinctly.

We let the PC's heat growing for about 240 seconds until 80-85°C, then the monitor program is started.

It immediately detects a temperature higher than the one that it is supposed to maintain and starts to inject idle cycles.

As a result, we can see a sudden decrease of temperature (really huge at first, because of the great number of idle cycles injected in function of the high temperature read) and then it becomes quite stable around 55-60°C, which is a temperature of stabilization empirically obtained from tests.

The time in which the temperature reaches this stabilization is affected by the number of processes and threads currently running on the machine (the greater is their number, the more time it's needed).

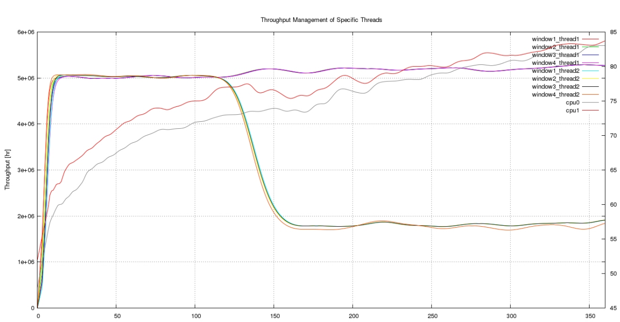
The difference of temperature between the two cores is probably related to physical reasons of how those two processors are built or how the workload is distributed on cores and not to our system.

B. Throughput Management of Specific Threads

With this second test we want to show that our implementation can really influence the throughput of an appointed process or thread.

For the demo, we used a process running two threads, one on each core. We also had to use the HRM system to monitor the thread's throughput and collect data.

The figure below shows our results:



Without going deeper, we can say that HRM program attaches 4 windows to each pointed thread, in order to collect information from about their throughputs. For this reason, we can see 4 windows linked to thread1, running on CPU0, and 4 to thread2, running on CPU1. We firstly let threads work normally, then, at about 120 seconds, we start idling one of them, the one running on CPU1. This result is obtained injecting one idle every 5 executions of thread2

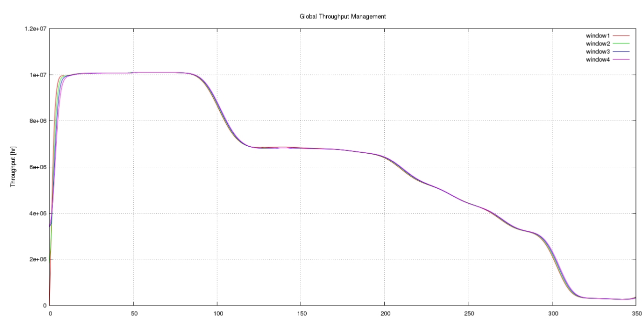
It's easy to see that its throughput decreases from $5 * 10^6$ heart rate to less than $2 * 10^6$ in really few time, just about 30 seconds.

Otherwise, thread1, which is not touched by our injection, continues its execution with the same rate.

As a secondary result, we can notice that the temperatures of the two cores tend to stabilize at a same value while, before injection, CPU1 has an higher one. This is due to the fact that idles partly reduces the overheating of that CPU. Because of this, we think that, as a future work, it will be possible to add a function to our implementation, in order to inject idles only on a single core and control its specific temperature, instead of the machine's one (see the Current and Future Works chapter below).

C. Global Throughput Management

In this last test we want to show how we can change the machine's throughput, by injecting idles on the whole system. Again, we used the HRM System to collect the final data. Here's the graph with our results:



As usual, we first let the PC work normally, then we start our monitor program, this time modified to take under control the system's throughput. It again uses a simple heuristic that inject more or less idles basing on the current machine's performance, within a range. But this time, we decided to increase the number of idle cycles executed if the throughput is low, to show that we can bring it near zero.

In fact, we can see that the throughput strongly decreases when the monitor is started after about 70 seconds, then it goes down linearly until it reaches another range and again quickly falls.

Again we want to emphasize the fact that we could have stopped downing the throughput at any time, we took it near zero for choice.

This case also gives an idea for a future improvement (see the Current and Future Works chapter below).

VII. Current and Future Works

The primary aim of our work is to help simple systems controlling their temperature directly or modifing some processes throughput, as stated several times before.

Secondly, our work can be a starting point for other interesting projects.

The first improvement that can be done is a Monitor which takes under control the temperature and throughput with a policy that also considers the number of processes running.

In addition, the Monitor should also treat the namespace number of the processes to provide a finer grain. This can be used in some kernel's versions (such as openvz) there's the possibility that two processes may have the same pid/tid, due to the fact that they belong to two different namespaces.

An easy improvement can be to provide the possibility to idle a single core directly, not only just specific processes and threads running on it or the global machine. As a result, we could be able to control the temperature and throughput of an appointed core, which can be useful for creating a differently-balanced architecture. Obviously this makes sense only in a machine with many cores, placed on different chips. This is because the core's temperature in a dual core PC where CPUs are quite near can't differ so much.

Test case 3 also suggested the chance to create a mechanism able to keep a core/process/thread's throughput in a stated range, calculated alculated dinamically from the current system's state, even with a simple heuristic. For example it can keep throughput X in a range defined as

$$\frac{MST + mst}{2} * 0.5 \leqslant X \leqslant \frac{MST + mst}{2} * 1.5$$

where MST is the maximum value of throughput of the system, mst the minimum one.

Finally, a nice challenge would be a porting of our project, to make it able to run over other kind of schedulers.

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