AUV + `WaveGlider` communication scenarios

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1 Problem Definition

We try here to explore how the `WaveGlider` could be used as a communication relay between deployed AUV(s) and the shore or a ship. The general idea is to replace the expensive — either financially or in term of energy required — and limited — iridium satellite connections with a more pervasive data point. While ideally the `WaveGlider` could be always connected to the shore (using for example a wireless data plan to send data as it come though) it is probably more realistic in general to consider it more as a proxy that stores data from an AUV operating nearby until it is connects to the wider world. In such a case, on connecting to the net, it can flush whatever data is currently cached (using for example some sort of `rsync` mechanism between its data and the shore).

The usage of the `WaveGlider` will be often considered in our scenario as *bi-directional* where not only messages from an AUV but also new objectives/missions from shore to it will transit through the `WaveGlider`. While it may not be efficient in some cases and make for a brittle network[1], it simplifies many considerations at this stage and specifically ensure that `WaveGlider` is aware of what the AUV is supposed to do.

Our general problem can be defined as follows: *(How)* can we use the `WaveGlider` as a means to improve communication between the shore and AUV(s) deployed? This of course while ensuring better results than ad-hoc communication using a satellite connection. Possible communication schemes available on the AUV are limited in term of their range, their bandwidth or the condition they can be used (most radio communication cannot be used

[1] Indeed a failure of any point with the `WaveGlider` results on no communication at all

underwater). Table 1 shows what some of these systems can provide in term of effective average bandwidth during a AUV mission assuming that the AUV surfaces for 1 minute every half hour. It is clear that there is a tradeoff between the range of communication and the amount of data that can be sent in an hour. In fact the only technology that would be reasonable for remote communication are either satellite or possibly for near shore operation wireless network communication such as EDGE. Which both due to the fact that the vehicle is underwater most of the time exhibits the lowest effective bandwidth[2]. These techniques do not allow sending very large data sets for long missions in a sustainable way. It is also worth noting that all the data presented here are idealistic; our experience has demonstrated that establishing a communication from an AUV in calm seas can be pretty difficult thereby impacting even these theoretical findings.

	Bandwidth (kbps)	AUV effective (kbph)	Limitations
Iridium	2.4	278.7	surface
Freewave	115	18000	surface, 2km
EDGE (max)	59.2	6874.8	surface, near coast
EvoLogics 18/34	up to 13.9	48425.8	medium range, 3.5km
EvoLogics 48/78	up to 31.2	108696.8	shallow, 1-2km

Table 1: Bandwidths from different communication possible on the AUV. The AUV is effectively at the surface for 1 minute every 30 minutes.

One expected benefit of using the `WaveGlider` is to provide a proxy with permanent communication to the shore. Table 2 gives a picture on how using the `WaveGlider` as a dedicated proxy between AUV and shore positively impacts the effective amount of data that can be sent from the AUV to shore. By just having the `WaveGlider` equipped with an Iridium modem and be able to connect with the vehicle by any other means, we improve the data rate by a factor of 30. Using EDGE connection instead is then only bounded by the effective communication bandwidth between the AUV and the `WaveGlider`.

While acoustic comms with EDGE presents the largest potential bandwidth this can vary substantially depending on the relative position of the two assets. In addition this technology can be very energy intensive (5 – 35

[2]It is also the 2 technologies that have a direct financial cost per data sent

	AUV to WG (kbph)	WG to shore (kbph)	Effective
Freewave + Iridium	18000	8640	8640
Freewave + EDGE	18000	213120	18000
Evo 18/34 + Iridium	48425.8	8640	8640
Evo 18/34 + EDGE	48425.8	213120	48425.8
Evo 48/78 + Iridium	108696.8	8640	8640
Evo 48/78 + EDGE	108696.8	213120	108696.8

Table 2: Bandwidth for comms from an AUV to `WaveGlider` and `WaveGlider` to shore. "Effective" considers that the AUV is always in range of the `WaveGlider` and that `WaveGlider` connection to shore is always available.

Watts for signal emission in good conditions and a little more than 1 Watt for reception). Therefore I think that most of our experiments should be covered efficiently using a simple freewave communication. While this constrains communication at the surface the range is usually larger than other approaches and the power consumption is better (often 5 Watts or less).

Even though acoustic comms can be considered further down the line provided that we need to send more data[3].

2 Incremental scenario

The main limitation in communication between the AUV and the `WaveGlider` is its range. We propose therefore, to start with simple scenarios that ensure that each asset stays in near-proximity and to eventually go to more complex scenarios with rendezvous points which can be either pre-decided (in term of location and time window) or identified autonomously.

2.1 `WaveGlider` as master

This first scenario relies on the drifter following missions already executed with `T-REX` in the recent past. The `WaveGlider` will act as the "drifter" and

[3] A quick look at the data we sent so far along with extrapolation based on 1Hz sending of basic sensor data suggests that 8640 kbph (or 1MB per hour) is more than enough and would be too expensive though Iridium anyway

the AUV will follow it by moving around it within a reasonable range (1km or so).

At first the `WaveGlider` can just act as a communication relay and the construction of a new goal for the AUV is still done on shore based on `WaveGlider` position and speed. This allow testing how much communication can be done without having to take into account the risk of not having the assets in range.

We can then refine it further by setting `WaveGlider` as an active master as it redirects the AUV autonomously without shore involvement and continues to send all the contextual data from the AUV to shore. Further one can picture to simply redirect the `WaveGlider` which will result on the AUV following it without need of reconfiguration.

2.2 AUV as master

This scenario can be tricky as the `WaveGlider` is slower than the AUV. Which mean that it cannot keep up on the AUV on a straight line. Therefore the `WaveGlider` should find the best shortcut to be close enough to the AUV on a future time.

One proposed scenario relies on the AUV doing a lawnmower pattern and the `WaveGlider` trying to find a next location to go to using this pattern, where it can arrive before the AUV and wait for it to surface as illustrated in Fig. 1. This scenario adds complexity on both sides; in order to decide its next waypoint the `WaveGlider` needs to know what is the likely future path of the vehicle in a reasonable time. Conversely the AUV may surface outside of the comm range of the `WaveGlider` (for example in the northern part of our lawnmower in Fig. 1) and needs to keep this data for next potential window.

This scenario does not ensure constant communication between the two assets and becomes more challenging as the AUV survey becomes closer to a straight line. This may require exploring some coverage planning of the `WaveGlider` which uses the AUV projected path to compute the best trajectory to follow in order to ensure the best communication coverage along the mission. This makes it even more chalenging when the AUV path is not known a priori.

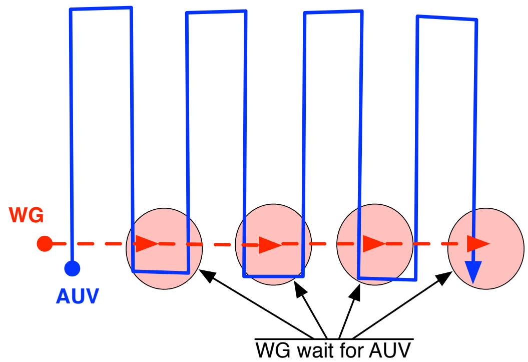

Figure 1: Example of scenario where the `WaveGlider` attempt to follow the AUV

2.3 Rendezvous interleaved within mission

The issue of the scenario presented so far is that they force the two assets to be in the same neighborhood during the full scope of the mission. A more flexible scenario would be to have only specific places and time windows where the two assets can meet. Meanwhile each asset can engage in its alternate tasks.

An example is having the `WaveGlider` used as a proxy for multiple assets (eg deep water comm for Brian Keift's project and data collection for the AUV). It then goes periodically between the two with the rendezvous for Keift being at a fixed location but can be done at any time while the rendezvous with the AUV can change location while constrained by periodic time windows.

The `WaveGlider` will then have to schedulle the best way to go back and forth between the multiple rendezvous points while the AUV will have also to do accordingly. Scientifically, this can be problematic as these communications alter the survey of the AUV by inserting these communication transits. Still these points can be set so they are limiting the impact in term of continuity of the survey. As this first scenario consider predfeined communication it is usefull to both anticipate the impact and check the feasibility (for example if the survey area is too far from where the underwater comm is, it may not be posible for the `WaveGlider` to do both).

An even more refined solution is to consider these rendezvous as being set dynamically as each asset has new data to exchange. For example the reception of the`WaveGlider` of a new mission for the AUV will make it initiate a rendezvous or conversely this can be intiated by the AUV having collected data it deems interesting. As illustrated in Fig. 2, we consider that both assets use Iridium communication to organize/negotiate a rendezvous and then autonomously alter their plan to go to this place and exchange the information they need to. Iridum communication is only used for negotiation between the two assets which ensures a lightweight data exchange while the more heavy information will be exchanged on a faster netwrok during the rendezvous.

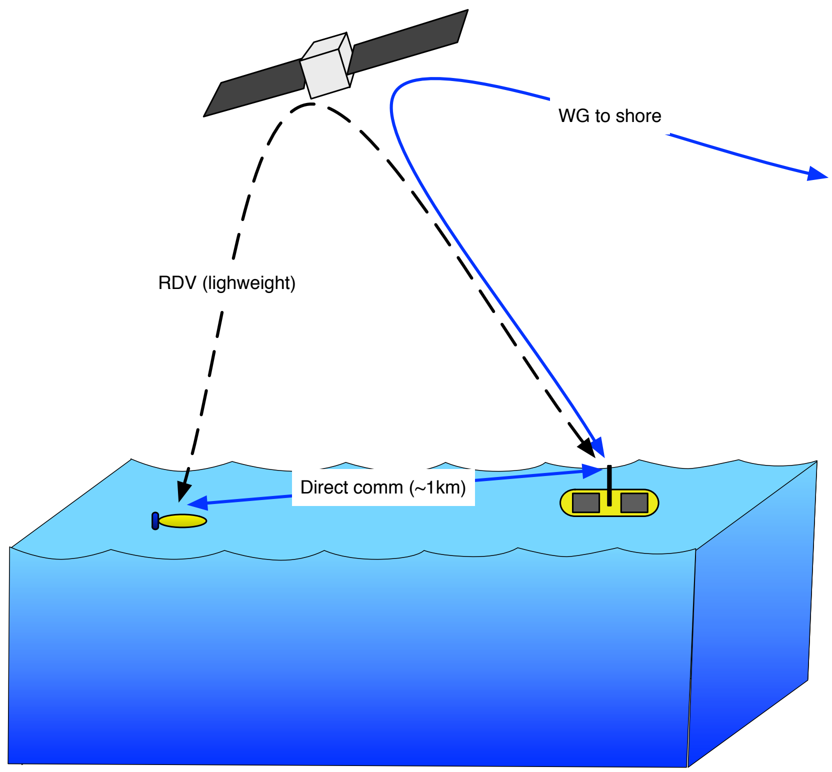

Figure 2: Dynamic rendezvous communications path. Blue lines are the comm links that transport meaningful information while the dashed lines indicate the data link used only to set a rendezvous. In this figure we consider that the link for `WaveGlider` to shore is through satellite, it could have been also through a 2G or 3g network when near shore.

This last scenario is in my opinion what we need to aim for it can be challenging but potentially provide a more dynamic solution that may also be extended to a situation where we have multiple AUVs and multiple `WaveGlider`s. In such a scenario all the assets could be used as data mule ensuring then a dynamic mobile ad-hoc network (for example one `WaveGlider` A reciving a message for the AUV B can delegate this message to another `WaveGlider` C which is closer to B and so on until the message reach its destination).

3 An Implementation Plan

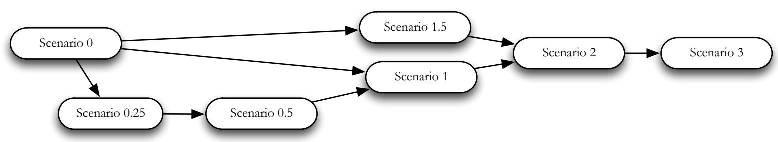

Figure 3: An approximate timeline and temporal dependency between the tasks below.

The overall idea is to ensure we have a viable plan of action to make operational use of the `WaveGlider` both as a communications 'hotspot' and as a means for demonstrating coordination techniques for AI Planning. The notion of the hotspot, is to have the `WaveGlider` as a focal point of communication between different assets in a field experiment. Currently while the `Dorado`is the intended coordination target, the steps we take ought to ensure that the architecture can scale to including heterogenous (underwater, surface and aerial) assets, as well as assets not belonging to and traditionally not operating out of MBARI. One specific point of coordination in this context is UPorto with their Seacon AUVs which are likely to participate in future `CANON` experiments.

With regard to autonomy specifically, the plan here is with respect to the use of `T-REX` whether onboard or on shore using the `ODSS`. What is important is that we are able to make a credible demonstration both to ourselves and to the MBARI MT, that we're on the path towards doing what we promised we would for 2013 irrespective of constraints imposed.

Fig. 3 shows an approximate dependency with demonstrating scenario 0 and 0.25 being somewhat co-temporal.

Date	Activity
~~April 10 and 26~~	Request to DMO to postpone
June 12^{th}	
July 11^{th}	
Aug 26^{th}	
Sept 4^{th}	
Oct 10^{th}, 14^{th}, 17^{th}, 21^{st}	
Dec 17^{th}	

Table 3: Table to be filled

3.1 Secenario 0

Dates: March end, April

- Demonstrate and characterize the use of freewave as a communication methodology by using the `WaveGlider` and using the *Paragon* with a hand-held freewave modem attached to a laptop. The hand-held modem mimics the `Dorado`.
- Measure in different wave conditions to characterize the bandwidth and link robustness with a freewave instrumented `WaveGlider`.
- Repeat over 2 or more days.

Following preconditions are necessary:

1. Two spare freewave modems. If the spares don't exist and/or are not available
2. The modem radio on the `WaveGlider` should be set up for multipoint communications.
3. This modem on the `WaveGlider` should be tested (on shore) with the freewave on the *Carson* when in the dock. The objective would be to ensure that this link with the config change works before setting out to sea in more involved experimentation.
4. The modem should be integrated on the `WaveGlider` as part of an autonomy task. The hand-held radio is configured like the `Dorado`.

3.2 Secenario 0.25

Dates: March thru April

- Work co-temporally with the task in Section 3.1
- Demonstrate that a freewave modem on shore can talk to the `WaveGlider` in near proximity. Test using Tom's office with an antenna nearby. Drive the `WaveGlider` from WGMS and perform experiments in distance from shore antenna and different environmental conditions.
- Build on this to use the shore-based SMC to write the freewave driver. See Section 3.3 below.
- Configure the freewave radio in multipoint mode to make sure it works with the `WaveGlider` at sea.

Following preconditions are necessary:

1. A suitable antenna can be found and rigged near by Tom's office (or some other convenient location facing the beach).
2. Proficiency of WGMS since more than likely the `WaveGlider` will be close to ship traffic from Moss Landing.
3. Suitable understanding of the C&C API.

3.3 Secenario 0.5

Dates: April and May

- Use the SMC (Sensor Mgmt. Computer) to demonstrate an SMC/C&C (Command and Control computer) client server applicability.
- `WaveGlider` ICD documents apparently shows the API to talk directly to the C&C. We should use this API first as a simple stand alone app to send lat/long from Tom's office to the `WaveGlider`. Then consider its integration into a UI within `ODSS` so people can pilot it outside `T-REX` control.

- In doing so, we initially rely on LRIs WGMS to get back all status messages (see user manual) and state information. In subsequent development, we incrementally return state updates from the C&C to the app, even if this means it just dumps into a log file.

- Doing the above, sets the stage for interfacing `T-REX` to the C&C, sending commands and receiving updates. Specifically the update mechanism should be configured to ensure that not just task completion, but other state info can be returned. This would be critical when and if we propose work on doing diagnostic information for re-planning and control with `T-REX` onboard.

- At the very least state info returned should include lat/long, status of umbilical to sub-surface glider and weather info from mast. If the radar reflector can be tapped for target range and bearing, that too might be useful for informational and potential path planning purposes even if the `WaveGlider` is slow to react and respond.

Following preconditions are necessary:

1. Adequate time and resources

3.4 Secenario 1

Dates: August thru December

Demonstrate the first simple interaction of 'coordinated' activity between a `WaveGlider` and the `Dorado`. This is the baseline demonstration that we ought to be aiming for, for 2013 based on the internal autonomy proposal.

- Use the scenarios starting in Section 2.1. This would demonstrate modeling capabilities within `T-REX` on shore which can make coarse-grained predictions on where the `Dorado` and `WaveGlider` could meet on the surface.

- Migrate to where the AUV is unconstrained and the `WaveGlider` is expected to 'arrive' at a location as in Section .

- Work closely with Porto and LRI to integrate multiple data link protocols and switching between the two. This would be a core functionality necessary for this project.

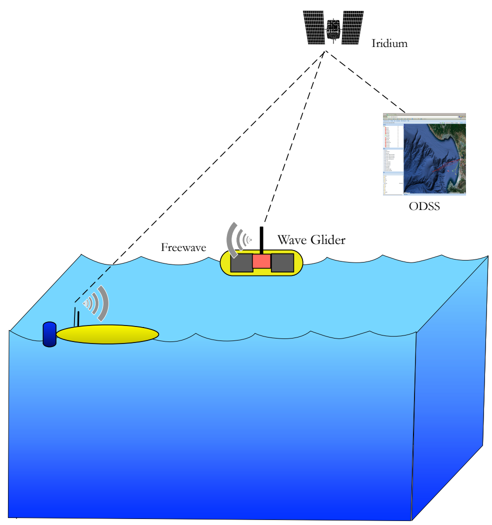

Figure 4: Communicate between the `WaveGlider` and the `Dorado` using free-wave to transfer CTD data (others?) from the `Dorado` and demonstrate multi-protocol gateway on the `WaveGlider`.

- My assumption is that this task will take up all the time and effort between other tasks planned for this year, including participating in REP.

3.5 Secenario 1.5

Dates: May thru August

This is a follow on to the task in Section 3.2 to make the `WaveGlider` fully standalone communication hotspot as originally envisioned in the comms scoping exercise and written into the 2013 autonomy MBARI proposal.

- A minimum objective is to demonstrate a gateway functionality which switches onboard data packets between 3G/4G and Iridium Rudics. Time permitting, the use of Globalstar as an alternative to Iridium comms would be worthwhile. However, 3G/4G is a far higher priority especially in the context of `CANON` field operations in the north bay.

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Following preconditions are necessary:

1. Scoping and obtaining the appropriate hardware for 3G/4G. As per Robert's message LRI has "integrated a COTS cell modem with the SMC". So obtaining this software and integrating it would be necessary.

3.6 Secenario 2

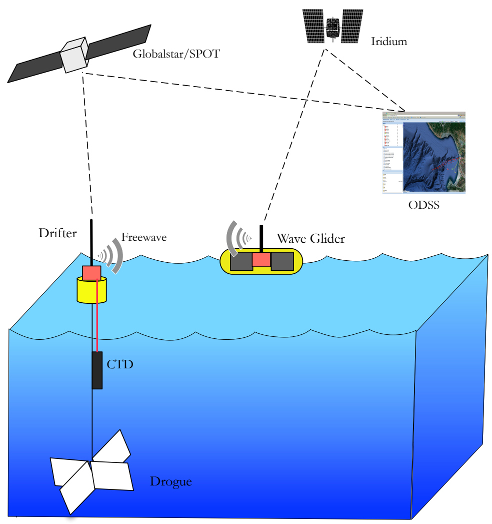

Figure 5: CTD is connected via a cable to the surface freewave modem on a Stella drifter which is continuously sending data to the `WaveGlider`.

Demonstrate the first simple interaction of 'coordinated' activity between a `WaveGlider` and a stella drifter, with the `WaveGlider` following the drifter. A CTD with a real-time readout will be hooked to the freewave and send data at the set sampling rate of the CTD.

Doing so will demonstrate the basic principles of mutability of the `T-REX` model from one vehicle (`Dorado`) to a very different vehicle on the surface. It will add another potent tool set for `CANON` science.

Following preconditions are necessary:

1. An appropriate CTD with a cable to the surface expression with the freewave modem.
2. Freewave modem would need to be encased in a water-tight box with a lead out for the antenna.

3.7 Secenario 3

Combine scenarios in Sections 3.6 and 3.4, to have a `WaveGlider` and `Dorado` moving around a stella drifter. It is unclear whether this scenario can be demonstrated given a lot depends on the smooth functioning and execution of all the above scenarios as a minimum.

4 Near-term ops and ideas

From Tom O'Reilly:

Tasks leading up to April 17 deployment:

1. Integrate FGR2 and antenna with WG/SMC [Maughan, Coenen]

2. Setup "testnode" consisting of FGR2/antenna connected with Linux/MacOS computer; testnode acts as stand-in for AUV or UAV in early tests [O'Reilly]

3. Setup onshore WG-to-testnode communications test environment (e.g. in high bay?) [Chaffey, Maughan, O'Reilly]

4. Ramp up on WG SMC software environment, FGR2 interfaces and APIs [O'Reilly]

5. Refine April 17 hot spot scenarios [OReilly, Maughan, Rajan, Py, Chaffey]

6. Demonstrate WG SMC code update through FGR2 [O'Reilly]

7. Demonstrate transfer of simulated "mission script" from WG to test node, simulated "telemetry" transfer from test node to WG. Use rsync/scp/ssh or DTN as appropriate. [O'Reilly]

4.1 2013 **OReilly Ocean Hotspot software tasks**

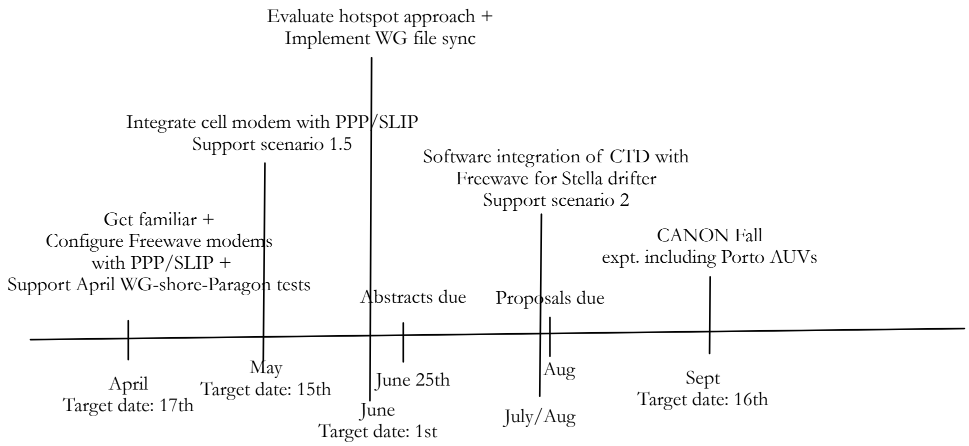

Figure 6: Suggested timeline of work based on Tom O'Reilly's task list. Note the temporal location of the drifter/tracking experiment prior to full MBARI proposals due.

Here is additional detail in terms of what Tom considers needs to be done in terms of Comm Hotspots from his end. Note that tasks are not yet ordered within a given priority level. Fig. 6 visualizes the timeline.

1. Get familiar with WG onboard software development environment (5 days)

2. Configure Freewave modems on WG and test node with PPP or SLIP Presumes that Maughan handles electrical/mechanical integration (1 day)

3. Support April WG-shore-Paragon tests; includes pre-deployment test support. Presume that Chaffey/Maughan handle electrical/mechanical issues. Supports Scenario 0.25. (10 days)

4. Integrate cell modem with PPP or SLIP Presume that Chaffey/Maughan handle electrical/mechanical integration Supports Scenario 1.5. (1 day)

5. Evaluate hotspot infrastructure approach (rsync/ssh vs DTN) Present rationales and trade-offs to team (5 days)

6. Implement WG file sync with test box via TCP/IP, rsync over Freewave (2 days)
7. Implement WG file sync with shore via TCP/IP, rsync over Rudics or cell modem (2 days)
8. Support Fall CANON 2013 Hotspot operations (10 days)
9. 6/25/2013 - Project abstracts due
10. Software integration of CTD with Freewave for Stella drifter experiment Presume Chaffey/Maughan handle mechanical/electrical integration Supports Scenario 2. (5 days)
11. Support Fall CANON 2013 Hotspot operations (10 days)

Lower priority 2013 tasks

1. Integrate Globalstar modem with PPP or SLIP Presume Chaffey/Maughan handle mechanical/electrical integration
2. Implement autonomous WG comms channel selection

Open questions:

1. What kind of antenna should testnode have?
2. RF safety issues with these radios/antennas?