Boosting Software Efficiency:

A Case Study of 100% Performance Improvement in an Embedded C++ System

GILI KAMMA

INTRO

- The talk today is about software development.
- I worked on a product for two years, and during this time, I drastically improved its capabilities.
- I wanted to share with you the journey I had.
- I hope you will get some useful ideas and inspiration to improve your own product.

I am Gili Kamma

20 years in the industry

B.S.c in Electronics

I love to improve things and solve problems

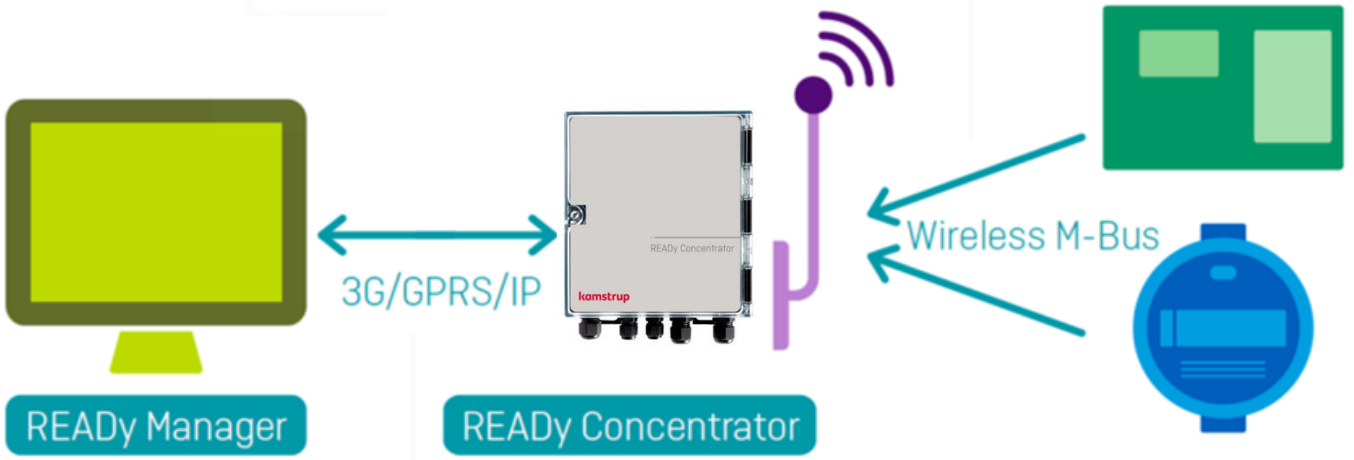
Team leader @ Priority-software

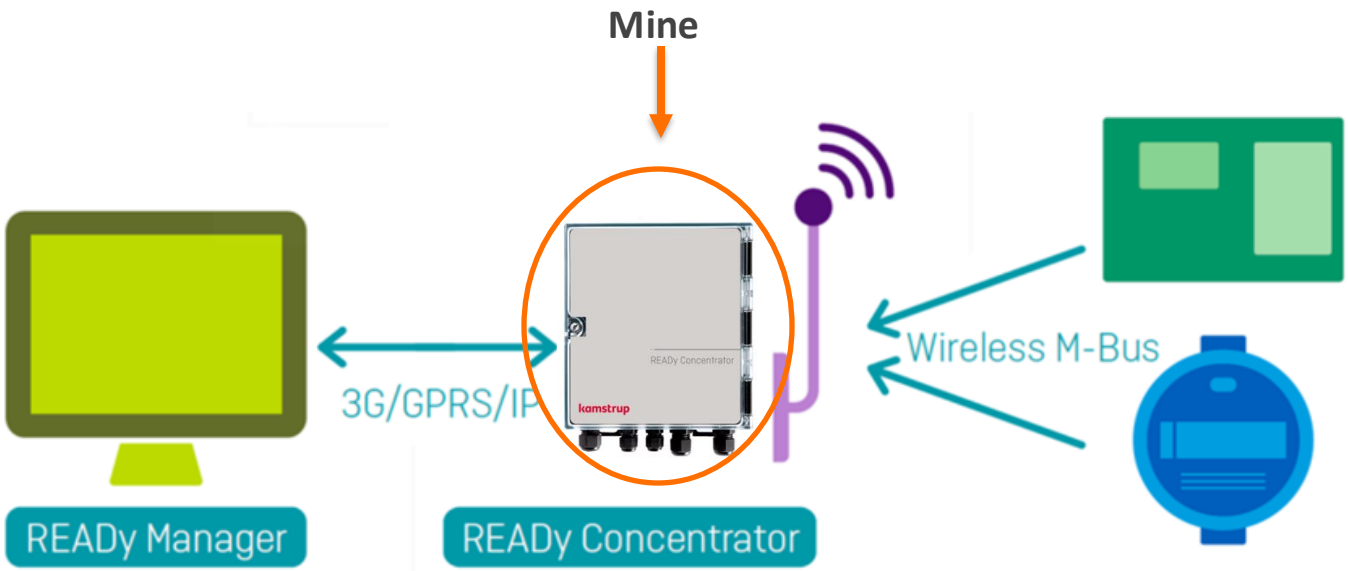
My story begins….

The business is meters (water, heat and electricity)

Smart metering

A system that uses digital devices to automatically send your utility data to the provider.


3G/GPRS/IP
READy Concentrator
kamstrup
Wireless M-Bus
READy Manager
READy Concentrator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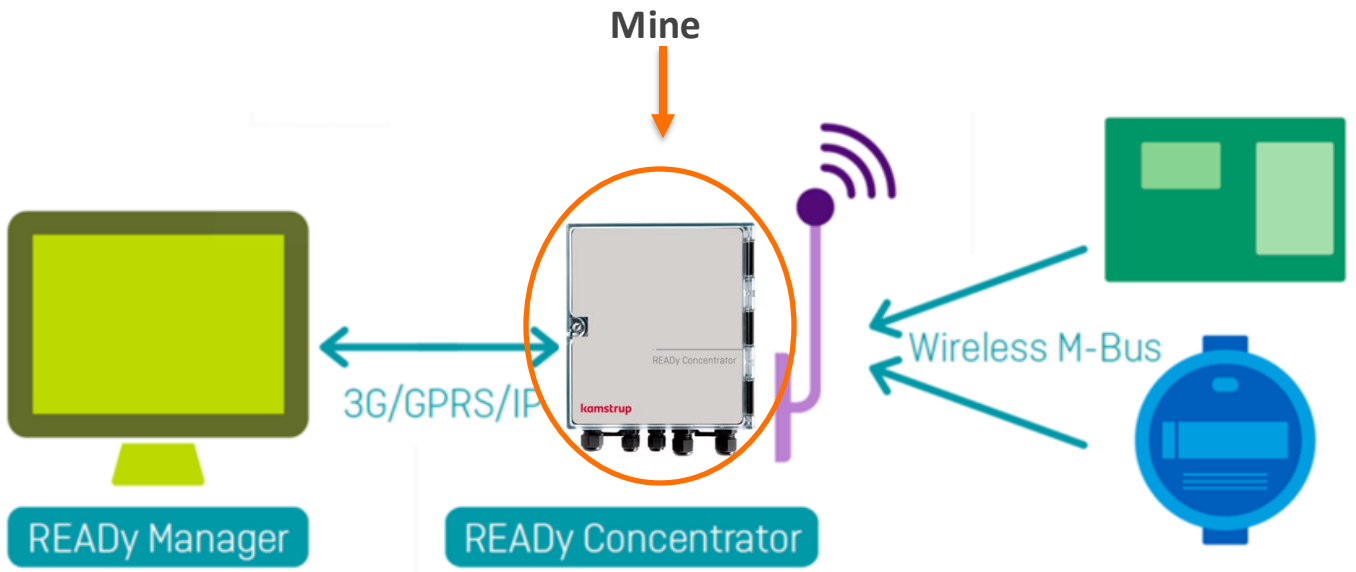
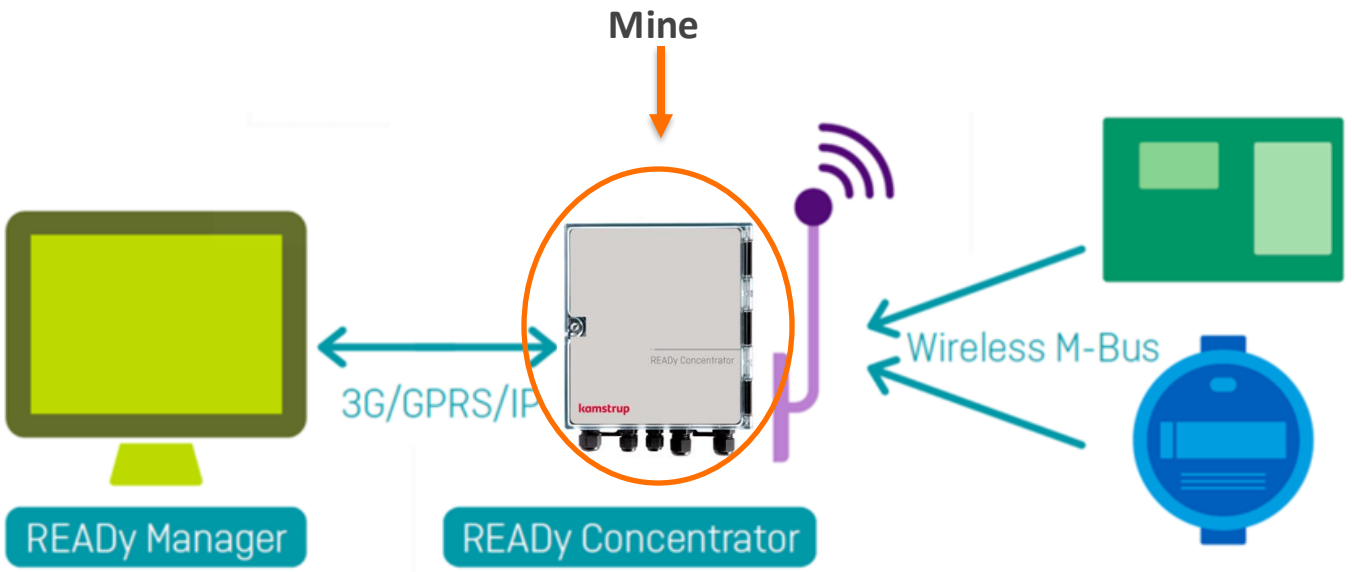


Collects meter measurements from water meters (wireless) and sends them to the cloud by cellular modem or ethernet.



Loss of data → loss of money.

The Problems

Built to work with less than 1000 water meters – in real life was expected to work with 7500 meters.

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- Unstable product.
- Unsatisfied customers.
- Unhappy developers.

- Memory issues – we didn't have enough memory.
- Unexplained crashes.
- Occasional data loss during network issues.

→ None of the errors were seen in the lab.

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Technology Stack

- Linux kernel, Yocto distribution – old image – no sources.
- 32 MB RAM.
- C++17 (in style of C++11 and earlier).
- Qt – an application framework – a wrapper to low-level programming.

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The Goal

Reduce (to zero) loss of data

and

create a stable product.

Reduce (to zero) loss of data

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create a stable product.

How Am I Going to Do That?

First Impression

A lot of news & deletes

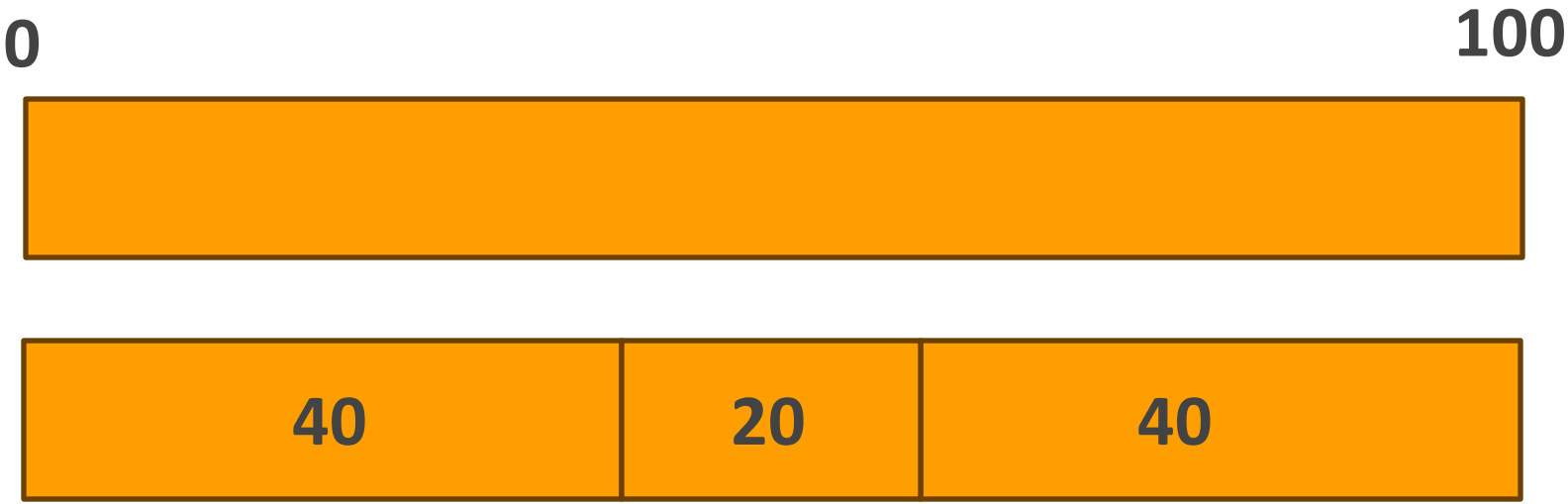
A lot of news & deletes

→ memory leaks & memory fragmentation

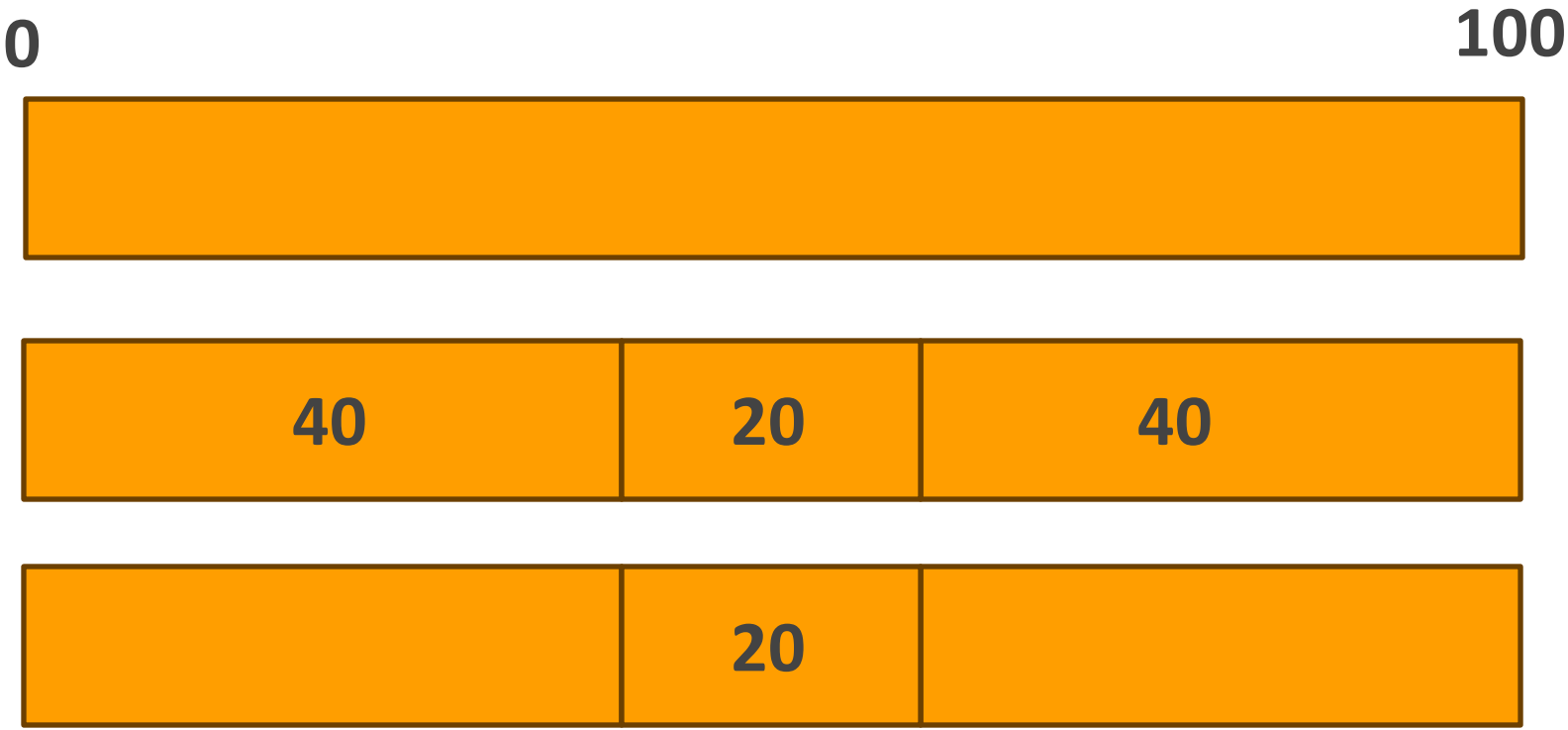
Memory fragmentation:

0 100

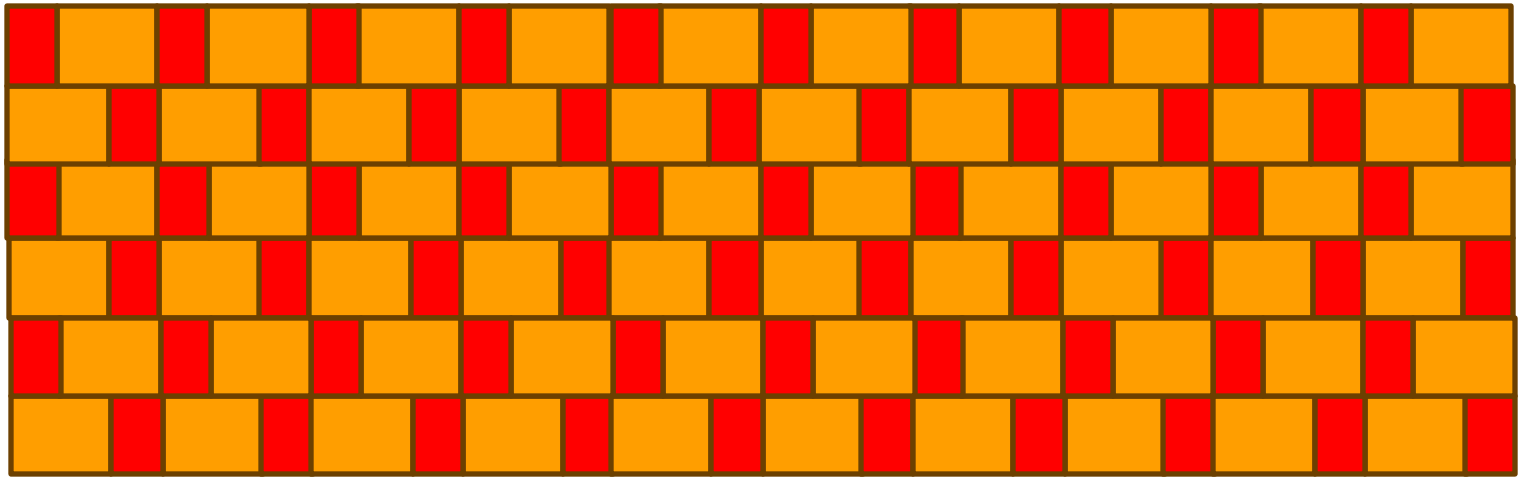
Memory fragmentation:



Memory fragmentation:



Memory fragmentation:



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memory leaks & memory fragmentation

→ explains not enough memory

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explains not enough memory

→ allocation fails

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allocation fails

→ accessing null

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accessing null

→ uncontrolled reset

A lot of news & deletes

memory leaks & memory fragmentation

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uncontrolled reset

→ Q.E.D 

Right?

Right?
Wrong!

Right?
Wrong!

It is not “wrong wrong” but it is wrong in this case

Wrong!

A lot of news & deletes

memory leaks & memory fragmentation

explains not enough memory

allocation fails

accessing null

uncontrolled reset

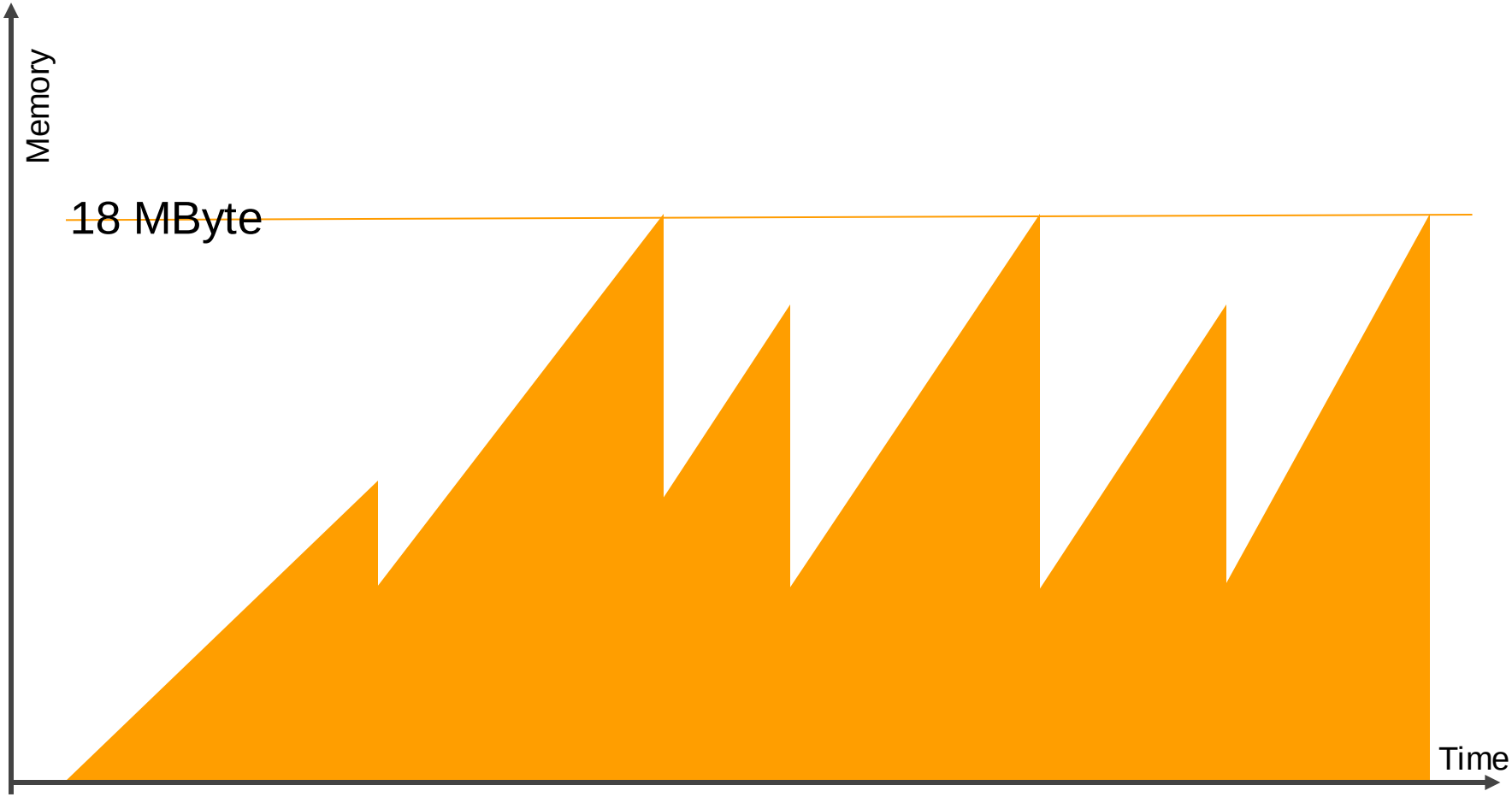
→ Q.E.D

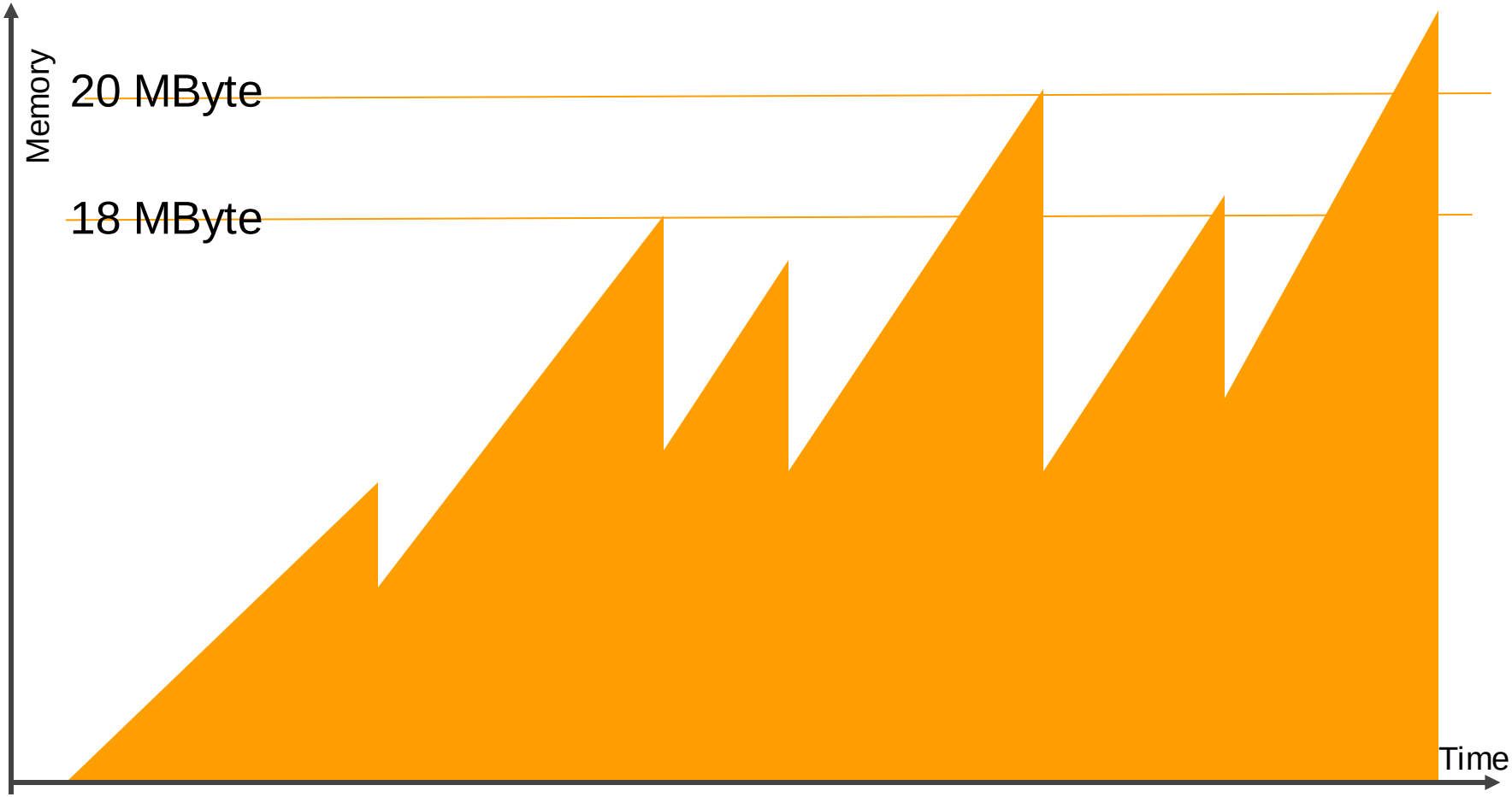
I needed to test my assumptions…

Memory Profiler

Gave me a good understanding of the sizes and the quantities of allocations.

I couldn’t use standard memory profilers as the Linux kernel was old.


Memory
18 MByte
Time


Memory
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Time

Interesting measurements:

- Number of allocations per second.
- Current and maximum number of allocations.
- Current and maximum bytes allocated.
- Current and maximum allocations per size value.

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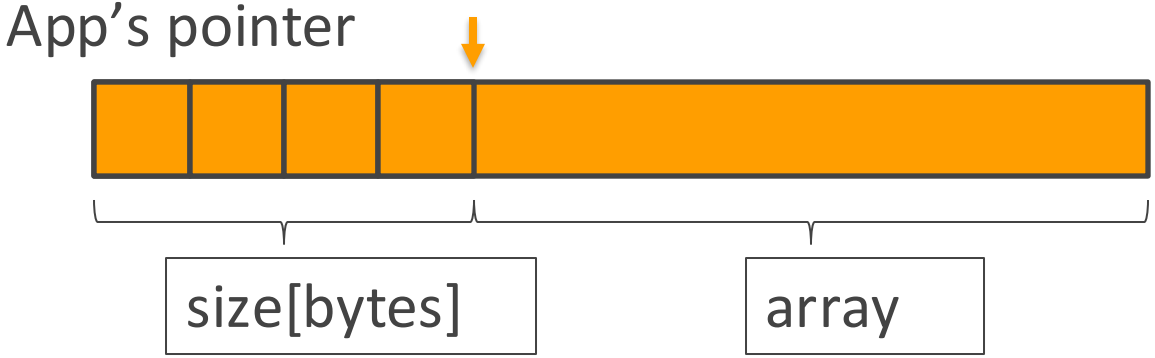
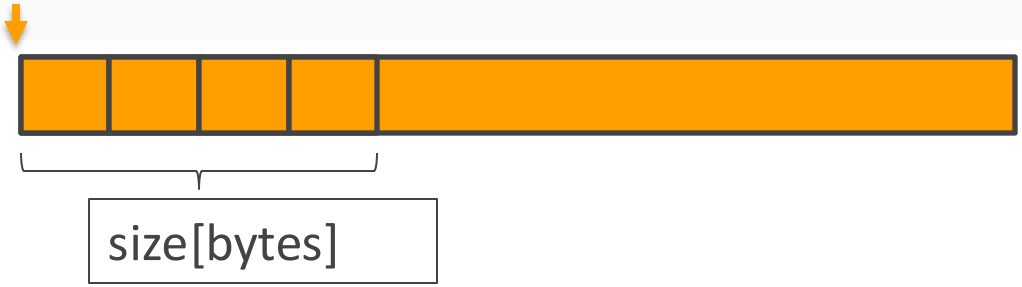
Implementation



- Overloaded new and delete operators.
- Added 4 bytes to each allocation.

```
void* operator new(size_t size)
{
    void* ptr = malloc(size+4);
    *reinterpret_cast<size_t*>(ptr) = size;
    profiler.addAllocation(size);
    return (reinterpret_cast<char*>(ptr)+4);
}
```



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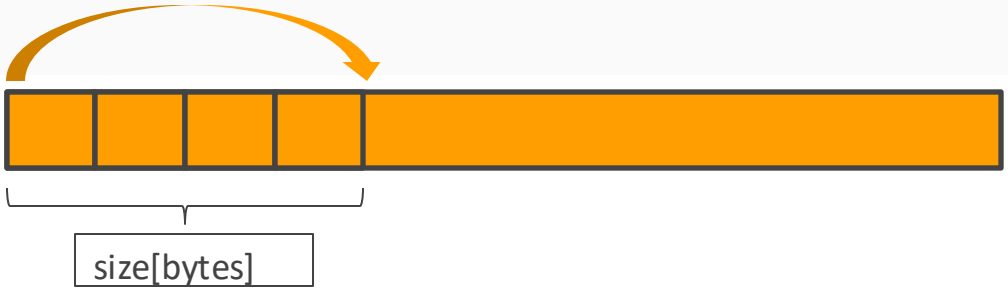

```
void operator delete(void* ptr, std::size_t)
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    size_t size = *reinterpret_cast<size_t*>(reinterpret_cast<char*>(ptr)-4);
    profiler.removeAllocation(size);
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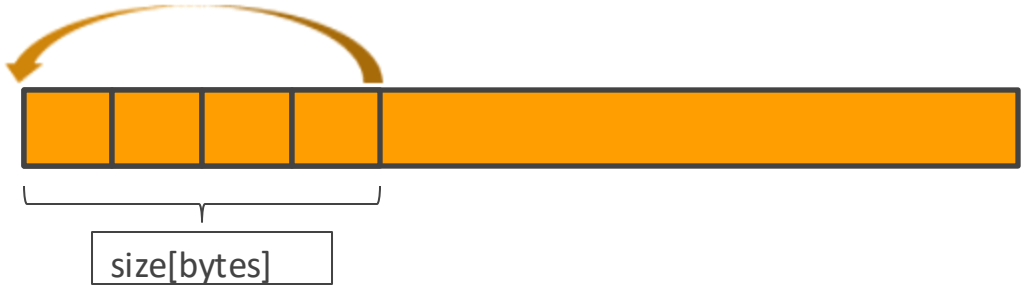

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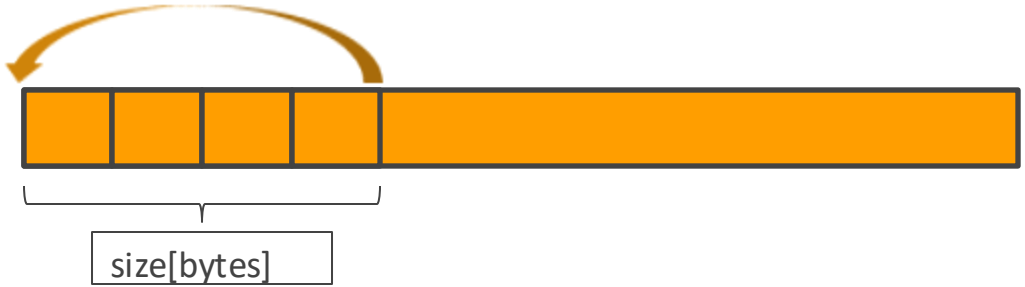

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- Find the memory leaks and clean them.
- Figure out this is not my main problem.

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I've come across many problems, some big and some small.

Let’s talk more about them

Problems:

- Unexplained crashes.
- Not enough information after crash.
- Occasional data loss during network issues.
- Suddenly, no meters are being detected anymore.

Unexplained crash after crash continuously
(with gaps of several minutes)
in big sites (>5000 water meters).

How to simulate 5000+ water meters?

- 1 data frame to 10-50 fake data frames.
- The unit crashed on my table when I simulated 6k meters and put “aggressive configuration”.

REPRODUCE THE ERROR

```
struct Message
{
    long opcode;
    long id;
    long value;
};
```

```
void ReceiveThread(queue<Message>& queue)
{
    Message message = {};
    const bool simulatorEnabled = std::filesystem::is_regular_file("myfile.txt");
    while (true)
    {
        message = {};
        bool isReceived = ReceiveMessage(message);
        if(isReceived)
        {
            queue.push(message);
            if(simulatorEnabled)
            {
                Message simulatorMsg = {};
                for(int i=0; i<100; i++)
                {
                    simulatorMsg = message;
                    simulatorMsg.id =  message.id + rand() % 1000;
                    queue.push(simulatorMsg);
                }
            }
        }
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What is special here:

- No special hardware required.
- Simple implementation.
- Easy access to simulator mode without additional building.
- Consistently crashed the system.

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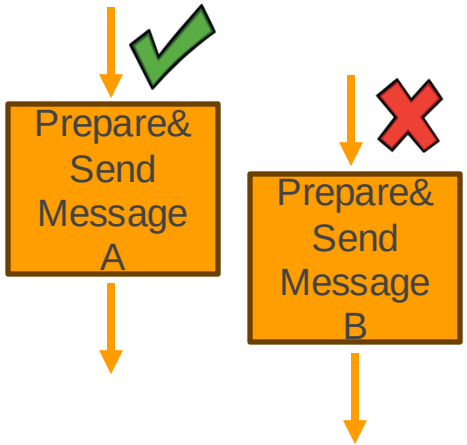
```

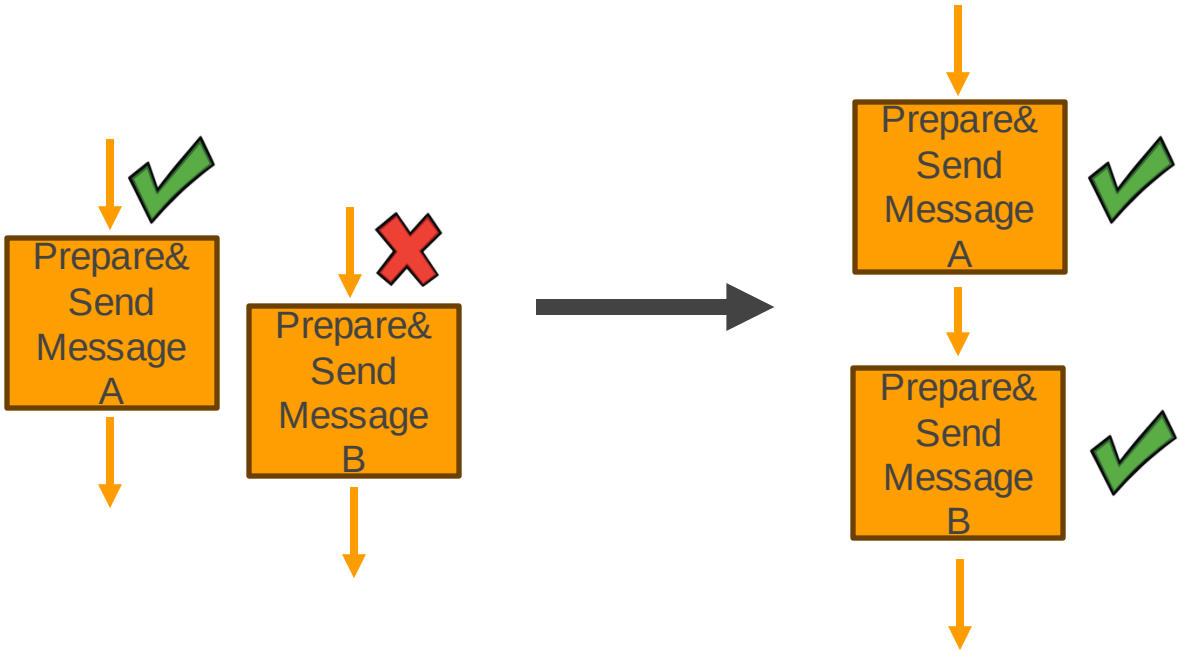
Two threads tried to create large messages about 5 MB each, at the same time.

The second one always failed.



Imagine this issue on your system. How would you solve it?

- Changed from asynchronous work to synchronous work.
- Split large messages into smaller ones.
- Rewrote the message preparation function using C++ instead of Qt.
- Used a static array instead of dynamic allocation.


Prepare&
Send
Message
A
Prepare&
Send
Message
B
Prepare&
Send
Message
A
Prepare&
Send
Message
B

- Asynchronous to synchronous

5MB+5MB ➡ 5MB

So, I am not crashing anymore. Can I stop here?

No!

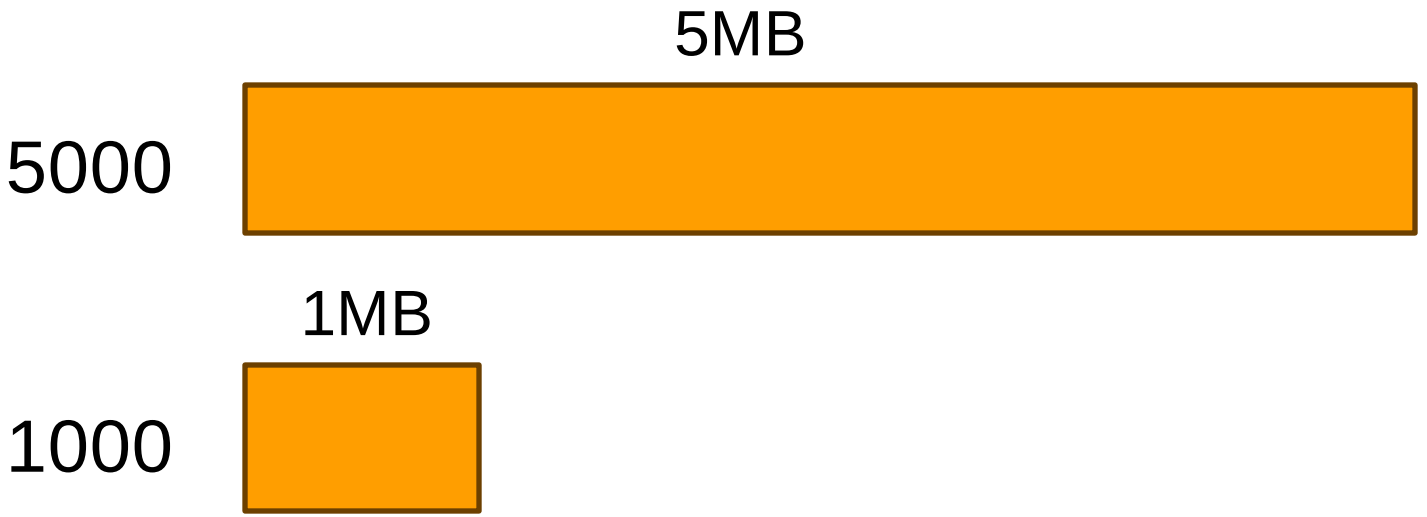
7500 meters and not just 5000

- Asynchronous to synchronous

5MB+5MB ➡ 5MB

Why doesn’t it happen in all sites?

The message size was proportional to the number of water meters the unit listened to.



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5MB

1X


5MB
1X
1MB
5X

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- Asynchronous to synchronous — 5MB+5MB ➡ 5MB
- Split large messages into smaller ones — 5MB ➡ 1MB
- Qt to C++ — 1MB ➡ 0.5MB

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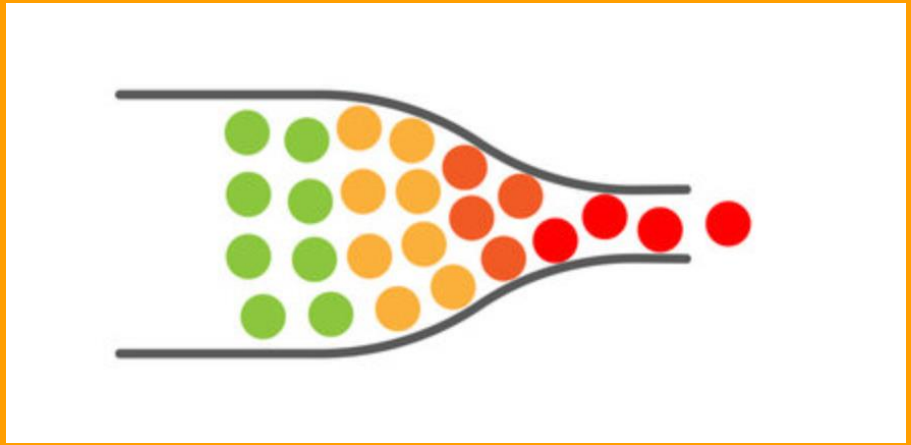
Bottle neck of the system



Problems:

- Unexplained resets.
- Not enough information after crash.
- Occasional data loss during network issues.
- Suddenly, no meters are being detected anymore.

- ❑ I had standard application logs.
- ❑ I didn’t have a remote access.
- ❑ I had an event mechanism (RAM).

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When the unit wakes up, send the last 100 lines from the application log to the backend using the event service.

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- tail -n 100 /var/log/my_log.txt → shortLog
- SendEvent (”reset reason”, shortLog)

Good example to good enough solution

80% result / 20% effort

Problems:

- Unexplained resets.
- Not enough information after reset.
- Occasional data loss during network issues.
- Suddenly, no meters are being detected anymore.

Data for transmission remains in RAM, awaiting further processing.

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So, what is the problem with that?

Data for transmission remains in RAM, awaiting further processing.

In case of unstable communication:

- Start to aggregate - takes a lot of space.
- Loss of data in case of reset.

.

Disconnect the Logic from the Network

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Thread #1 → Logic

Thread #2 → Sending

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Always execute the same logic and store the results in nonvolatile memory (regardless of the current network status).

Implementation Achievements:

- Maximum data loss is now limited.
- Not being sensitive any more to network errors.

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After implementing this change, we no longer experienced any significant data loss.

A good example of always using the same scenario to avoid any edge cases

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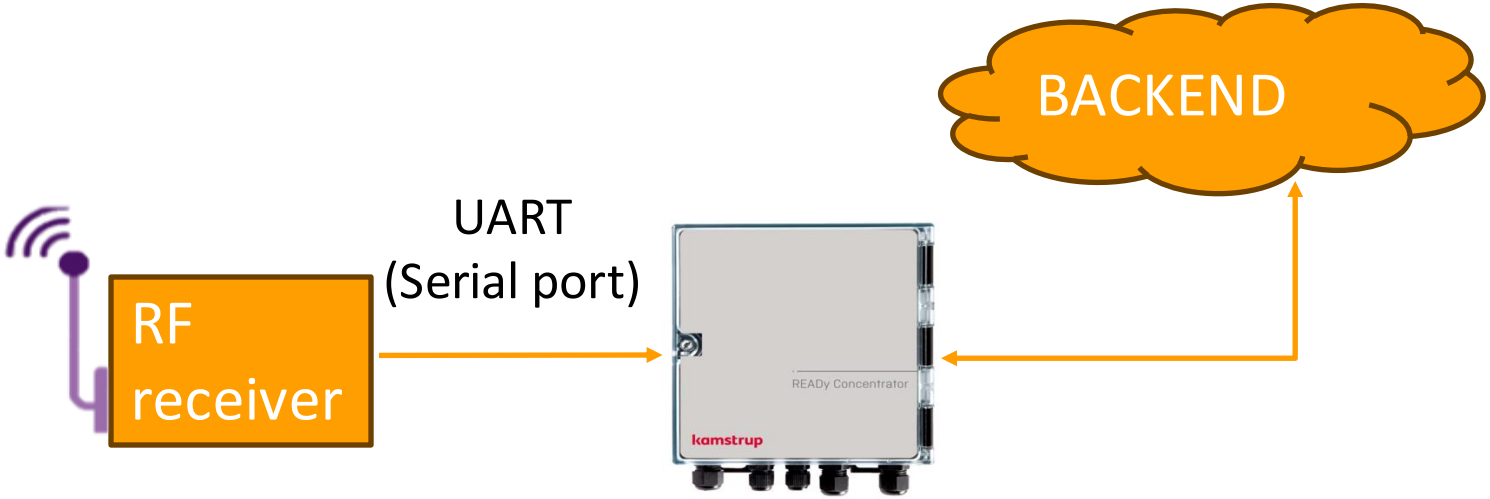
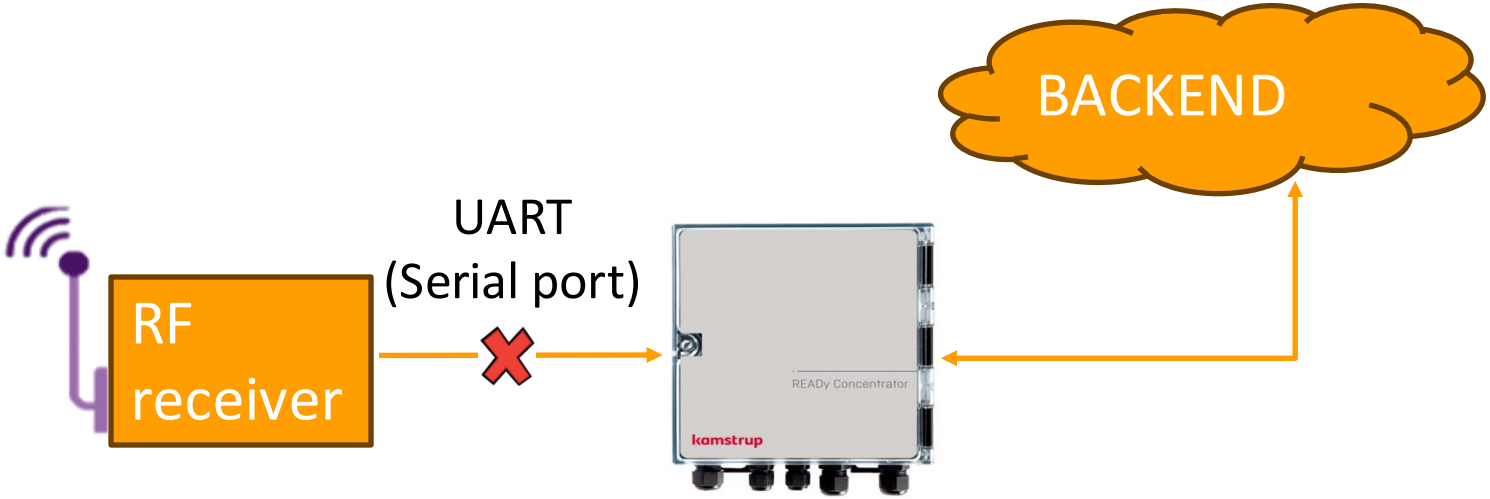


READy concentrator



READy concentrator

Once in a while we stopped receiving frames

(The system doesn’t recover on its own)

- Customers complained.
- Every time it was a different unit.
- We didn’t understand why it happens.
- Controlled Reset solved the problem.

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- Reset the HW after 1 hour of silence.

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Second solution :

- Reset the HW after 4 minutes of silence (sweet spot).

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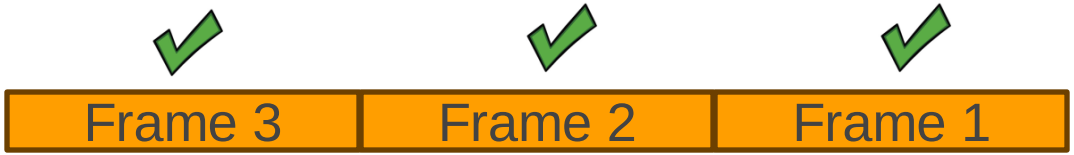
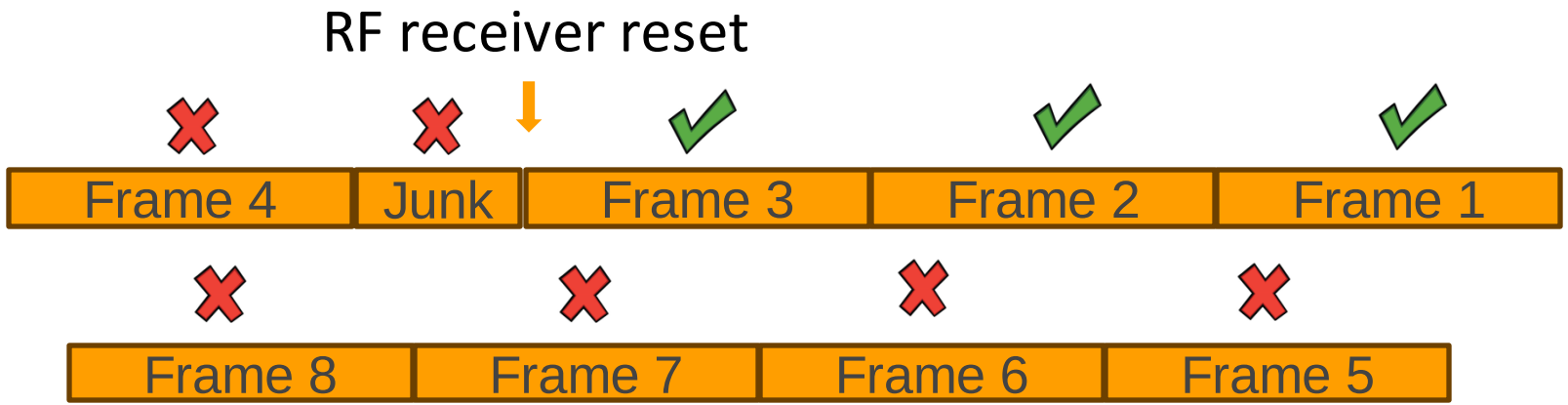
Months later, I was looking in logs of a unit that had this silence issue – and I realized the RF receiver reset itself.



As a result, the READY concentrator couldn’t sync again on the next message.



A real solution:

- Initialized the UART when I detected silence instead of a controlled reset.

Sometimes it takes time to identify the real problem,
so we use temporary solutions in the meantime.

Monitoring

How it was when I started to work:

Complaints

Look at the event service

After several weeks:

Look at the event service

! Complaints

How I started:

- Started reading events for specific units, but it was uncomfortable.
- Two students proposed writing a script to retrieve the events and save them to a local text file.
- Wrote a Python script to analyze the text and export to an Excel file (sort, filter, plot).

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Timestamp	Event			
9/16/23 10:00	data send			
9/16/23 11:00	data send			
9/16/23 12:00	data send			
9/16/23 13:00	data send			
9/16/23 14:00	data send			
9/16/23 15:00	data send			
9/16/23 16:00	data send			
9/16/23 17:00	data send			
9/16/23 18:00	data send			
9/16/23 19:00	data send			
9/16/23 20:00	data send			
9/16/23 21:00	data send			
9/16/23 22:00	data send			
9/16/23 23:00	data send			
9/17/23 0:00	data send			
9/17/23 1:00	data send			
9/17/23 2:00	data send			

How I started:

- Ran the scripts every morning, analyzing for 10 minutes daily.
- Added more units and parameters.
- Automated the scripts to run at night and receive results by email in the morning.

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Metrics (once a day) per unit

- ⊡ Max memory usage.
- ⊡ How many errors.
- ⊡ Last time to be seen.
- ⊡ How many resets.
- ⊡ How many meters were reported.
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Be proactive!

Use the data you already have

Testing

E2E tests:

- ☑ Rewrote the test paper from manual tests to automatic tests.
- ☑ Implemented the automated tests.
  - ☐ Two pipelines – long and short tests.
  - ☐ 24/7 - to stabilize the tests.

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The question isn’t if there’s a bug - it’s who will find it first

How did it end?

8 Months Later

- Product without any resets.
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2 Years Later

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Take Home Messages

Measure Everything – Avoid Assumptions

(Remember – my first impression)

Write Robust Software

Unexpected inputs are unavoidable, but don’t let your system crash – have safeguards in place

- Split large messages into smaller, fixed sizes.
- Decouple logic and network operations.

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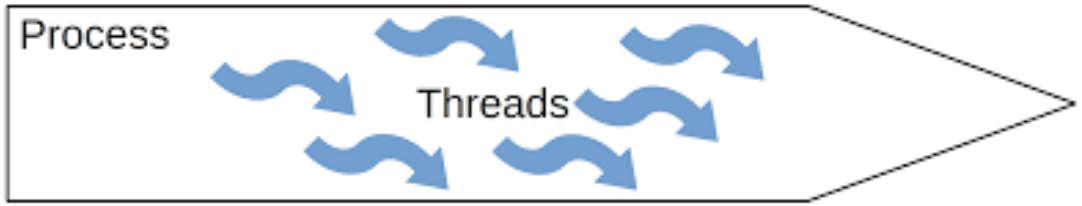
Reduce the Number of Threads



(The most challenging bugs in the system arise from multiple threads running simultaneously)

Monitoring – Be Proactive.

Don't Wait for Customer Complaints

Create Simple Software

Creating simple software is more challenging than making it complex.

Thanks!

Any questions?