# Component based software design

Linber

RPC/IPC framework

*Falzone Giovanni*

*jointly M.Sc Embedded Computing Systems*

*Sant'Anna School of Advanced Studies*

*University of Pisa*

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## 1 Introduction

Linber is a kernel driver module that allow the user to register and request a service exchanging the payload between two applications, *Server worker* and *Client*.
The Server application can register a service and define a number of worker threads waiting to serve the incoming requests.
During the **Service registration** it also define the *period* and the *budget* used to set the *Rreal Time* policy when the request have timing constraints; the budget from an application point of view is considered as the number of request that a worker can serve in the same period.

The Client application **request a service** specifying a relative deadline, it can choose between different type of request:

- Blocking request with payload in buffer
- Blocking request with payload in shared memory
- Non blocking request with payload in buffer
- Non blocking request with payload in shared memory

Also the Server worker can choose between both a response in buffer or in shared memory.

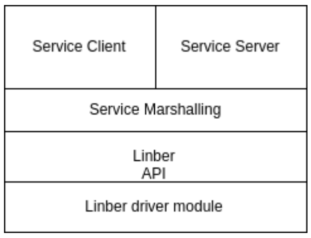
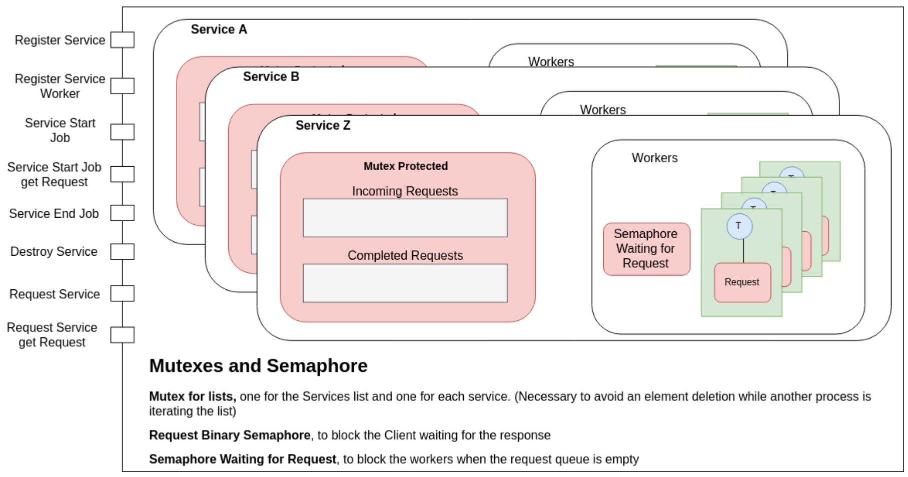


Figure 1: linber layers

## 2 Implementation

The module is realized as a driver module and uses IOCTL to comunicate with user space, it uses 0xFF as identifier of the ioctl call and a sequence number in the range [0, 10].
The module mantains a list of registered services, each service is also a node in a *RBtree* sorted using the service uri, the service uri is an unique identifier of the service.
The operations that manage the service list are protected using a module mutex to avoid inconsistencies.

Each service mantains an *RBtree* of **waiting requests** and a list of **completed requests**. Every service worker is associated with a request that represents the serving request for that worker. The operations that operate on the lists and the *Rbtree* are protected using a service mutex to avoind inconsistencies.



**Mutex for lists,** one for the Services list and one for each service. (Necessary to avoid an element deletion while another process is iterating the list)

**Request Binary Semaphore**, to block the Client waiting for the response

**Semaphore Waiting for Request**, to block the workers when the request queue is empty

Figure 2: component view

### 2.1 Request

A request can be in one of the following states:

- **Waiting**
- **Serving**
- **Completed**

A *Waiting* request is stored in the service incoming *RBtree* that is sorted using the absolute deadline of the request. Each node in the *RBtree* can have multiple request organized in a FIFO queue, we can have multiple requests with the same absolute deadline.

Once a request arrives, the workers are notified of this event using a semaphore where they can block when there aren't waiting requests. The *Client* that sent the request is blocked on a binary semaphore associated with the request until the request is completed or aborted. If the *Client* used a non blocking request then can retrieve the response later using an unique *token* and the absolute deadline received with the request.

When a blocked *Worker* is notified of a new request, it pick-up the oldest one among the requests that have the shortest absolute deadline and store it in his serving request slot. Once the *Worker* completed the request then move the request in the *Completed* FIFO queue and notify the *Client* that the request is completed using the request semaphore.

### 2.1.1 Non Blocking request

In the case of a non blocking request case the *Client* is not blocked in the request semaphore and return the control to the user. Once the user want to retrieve the response it calls the *get response* API function, this will start a procedure to find the request in the service. The request after the non blocking request call can be in one of the three different states:

- **Waiting**, the request is still in the incoming *RBtree*, we search it using the absolute deadline and the unique token, then the *Client* blocks on the request
- **Serving**, one of the workers taken it and is serving it, we search among all the workers, check with the token and block the *Client* in the request
- **Completed**, the request is in the Completed FIFO queue, we search it among all of them and then return the response and the control to the *Client*

## 2.2 How the data are exchanged

The framework allow the client and the server to exchange the request and the response using shared memory or kernel memory, for each of them there are dedicated API function.

In the case of kernel memory, every message is copied from the user space into the kernel space and linked in the request; let's consider the example of a Client and a Worker exchanging request and response using the kernel memory:

1. Request call from the user, the request is copied into the kernel space
2. Worker wake-up to serve, the request is copied from kernel space into the worker's user space
3. Worker served the request, the response is copied from user space into kernel space
4. Client wake-up, the response is copied into the Client's user space.

In the following fig:3 is reported the sequence call for a blocking request that is using the kernel memory to exchange the payload. Notice that when the Client wake-up it knows the dimension of the response, allocate the buffer into the user space and then invoke another ioctl call to get a copy of the response into the buffer.

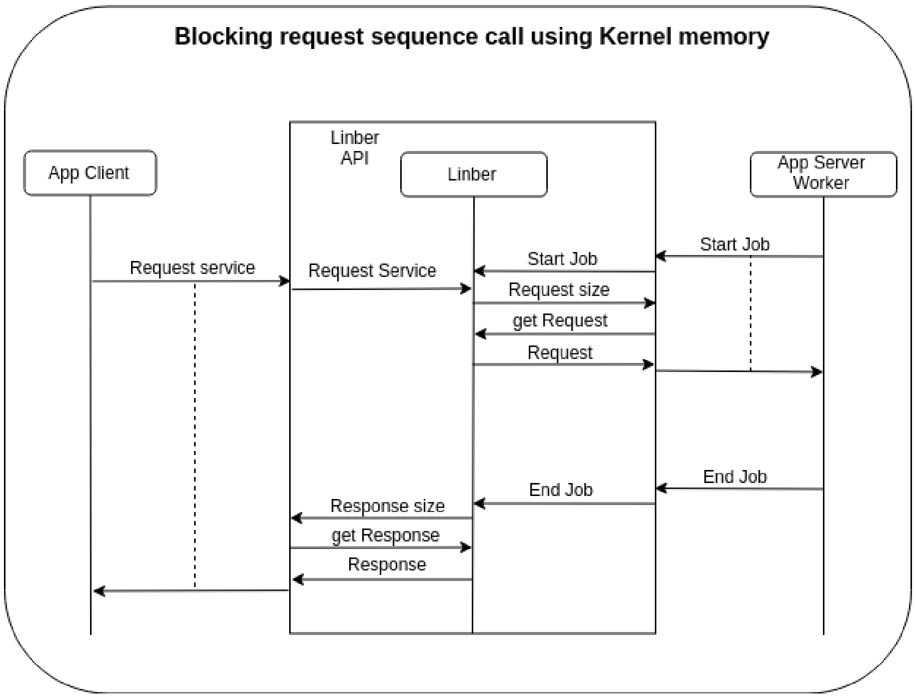


Figure 3: Sequence call of a blocking request

The latter situation where it is needed another iotcl call is not necessary in the case of Shared memory because the applications are exchanging the keys of shared memory and not the payload, but they need to use the syscall to manage the sahred memory.

The client is responsible to clean the memory after using the response, this is done by the *linber_request_service_clean* that will *free* the response if it is in dynamic memory or will detach the shared memory. When the client retrieve the response the api function, before giving back the control to the main execution, will automatically *attach* and set the remove flag to the shared memory, in this case when the *detach* will occur the shared memory will be destroyied by the operating system.

## 2.3 Serving policy and Scheduling

When the *Client* requests a service specify a relative deadline, if this is set to zero then the absolute deadline for the request is set to the maximum value $2^{64} - 1$ and will be served only if the *RBtree* of the waiting request is empty or there aren't requests with timing constraints.

Every time a worker pick-up a waiting request, it looks at the absolute deadline and choose one of the following policies.

- **Real time**
- **Best effort**

### 2.3.1 Best effort

The best effort policy is obtained setting the worker's scheduler to SCHED_FIFO with a priority equal to 99, that is the maximum for a *Real Time* task scheduled under SCHED_FIFO or SCHED_RR.
The worker choose this policy if one of the following conditions are valid:

- the absolute deadline is equal to the maximum value, $2^{64} - 1$
- the deadline is expired, $absolutedeadline > now$

### 2.3.2 Real Time policy

The *Real time policy* is obtained setting the worker's scheduler to SCHED_DEADLINE with period and budget defined during the service registration.
The relative deadline is computed as $rel\_deadline = (now - absolute\_deadline)$, if the relative deadline is greater then the service period then is set to the service period.

## 3 Performance evaluation

The module have been tested measuring the elapsed time of a blocking request, the same request have been executed for 1000 times and the elapsed times collected to evaluate the performance of the framework.
The request deadline have been set to 0, in order to force the worker to execute with SCHED_FIFO with maximum priority.
The server have only one worker and an execution time equal to 0, it only allocate the space needed for the response that is equal to the request' size.

In order to mantain as stable as possible the cpu frequency and to avoid interferece during the test, the following configurations have been applied on the testing machine:

- Disable turbo boost
- Limits the maximum and minimum P-State to the same value
- Set the governor policy to performance for all the cpus
- Set to maximum the budget for RT tasks
- Execute the client with a nice value of -20

Hardware used for the tests

```
Intel(R) Core(TM) i7-8550U CPU running @1.60Ghz
L1d cache: 32K L1i cache: 32K
L2 cache: 256K
L3 cache: 8192K
```

The performance test have been done starting with a payload of 1 byte and multiplying its size by a factor of 2 until reaching 1 Mbyte when using kernel memory and 1GB when using shared memory.

All of the following figures and more are located in *test/test_ efficiency/plots*, the stored values in two csv files located in *test/test_ efficiency/plots*, a matlab script generates and save the figures starting from the csv files.
Executing the client_eff_mem and client_eff_shm the two csv files will be substituted with the new results, remember to execute the client that use the shared memory with the server that use shared memory because the kernel allocation is limited to 4MB.

In the following figure is reported the average execution time for both cases.

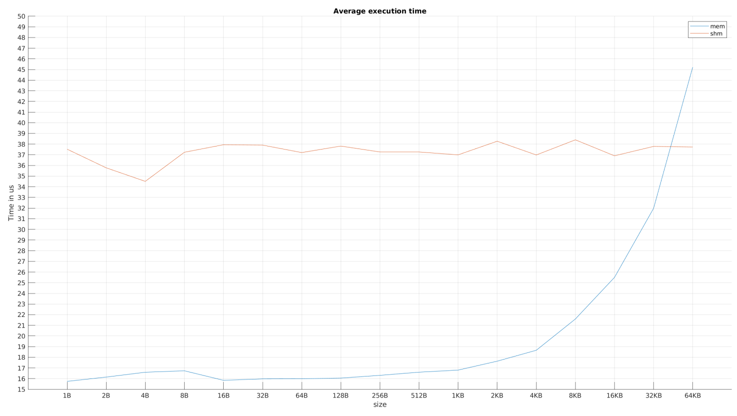


Figure 4: Average Execution time comparison

Also if the tests have been executed giving the maximum priority both to the client and the worker, the results have a markable variability that is not related to the payload size.

## 3.1 Results obtained using kernel memory

In figure 5 is reported for each size the maximum, average and minimum execution time in microseconds obtained over the 1000 iterations;

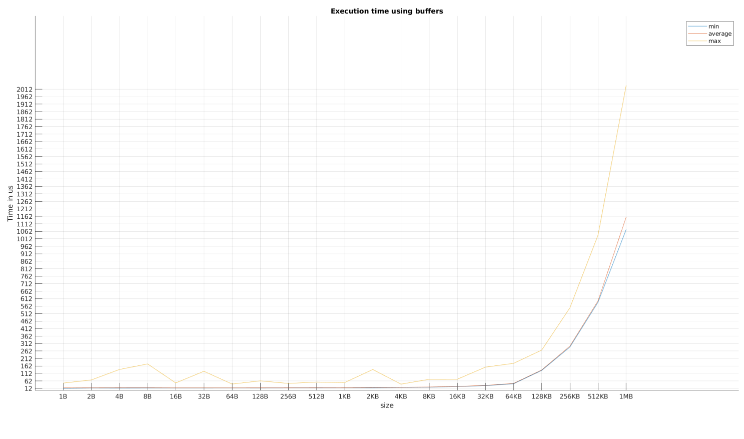


Figure 5: execution time results

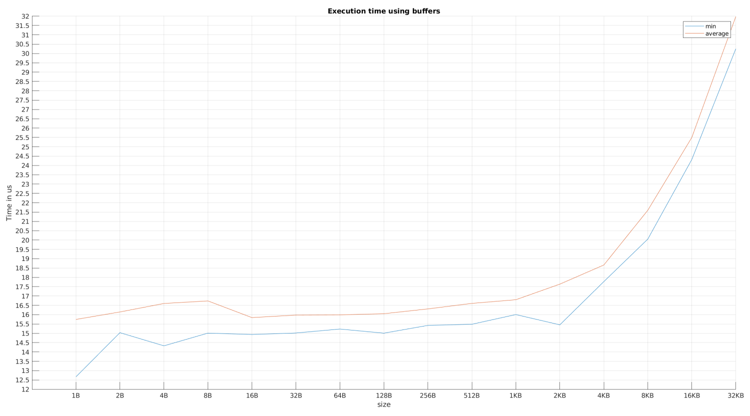


Figure 6: execution time results zoom

In figure 7 is reported the probability distribution for each size in a logarithmic scale.

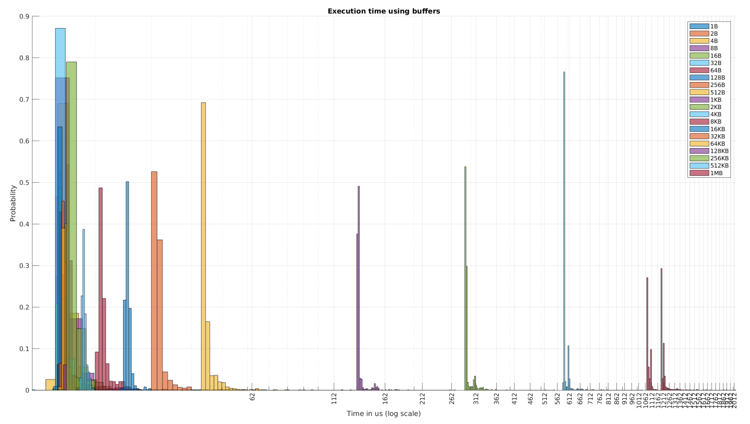


Figure 7: probablity distribution for every size

Then in 8 and 9 are reported the cases with a smaller payload size.

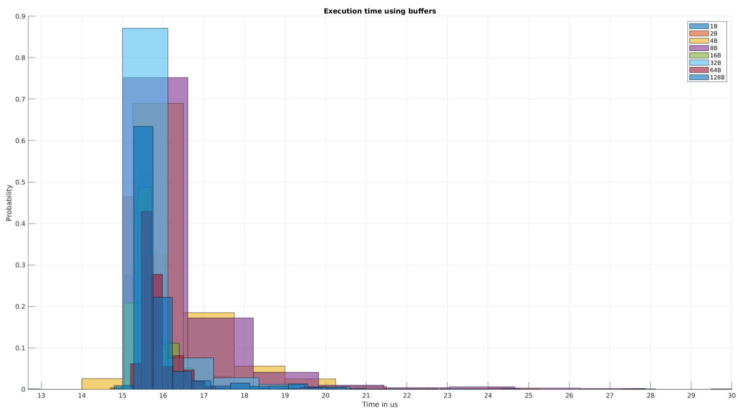


Figure 8: probablity distribution small payload

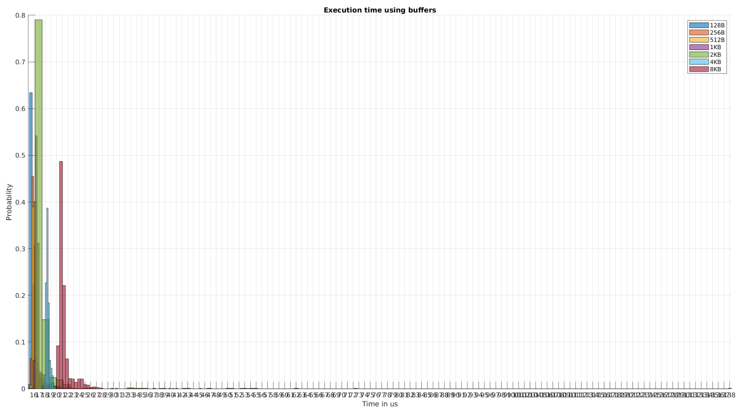


Figure 9: probablity distribution small payload

Finally the last figure 10 is a plot of the execution time for each size and iteration, it is reported in a logarithmic scale.

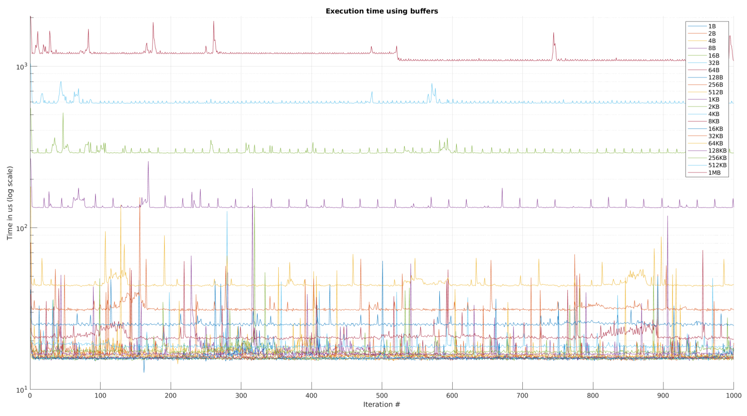


Figure 10: execution time, all cases all iterations

## 3.2 Results obtained using shared memory

The results are flatter respect to the other case because using the kernel memory we have to copy from and into the kernel, here we copy just the shared memory key but we have to pay in overhead due to the syscalls needed to manage the shared memory. In the figure13 are reported the histograms related to all the cases.

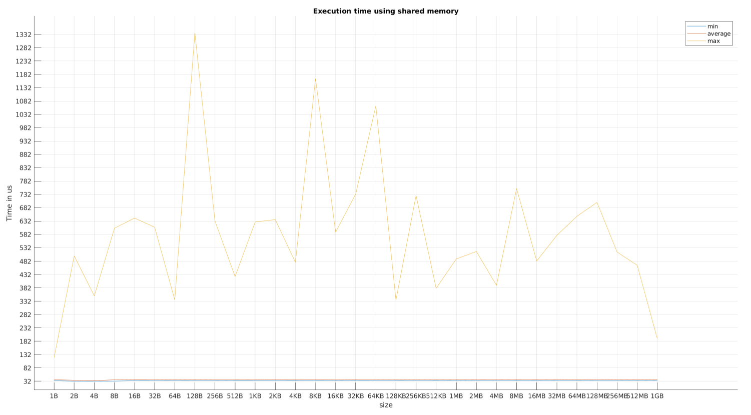


Figure 11: Execution time, minimum average and maximum

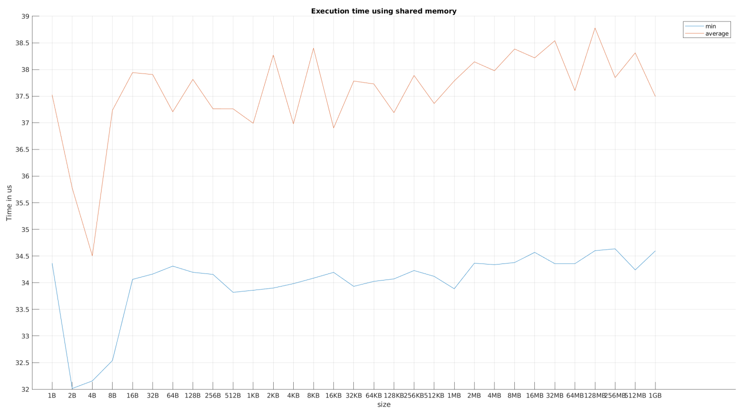


Figure 12: Execution time, minimum and average for all cases

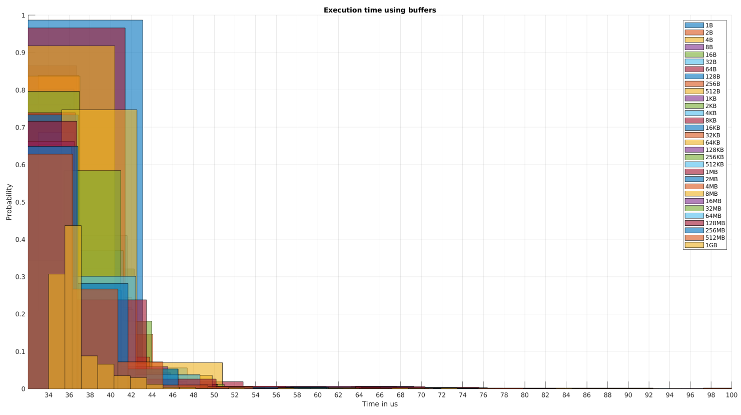


Figure 13: Probability distribution for all cases

## 4 Future work

- Request TTL, maximum time that a request can stay in the system
- Linber manager, periodic kernel thread that check all the completed request and destroy them if expired (TTL)
- Improve security mechanism, set the owner uid and gid of the response in shared memory to the uid and gid of the client with permissions 600

## A Application example

### A.1 Server

Once registered the service using the *Linber API* the server needs to create the workers, it is possible to extend the *LinberServiceWorker* and implement the virtual funcion *execute_job* that will be called every time arrive a request. .

```
class linberServiceWorker {
  char *service_uri;
  char *file_str;
  int uri_len;
  unsigned long service_token;
  unsigned int exec_time;
  unsigned int worker_id;
  unsigned int job_num;
  std::thread thread_worker;
  bool worker_alive;

  void worker_job();
protected:
    boolean request_shm_mode;
    char *request;
    int request_len;
    char *response;
    int response_len;
public:
  linberServiceWorker(char * service_uri, unsigned long service_token);
  virtual ~linberServiceWorker();
  void join_worker();
  void terminate_worker();
  virtual void execute_job();
};

class calculator_service : public linberServiceWorker{
  Calculator::Calculator_request request_msg;  // protobuf message
  Calculator::Calculator_response response_msg; // protobuf message

  public:
  calculator_service(char * service_uri, unsigned long service_token);
  float sum(float a, float b);
  float difference(float a, float b);
  float product(float a, float b);
  float division(float a, float b);
  float power(float a, float b);
  float square_root(float a);
  float compute(unsigned int operation, float a, float b);
  void execute_job()override;
};
```

## A.2 Client

.

```
class linberServiceClient {
  char *service_uri;
  int service_uri_len;
  int request_len;
  int response_len;
  char* request = NULL;
  char * response = NULL;
  key_t request_shm_key;
  boolean response_shm_mode = FALSE;
  boolean request_shm_mode = FALSE;
  unsigned long token, abs_deadline;
  int request_state = 0, request_shm_state = -1;
  int rel_deadline;

  public:
  linberServiceClient(char * service_uri, int service_uri_len);
  ~linberServiceClient();
  void linber_sendRequest(char *req, int req_len, char **res, int *res_len, bool blocki
  void linber_create_shm(char **req, int req_len);
  void linber_sendRequest_shm(char **res, int *res_len, bool blocking, int rel_deadline
  char* linber_get_response();
  void linber_end_operation();
};

class Calculator_service_client : public linberServiceClient{
  Calculator::Calculator_request request_msg;
  Calculator::Calculator_response response_msg;

  public:
  Calculator_service_client();
  float sum(float a, float b);

  float difference(float a, float b);
  float product(float a, float b);
  float division(float a, float b);
  float pow(float a, float b);
  float sqrt(float a);
};
```