BLUEFIN ROBOTICS

TOPICS : A High-Latency Communication Architecture for Underwater Vehicles

(and a preview of coming attractions...)

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IEEE OCEANS 2013

AComms Protocol Concerns

High Latency

What we communicate should not require much back-and-forth between the surface and vehicle; round-trips are less efficient than one-way communication.

A Shared Broadcast Medium

Communication needs must be balanced with navigation and acoustic sensing; multiple vehicles must be able to coordinate when they communicate and navigate to avoid conflicts.

Low Bandwidth and High Packet Loss

If we only receive one message out of ten (or one out of one hundred), it should ideally provide us SOME information, even if we're missing other packets.

Modems With Small Packet Sizes

Protocols should impose minimal overhead, and **compression** is absolutely essential.

Compatibility

It'd be nice if different vehicles could speak the same language!

Bluefin AComms: A History Lesson

<u>Option A: 9" / 12" Shallow</u>

WHOI Micromodem (FSK)

CCL Protocol

Only Basic Capabilities:

- Vehicle status + location
- Simple Commands (e.g. Abort)

Designed for AComms / Reliable

Open Protocol

<u>Option B : 12" Deep / 21"</u>

Benthos ATM880

SOMA / Edgeserver Protocol

Nearly <u>identical</u> capabilities as on the surface

Designed for Low-Bandwidth RF / Not Reliable over AComms

Proprietary Protocol

Option A : CCL

Standard Data Encodings
Supported by multiple AUV manufacturers.

Compatibility Between AUVs
Provided they're both using the WHOI MicroModem.

Reliable, Single Packet Solution
Every message stands alone, and can be decoded without additional messages.

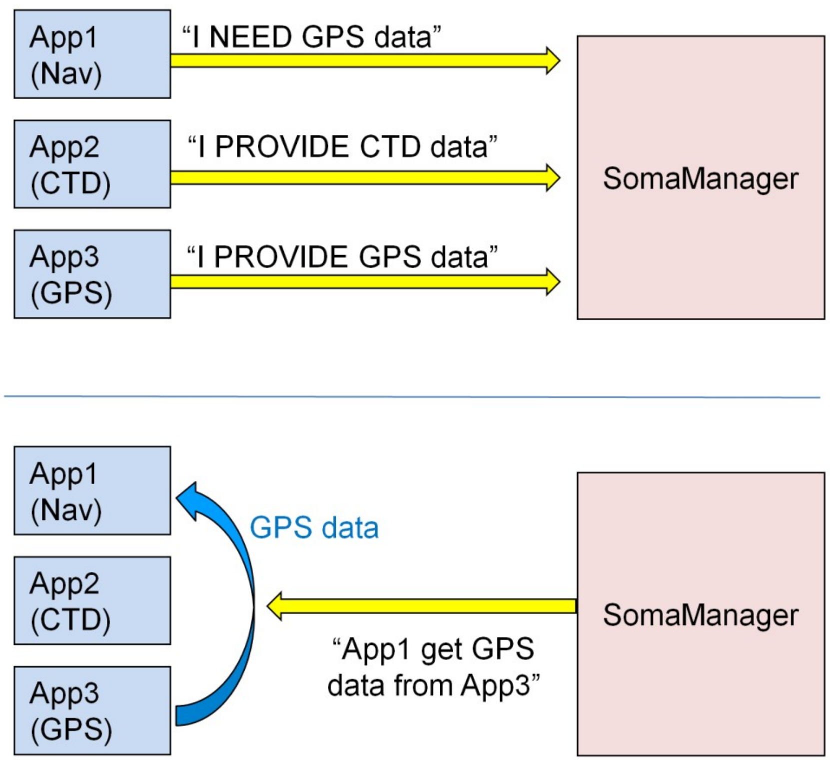
Inflexible
Want to send > 32 Bytes? Tough!

Messages don't match your needs exactly? Tough!

Byte	Description
0	Type: CCL_SCIXY_OWTT
1	X position in Meters
2	
3	
4	Y position in Meters
5	
6	
7	Heading in $\frac{360}{255}$ths of a degree
8	Depth in Meters
9	
10	Altitude in Meters
11	
12	Goal ID
13	
14	Goal X position in Meters
15	
16	

Byte	Description
17	Goal Y position in Meters
18	
19	
20	Goal Depth in Meters
21	
22	LBL#3 Travel Time in Sec.
23	
24	LBL#4 Travel Time in Sec.
25	
26	Arbitrary Science Payload
27	
28	
29	
30	
31	One-way Travel Time data

Option B : SOMA (ish)



Bluefin's Flexible IPC Protocol
Used to communicate between all software components onboard vehicle.

Publish-Subscribe Message Architecture
Applications onboard, or on the surface, can subscribe to data on the vehicle.

Guarantees (but Requires) Reliable Delivery
Every message stands alone, and can be decoded without additional messages.

Session-Based Protocol
Requires a negotiated session. If session becomes invalid, renegotiating is costly over acoustics.

No Real Compression

Next Generation : DCCL

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Flexible, Text-Based Message Definitions
Flexible definition of data to be transmitted, without writing any new code.

Provides Basic Compression / Quantization “For Free”
Basic data compression built into the protocol.

Allows Extension with Novel Compression Methods
Additional open or proprietary codecs can be added to support specific message types or use cases.

Open Source / Open Standard
Developed by Toby Schneider et al. at MIT / WHOI – tested on Bluefin vehicles.
I've been involved since I was at WHOI, still actively contribute.

Successor to CCL?

Option C: TOPICS

Unify capabilities and approach across hardware / vehicles

- Separates (most) vehicle capabilities from modem implementation
- Modular architecture to support current *and* future capabilities
- Allow new capabilities to run alongside tested + trusted capabilities

Support multiple acoustic modems per vehicle & multiple vehicles

- Redundant modems can be used to add reliability
- Vehicles can have both omni and directional modems for deep water

Improve protocol reliability and advance acoustic capabilities

- Compression is core to new approach
- Build on (open source) DCCL for low-level protocol

TOPICS Architecture

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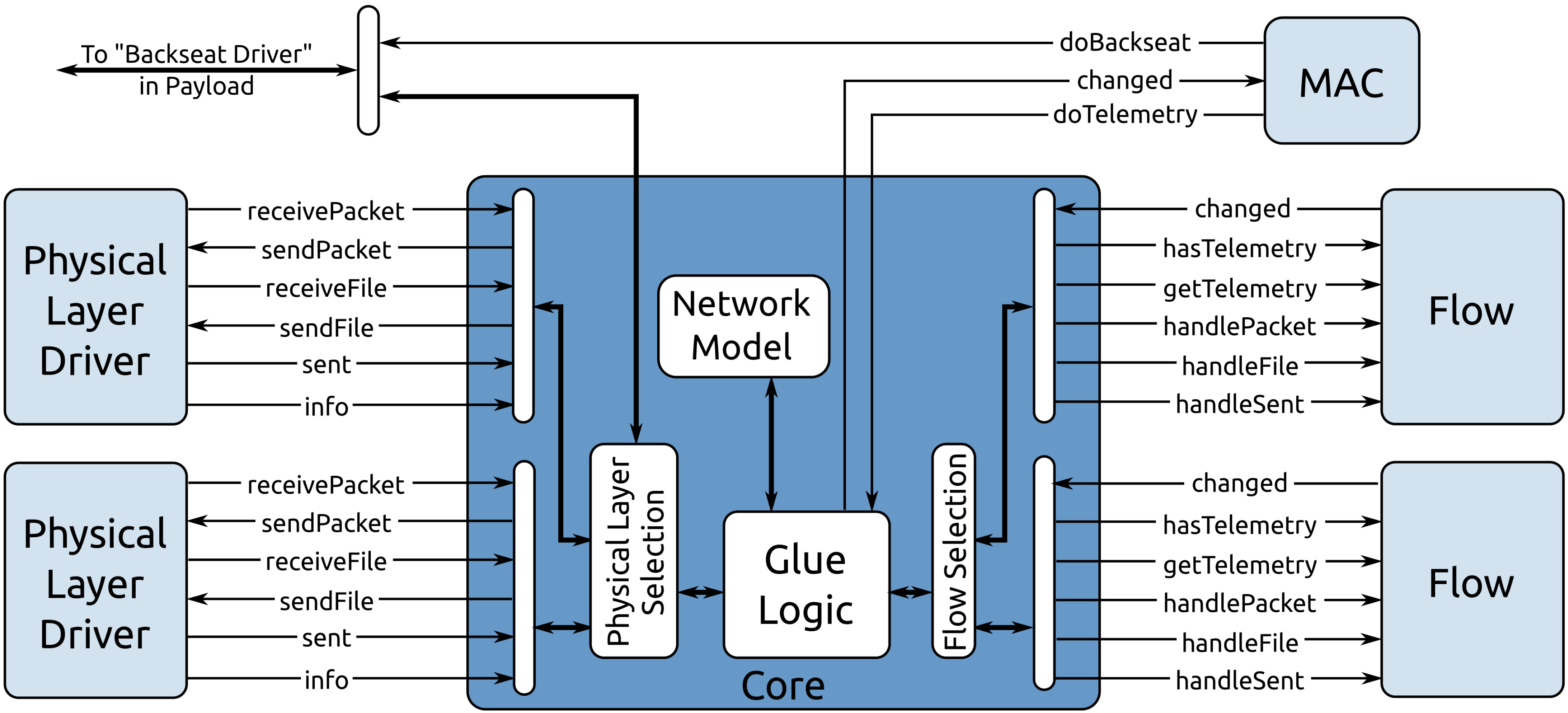
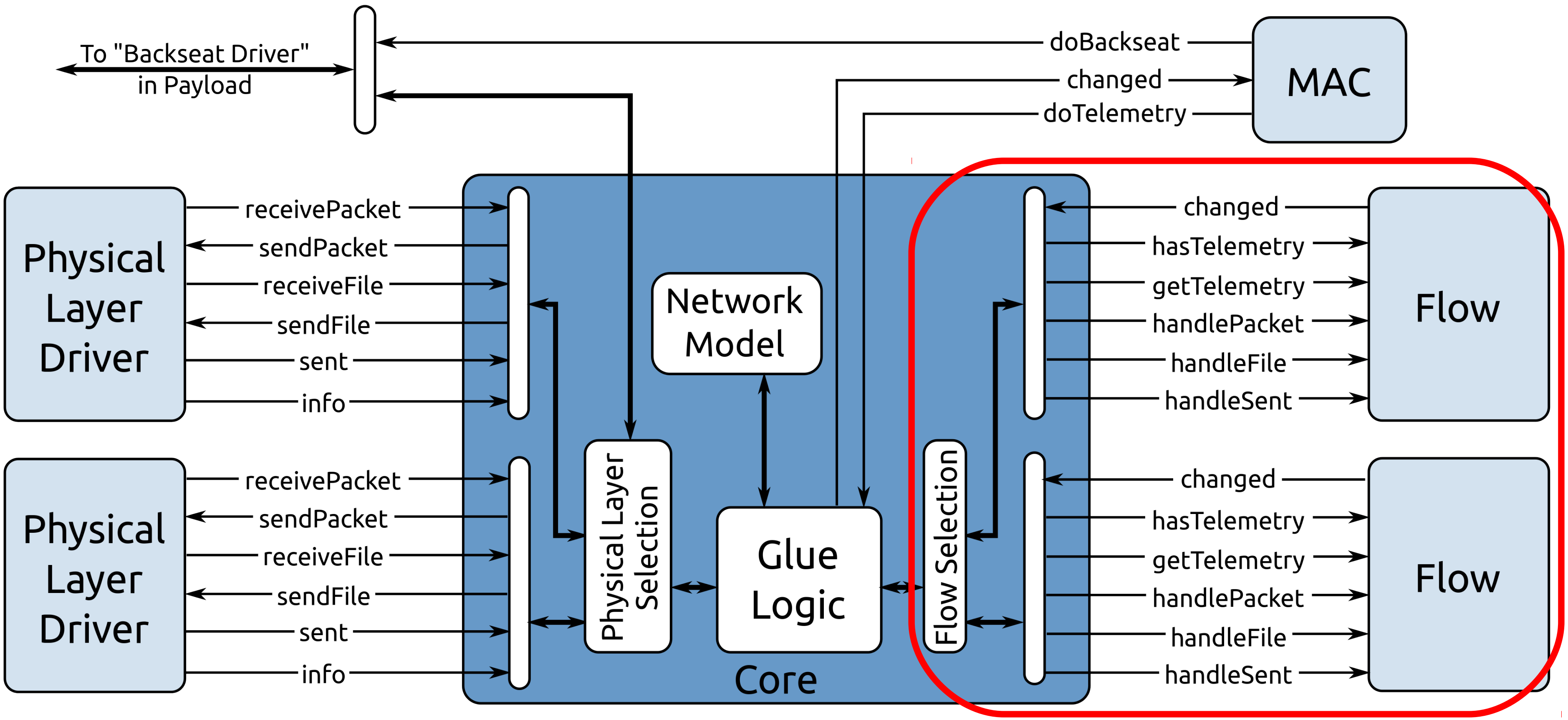


Data Flows (Application Layer)



Data Flows (Application Layer)

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Flows Independently Produce and Consume Data

All capabilities are implemented within separate Flows

Examples: VehicleStatusFlow, VehicleCommandFlow, USBLDownlinkFlow

Flows Manage Their Own Traffic

A variety of queuing strategies are used, depending on traffic type

Modular.

Image Transmission Flow?

Twitter Gateway Flow?

Compressed Audio Flow?

CAD / CAC Flow?

...

Flows Communicate to Vehicles, Not Modems

Flows do not need to know specific hardware addresses – only a vehicle identity

All Traffic is DCCL

All the messages in and out of flows are DCCL.

DCCL ↔ SOMA Interface

Protobuf

```
message Status {
  required float latitude = 10;
  required float longitude = 20;
  required float depth = 30;
}
```

Protobuf File With DCCL (*.proto)

```
message Status {
  option (goby.msg).dccl.id = 37;
  option (goby.msg).dccl.max_bytes = 64;

  required float latitude = 10 [
    (goby.field).dccl.min = -90,
    (goby.field).dccl.max =  90,
    (goby.field).dccl.precision = 5
  ];

  required float longitude = 20 [
    (goby.field).dccl.min = -180,
    (goby.field).dccl.max =  180,
    (goby.field).dccl.precision = 5
  ];

  required float depth = 30 [
    (goby.field).dccl.min = 0,
    (goby.field).dccl.max = 11000,
    (goby.field).dccl.precision = 1
  ];
}
```

Protobuf + DCCL + Bluefin SOMA Extensions (*.proto)

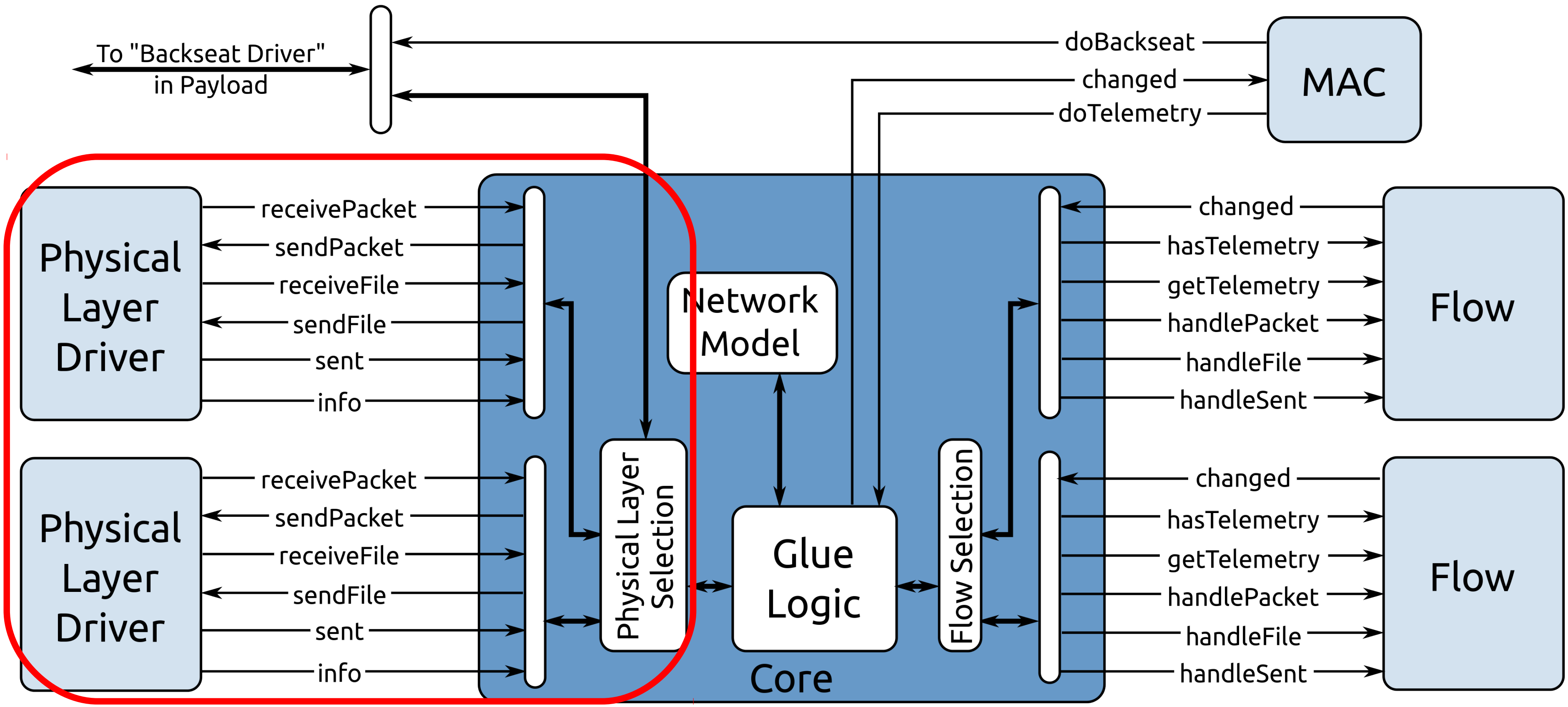
```
message Status {
  option (goby.msg).dccl.id = 37;
  option (goby.msg).dccl.max_bytes = 64;

  required float latitude = 10 [
    (goby.field).dccl.min = -90,
    (goby.field).dccl.max =  90,
    (goby.field).dccl.precision = 5,
    (bluefin.field).somachannel = "*/navState.latitude/*",
    (bluefin.field).quantityas = "deg",
    (bluefin.field).somagroup = 1
  ];

  required float longitude = 20 [
    (goby.field).dccl.min = -180,
    (goby.field).dccl.max =  180,
    (goby.field).dccl.precision = 5,
    (bluefin.field).somachannel = "*/navState.longitude/*",
    (bluefin.field).quantityas = "deg",
    (bluefin.field).somagroup = 1
  ];

  required float depth = 30 [
    (goby.field).dccl.min = 0,
    (goby.field).dccl.max = 11000,
    (goby.field).dccl.precision = 1,
    (bluefin.field).somachannel = "*/tracking.depth/*",
    (bluefin.field).quantityas = "m"
  ];
}
```

Physical Layer



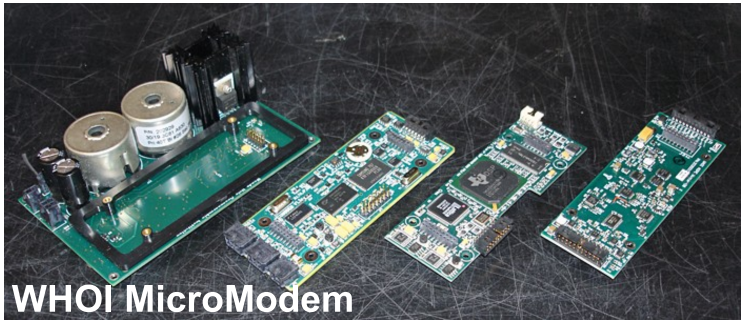
Physical Layer

Modem Hardware Driver Isolated from Capabilities
- Modem drivers do not understand the contents of transmissions
- Interface is fundamentally packet based
- Modem drivers may implement a file transmission interface

Vendor Independent Interface Between Driver and Capability Implementation
- e.g. – SendPacket(packet, destination, requestAck, telemetryRate)
- First implementation – Sonardyne AvTrak6

Hardware Drivers Operate in Terms of Hardware Address
- Modem drivers don't know or care which vehicle a modem is attached to

Concept of "Primary Device" In TOPICS Core
- One (switchable) modem used for transmission
- All modems used to receive
- Redundancy!


WHOI MicroModem


Sonardyne AvTrak6

Glue / Network Model

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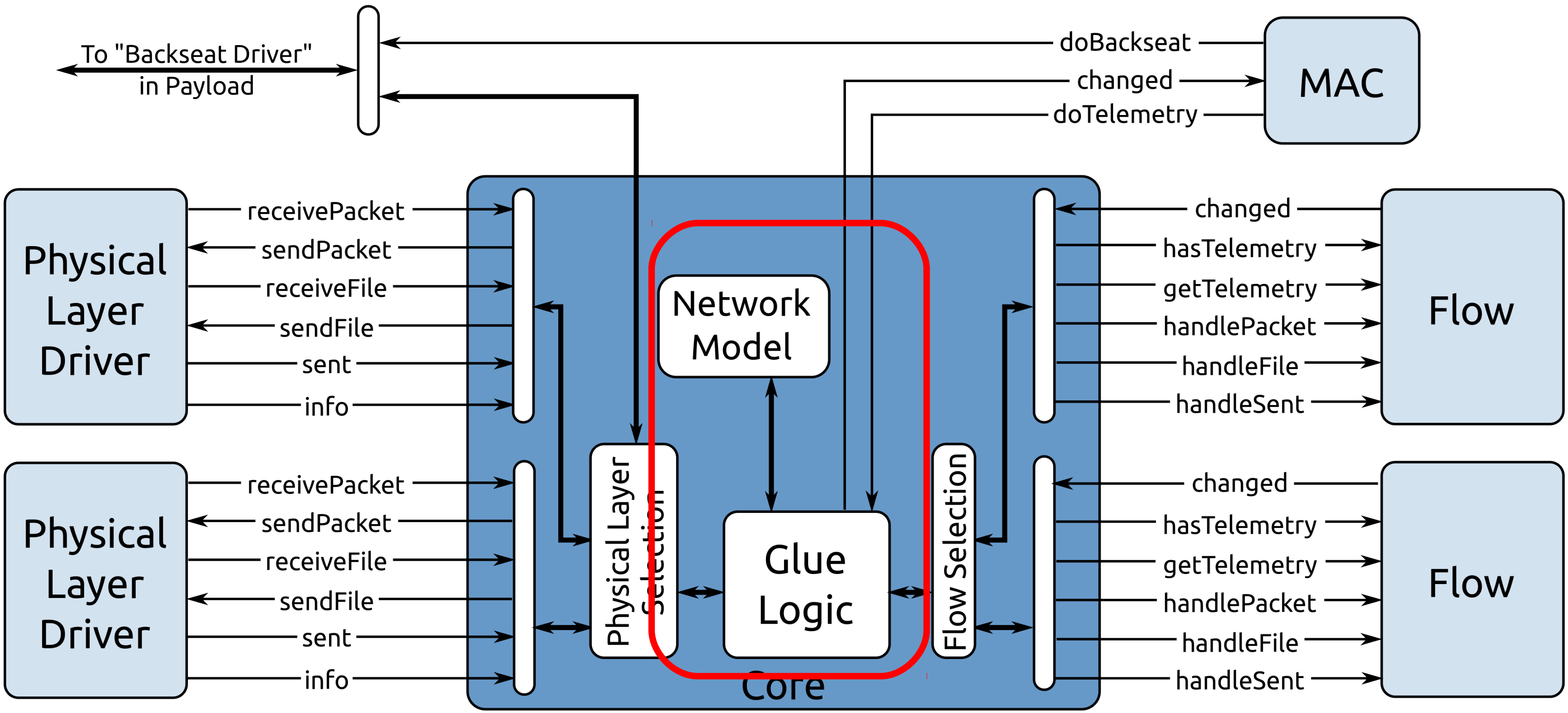


Glue / Network Model

Data Flows Speak "Destination Vehicle"
Application layer identifies a destination

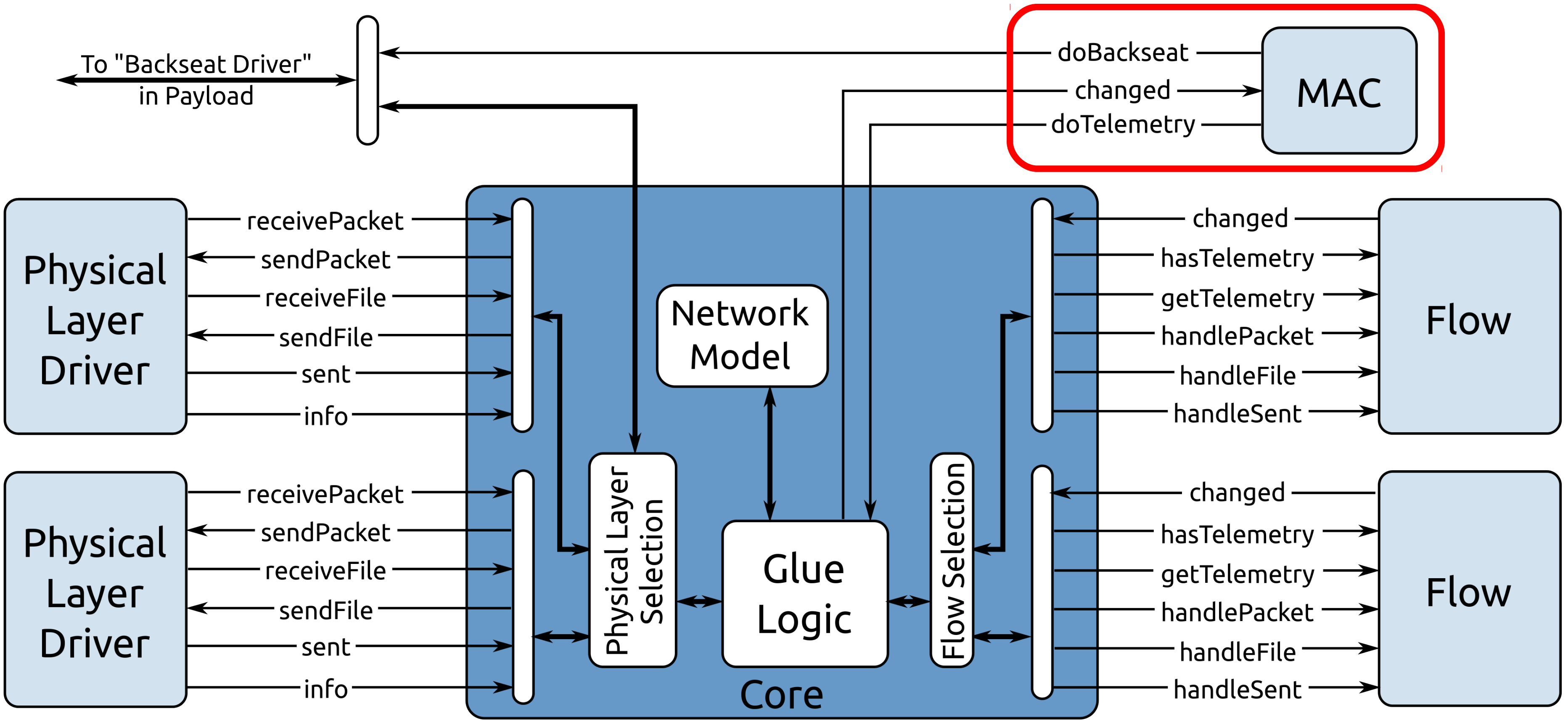
Physical Layer Speaks "Hardware Address"
Modem drivers don't know or care which vehicle a modem is attached to

Network Model provides Modem ↔ Vehicle Mapping
Supports arbitrary number of vehicles
Assumes a priori list of nodes and modems

Switchable "Primary" Modem and Destination
Surface operator can switch which modem is used for transmission
Surface operator can switch destination of packets

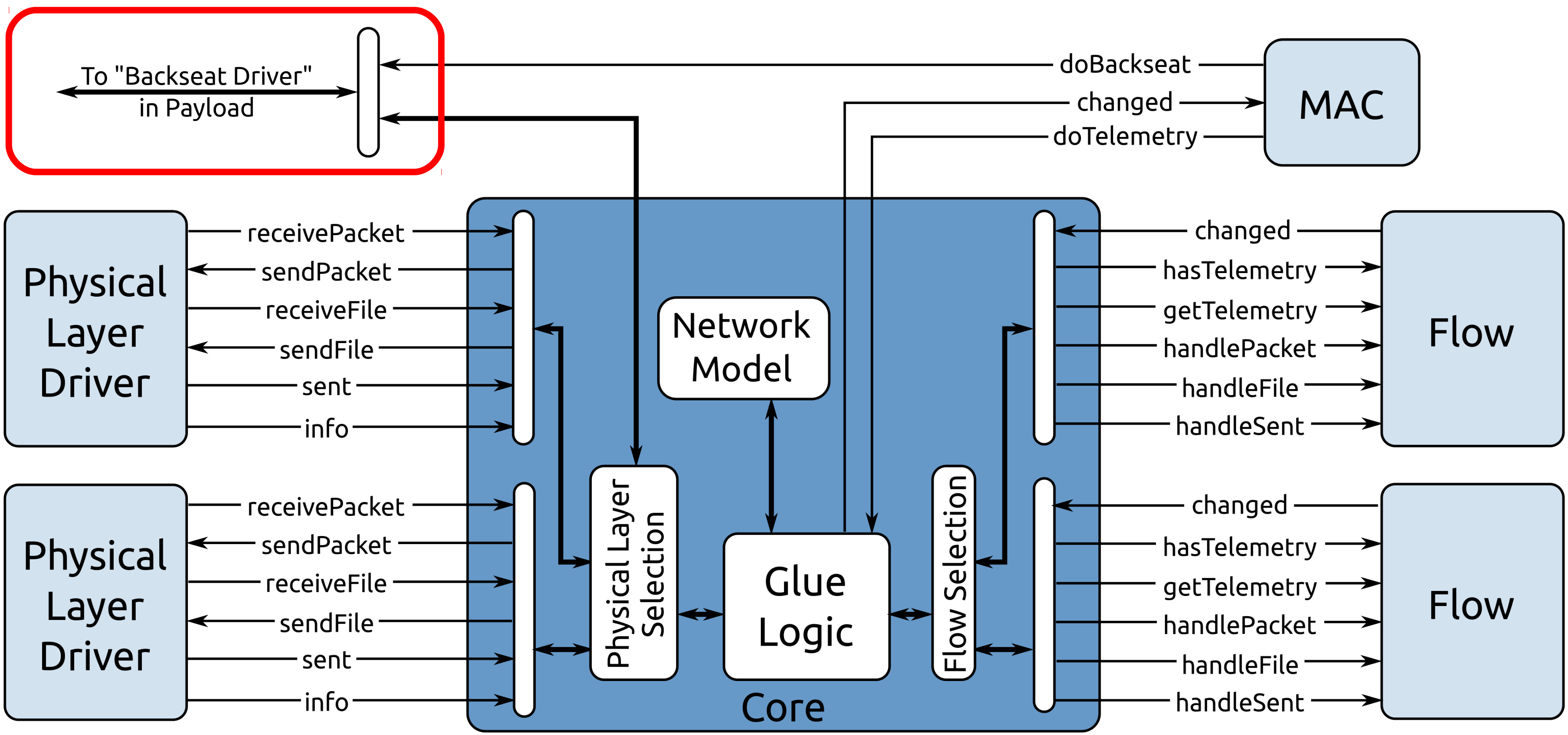

Bluefin 21" AUV with Dual AvTrak6 HP

MAC



Only indicates when transmission may occur
Currently just a schedule
Lots of room for future creativity here (ours, or yours!)

Backseat Driver



Payload Autonomy Support

Supports "Backseat Driver" Paradigms

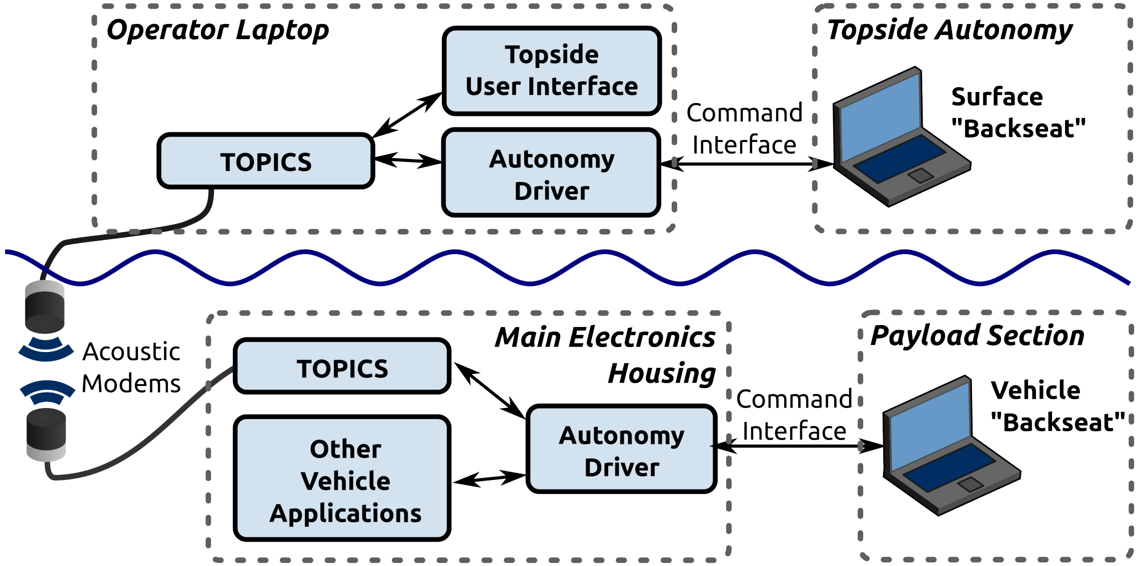
- Academic users experimenting with advanced autonomy
- Researchers experimenting with MAC / acoustic protocols

Exposes Same Hardware Interface We Use

- Same parameters, same capabilities, same (TCP) interface on vehicle and surface
- Rely on low-level modem capabilities, without worrying about driver implementation

Leased "Time-Window" Operation

- Within time window, payload can implement own MAC scheme / protocols
- Time-limited lease, can be rescinded for vehicle safety reasons



Highlights

Hardware isolated from capability implementation

Multiple (redundant) acoustic modems per vehicle

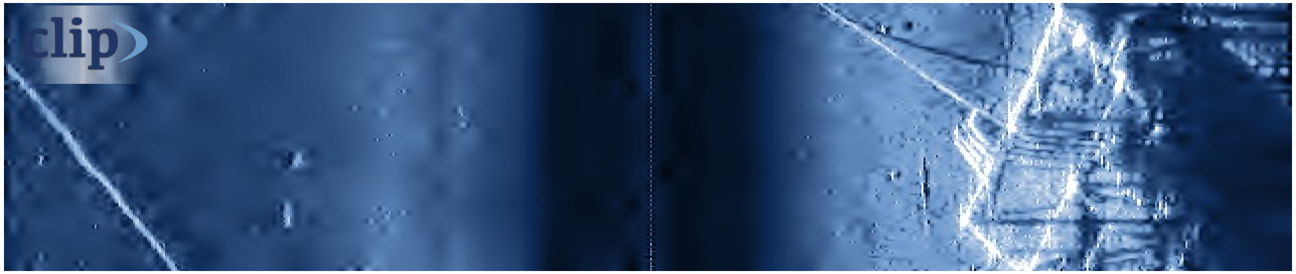
Multiple vehicle support

Compression a design priority

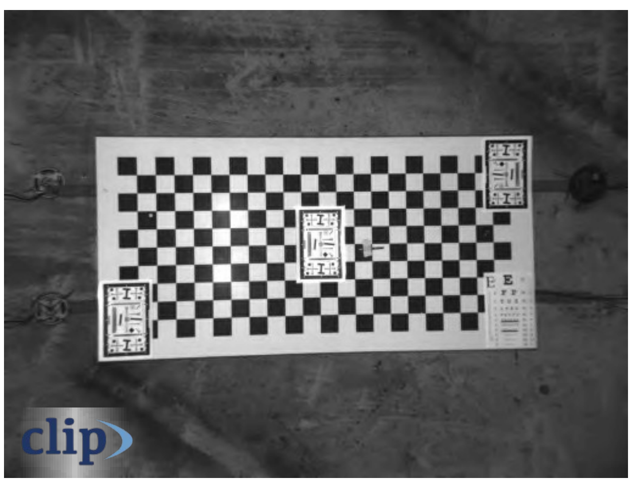
Builds on open source / open standard (DCCL)

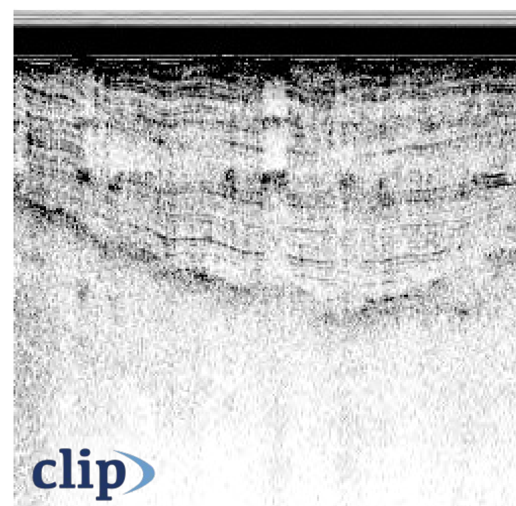
Modular to facilitate development of specific capabilities

"Backseat Driver" Autonomy Support



BLUEFIN witness





What?

Witness communicates

imagery clips

to operators

via acoustic modems

Why?

- To **verify** payload data quality
- To **tune** payload parameters
- To **adapt** missions based on data
- To **explore** extreme environments

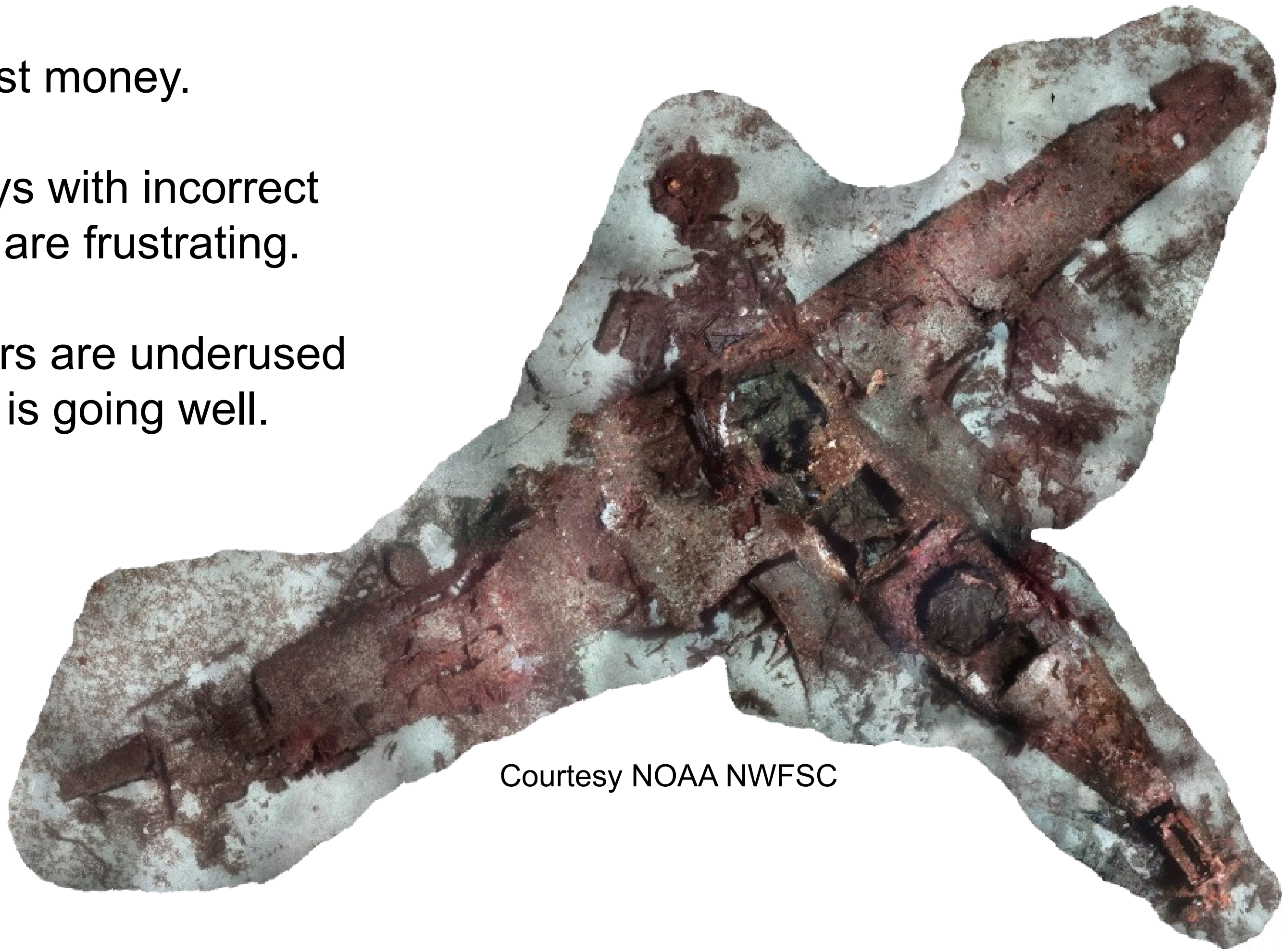
(Roughly in order of difficulty)

Verify and Tune

Wasted dives cost money.

Multi-hour surveys with incorrect payload settings are frustrating.

Humans operators are underused when everything is going well.

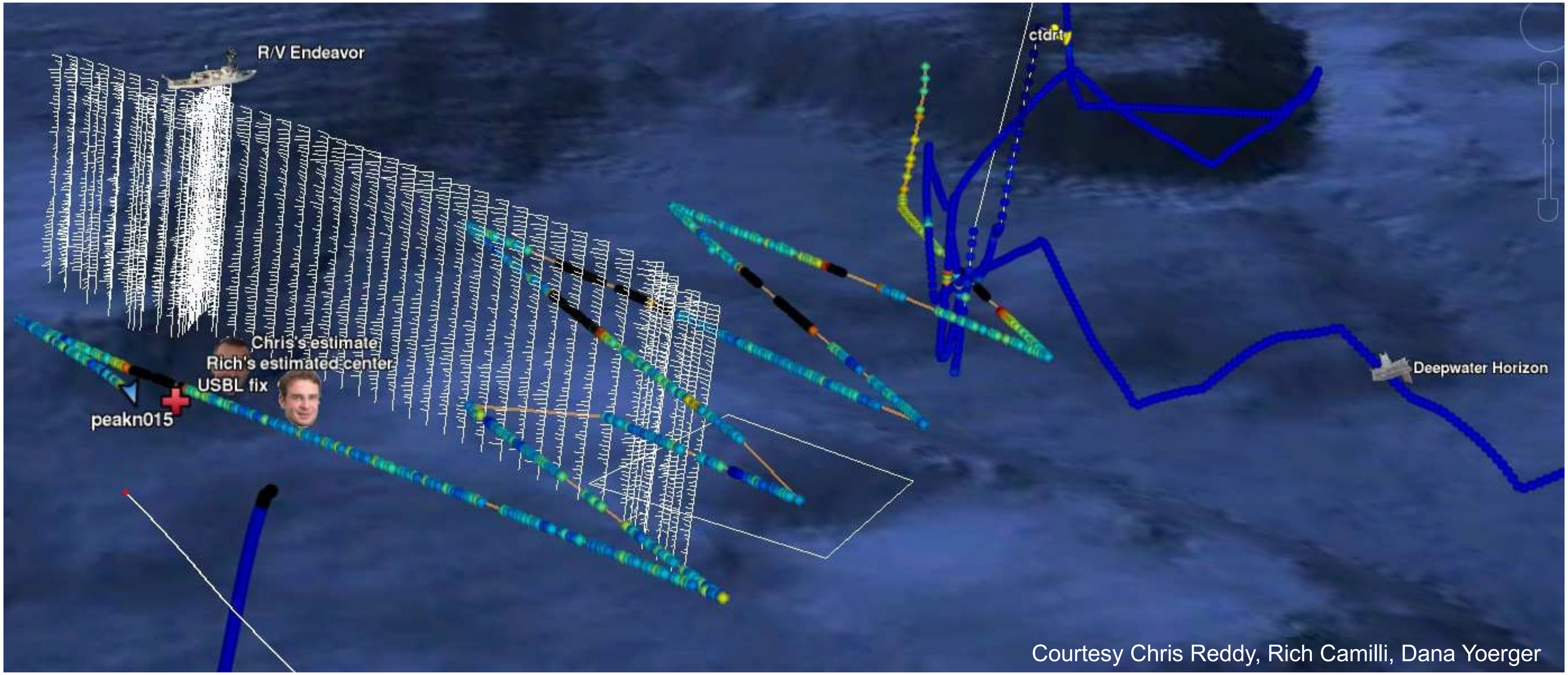


Courtesy NOAA NWFSC

This is what we're working on **today.**

Adapt and Explore

“Second dives” are impossible in some environments.
Loss of a robot may be an acceptable risk, if data can still be recovered.



These cases are for **the future.**

How?

- **TOPICS:** Bluefin's subsea communication architecture
- **Sonardyne 6G** acoustic modem
- Subsea **Payload Data Processing**
- Advanced **Wavelet Compression** algorithms
- HTML5 Tablet-friendly **User Interface**

How – The Steps

Step 1: Decode sensor data in-situ

Step 2: Perform sensor-specific pre-processing

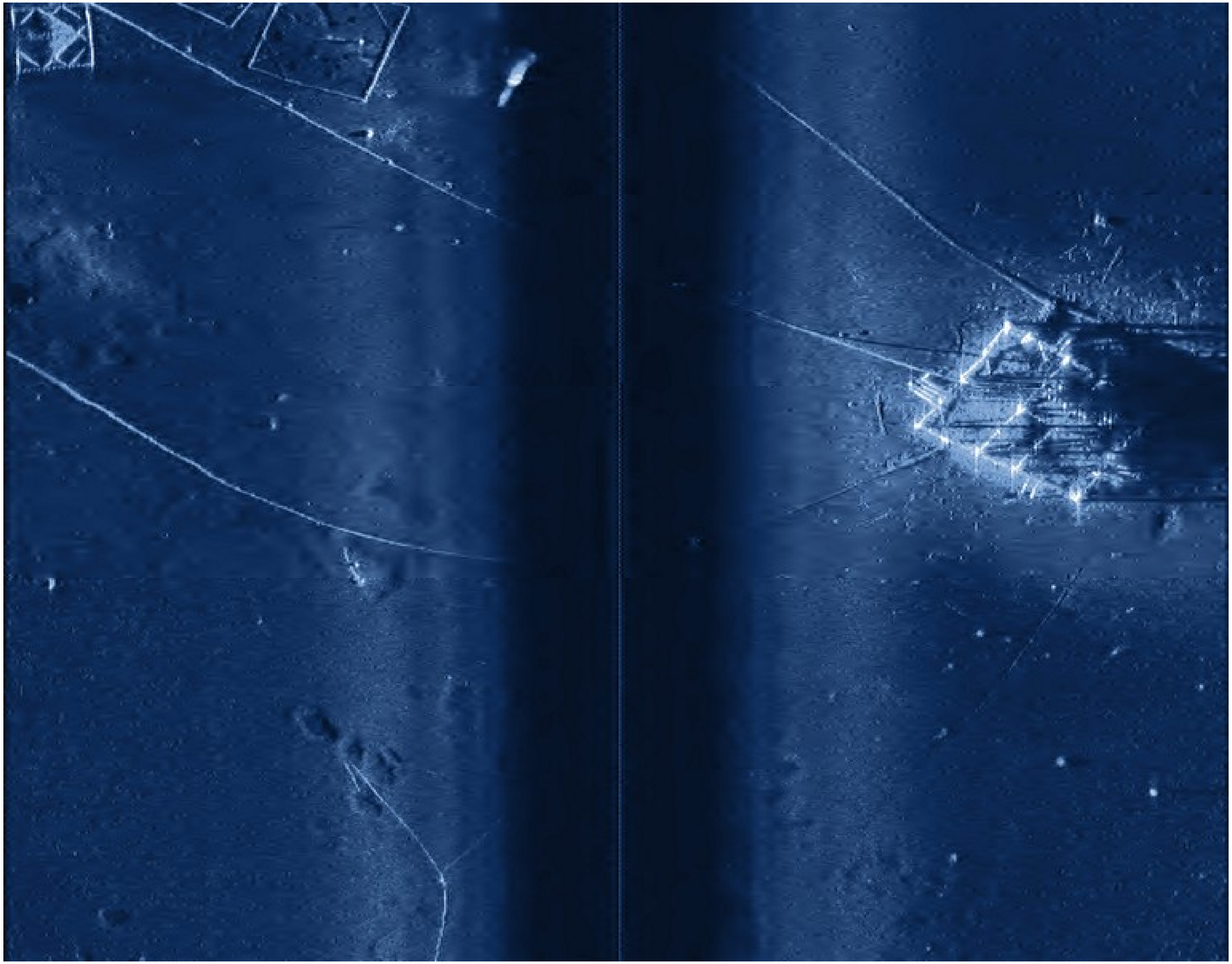
Step 3: Convert data into an image

Step 4: Compress image

Step 5: Transmit image & metadata to surface

Step 6: Display it to the user

Wavelet Compressed Imagery



Per Clip:
5184 Bytes

Total (3 Clips):
25920 Bytes

Browser-Based User Interface

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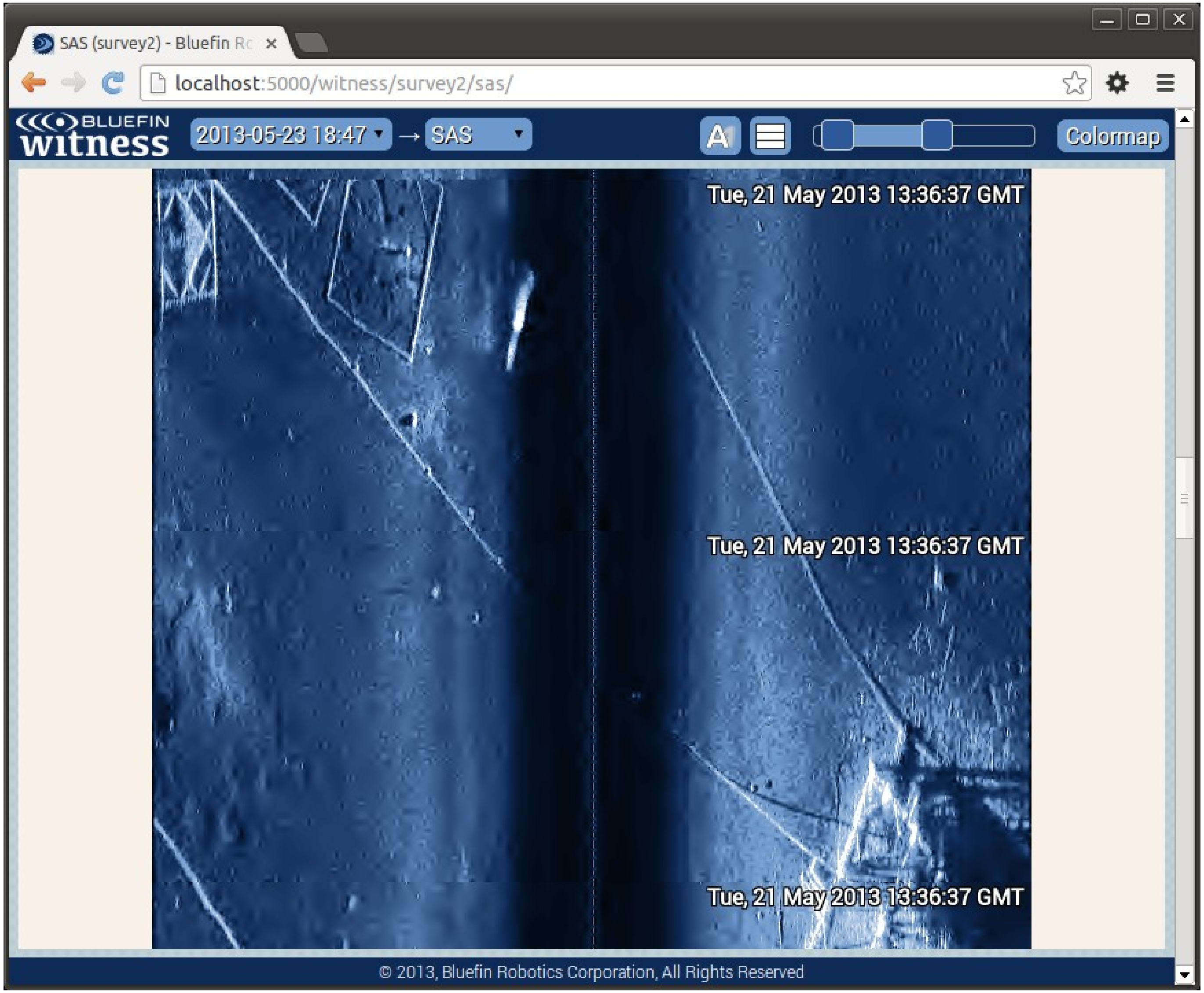

BLUEFIN witness

Thank you!

Questions?