Synchronous Transmissions Made Easy: Design Your Network Stack with Baloo
Designing protocol is a balancing act between generality, performance, and development effort.

<table>
<thead>
<tr>
<th>Generality</th>
<th>of the design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>of the solution</td>
</tr>
<tr>
<td>Development ease</td>
<td>of the team</td>
</tr>
</tbody>
</table>
Synchronous Transmissions shone in these competitions

Generality

Performance

Development ease

Reliable
Fast
Energy efficient
Many Synchronous Transmissions primitives have been proposed:

- 2011: Glossy
- 2013: Chaos
- 2013: Splash
- 2013: SCIF
- 2014: P3
- 2015: Pando
- 2015: Ripple
- 2016: RedFixHop
- 2017: Robust Flooding
- 2017: LiM
- 2018: Codecast
- 2018: Mixer

... and more
Many network stacks aim to harness the benefits of ST

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<tr>
<th>Year</th>
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... and more
Many network stacks aim to harness the benefits of ST but it’s not easy.

We designed quite a few...

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As ST is very sensitive to timing, network stacks using ST are difficult to generalize and hard to develop.
As **ST** is very sensitive to timing, network stacks using ST are **difficult to generalize** and hard to develop.

- Generality: 
  - Poor
- Performance: 
  - Weak
- Development ease: 
  - No specific data available
As ST is very sensitive to timing, network stacks using ST are difficult to generalize and hard to develop.

| Generality | Difficult to adapt |
| Performance |
| Development ease | Hard to develop |
Many network stacks aim to harness the benefits of ST **but it’s not easy.**

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We designed quite a few...
Can we facilitate the design of ST-based network stacks?

Can we get most of the benefits with minimal development effort?

- Yes, we can.
This is why we present Baloo

Baloo is a design framework for network stacks based on Synchronous Transmissions

- Flexible
- Performant
Synchronous Transmissions Made Easy: Design Your Network Stack with Baloo

Why Synchronous Transmissions?
Let’s make our life easier

Generic yet flexible framework
Divide and conquer

What about performance?
The cost of abstraction
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Divide and conquer

What about performance?
The cost of abstraction
repeats synchronously

A

repeats synchronously

B
B gets the packet
Synchronous Transmissions abstracts the multi-hop network as a bus
Synchronous Transmissions realised an any-to-all communication in bounded time*  

* Given the network diameter
Many network stacks aim to harness the benefits of ST but it’s not easy.

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... and more
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What about performance?
The cost of abstraction
High-level Protocol

Low-level Protocol

ST primitive

HW
High-level Protocol

Middleware

ST1

ST2

ST3

ST4

HW1

HW2

HW3
Baloo is a framework built on a middleware layer that separates ST primitives and network layer.

Baloo:
- Protocol A
- Protocol B
  - Middleware
    - ST1
    - ST2
    - ST3
    - ST4
  - HW
    - HW1
    - HW2
    - HW3
The middleware structures communication in **rounds**
The control packet defines all parameters for the round.
The middleware starts and stops primitives, it **controls the timing** of operations for you.
The network layer defines the **protocol logic** using **callback functions**

Middleware executes the callbacks

Network layer defines the instructions

```c
if(is_initiator) {   /* I am scheduled for this slot, prepare packet */
    out_payload[0] = counter--;  
    out_payload[1] = 0xaa;  
    *out_len = 2;  }
```
The network layer defines the protocol logic using callback functions.

Middleware executes the callbacks:

```c
if(!is_initiator) { /* I was a receiver in the last slot */
    if(len == 2) { /* If I received something, process it */
        rcv_cnt++; }
```
The network layer defines the **protocol logic** using **callback functions**

Middleware executes the callbacks

Network layer defines the instructions

```c
/* Default state update
 * - suspend execution if control is missed
 * - go to bootstrap after two consecutive missed controls
 * - run normally otherwise
 */
```
The network layer defines the **protocol logic** using **callback functions**

Middleware executes the callbacks

Network layer defines the instructions

```
on_round_finished()
DEBUG_PRINT_INFO("received %u of %u packets", rcv_cnt, number_of_static_nodes);
rcv_cnt = 0;
```
Many features are available to enrich the protocol design

- Functionalities
  - Interference detection
  - Advanced state machine
  - Switching primitives

- Advanced scheduling
  - Starvation protection
  - Contention slots
  - Per-slot configuration
  - Static schedules and configuration
  - Slot- and round-skipping

- Radio settings
  - Slot repeat
  - Channel hopping
  - Transmit power setting
Case study – 2019 Dep. Comp.
Aperiodic Data Dissemination

Cluster 1

Cluster 2

Cluster 3
Case study – 2019 Dep. Comp.
Aperiodic Data Dissemination

All clusters are mixed and form one multi-hop network
Sparse message releases
No wake-up radio

Criteria
- Reliability
- Latency
- Energy consumption
Case study – 2019 Dep. Comp.
Aperiodic Data Dissemination

All clusters are mixed and form one multi-hop network
Sparse message release
No wake-up radio

Criteria
- Reliability
- Latency
- Energy consumption

What protocol would you design?
Let’s start simple.
Increase reliability by adding ACKs
Reduce energy consumption by using per-slot configuration
Reduce energy consumption by using per-slot configuration by using specialized primitives.
Reduce latency by using contention
Reduce energy consumption by skipping unnecessary slots
Reduce energy consumption by using static control
Increase reliability with channel hopping
Increase reliability with channel hopping

With Baloo, you can do all this (and more) without you having to set a single timer.
Many features are available to enrich the protocol design

| Functionalities                     | Interference detection |
|                                   | Advanced state machine |
|                                   | Switching primitives   |
| Advanced scheduling               | Starvation protection  |
|                                   | Contention slots       |
|                                   | Per-slot configuration  |
| Radio settings                    | Static schedules and configuration |
|                                   | Slot- and round-skipping |
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</table>
ISR(timerA) {
    /*
    * Time
    * sensitive
    * instructions
    * for ST1
    */
}

ISR(timerA) {
    /*
    * Time
    * sensitive
    * instructions
    * for ST2
    */
}

ISR(timerA) {
    /*
    * Time
    * sensitive
    * instructions
    * for ST3
    */
}

ISR(timerA) {
    /*
    * Time
    * sensitive
    * instructions
    * for ST4
    */
}
ISR(timerA){
    if(ST1){
        ST1_int_cb();
    }
    ...
}

Middleware

The ISR becomes a “switch” implemented in the middleware

ISR(timerA){
    ST1_int_cb(){
        /*
         * Time
         * sensitive
         * instructions
         * for ST1
         */
    }
}

ISR(timerA){
    ST2_int_cb(){
        /*
         * Time
         * sensitive
         * instructions
         * for ST2
         */
    }
}

ISR(timerA){
    ST3_int_cb(){
        /*
         * Time
         * sensitive
         * instructions
         * for ST3
         */
    }
}

ISR(timerA){
    ST4_int_cb(){
        /*
         * Time
         * sensitive
         * instructions
         * for ST4
         */
    }
}
Baloo is made of many such “tricks” put together is a sensible way to make things work.
Synchronous Transmissions Made Easy: Design Your Network Stack with Baloo

Why Synchronous Transmissions?
Let’s make our life easier

Generic yet flexible framework
Divide and conquer

What about performance?
The cost of abstraction
We used Baloo to re-implement three network stacks and compare performance with the originals

<table>
<thead>
<tr>
<th>Low-power Wireless Bus</th>
<th>Packet Reception Rate</th>
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<tr>
<td>Crystal</td>
<td>Radio duty cycle</td>
</tr>
<tr>
<td>Sleeping Beauty</td>
<td>Binary size</td>
</tr>
<tr>
<td></td>
<td>Lines of Code</td>
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We used Baloo to re-implement three network stacks and compare performance with the originals.

<table>
<thead>
<tr>
<th>In short</th>
<th></th>
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<tr>
<td>PRR similar</td>
<td>Re-implementations “work”</td>
</tr>
<tr>
<td>Little energy overhead</td>
<td>5 - 15% Radio DC increase</td>
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<tr>
<td>Binary size comparable or smaller</td>
<td></td>
</tr>
<tr>
<td>Code length tend to reduce</td>
<td>Down to 50%</td>
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### Results – Category 2 (Dissemination)

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<tr>
<th>Team #</th>
<th>Jamming Layout</th>
<th>None</th>
<th>Mild</th>
<th>Strong</th>
<th>Dynamic</th>
<th>∑ points</th>
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<td>561</td>
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<td>08</td>
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**Legend**
- From left to right, for each message length: aperiodic, periodic 5s, periodic 30s
### Results Category 2 (Dissertation)

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<th>Team #</th>
<th>Jamming Layout Message Len.</th>
<th>4</th>
<th>8</th>
<th>32</th>
<th>64</th>
<th>8</th>
<th>32</th>
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**Legend**: 9 6 4 3 2 1 1 From left to right, for each message length: aperiodic, periodic 5s, periodic 30s
We were the first people that used Baloo outside the initial developer team. We had not much prior experience in WSN protocol design. While the result is not perfect, we managed implement our protocol within 8 weeks of part-time work. We would not have been able to do that without Baloo.

Without Baloo, we would likely not have been able to implement a protocol of this degree of sophistication within the timeframe of the project.
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Without Baloo, we would likely not have been able to implement a protocol of this degree of sophistication within the timeframe of the project.
The usability and performance of Baloo has been showcased with our Dependability Competition project.

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Without Baloo, we would likely not have been able to implement a protocol of this degree of sophistication within the timeframe of the project.
Baloo makes it easy to implement and port network stacks based on ST

- Code is much simpler
- No time management
- No interrupt handling
Baloo makes it easy to implement and port network stacks based on ST

- Code is much simpler
- Network layer is platform-independent
- Very limited HW/SW requirements
- Available for TelosB and CC430

- No time management
- No interrupt handling
- Contiki-NG v4.2
- 1 CRR for Baloo
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The cost benefits of abstraction
Synchronous Transmissions Made Easy: Design Your Network Stack with Baloo

Why Synchronous Transmissions?
Let’s make our life easier

- Generic yet flexible framework
- Divide and conquer

What about performance?
The cost benefits of abstraction

Baloo

<table>
<thead>
<tr>
<th>Protocol A</th>
<th>Protocol B</th>
</tr>
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<tbody>
<tr>
<td>Middleware</td>
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<thead>
<tr>
<th>ST1</th>
<th>ST2</th>
<th>ST3</th>
<th>ST4</th>
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<tbody>
<tr>
<td>HW1</td>
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<td>HW3</td>
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What about performance?
The cost benefits of abstraction
Generality: Difficult to adapt
Performance: Reliable, Fast, Energy efficient
Development ease: Hard to develop
This was made possible by **Baloo**

- Generality: Easy to adapt
  - as much Reliable
  - a bit less Fast
  - a bit less Energy efficient
- Performance
- Development ease: Easy to develop
This was made possible by **Baloo**

Baloo is a design framework for network stacks using Synchronous Transmissions

- Flexible
- Performant
- Open source

Future research

- New protocol design
- Benchmarking

Protocols Platforms

Check it out! [www.romainjacob.net/baloo](http://www.romainjacob.net/baloo)
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Reto Da Forno
Jan Müller
Anna-Brit Schaper

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Dep. Comp. Students

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ETH Zürich
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The “bare” necessities for your design.

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