AN INVESTIGATION OF OCEANOGRAPHIC PARAMETERS AFFECTING ACOUSTIC MODEM PERFORMANCE FOR HORIZONTAL DATA TRANSMISSION

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Abstract: *This study investigates the performance of underwater acoustic modems for long range horizontal communication in shallow water. The AQUAmodem, a frequency shift keying (FSK) based long range acoustic modem developed by Aquatec Group Limited is tested to maximum range in approximately 30m of water on the coast of Western Australia. Accompanied by high frequency noise recorders, data from the trial indicated the sea-bed modem received data effectively at up to approximately 7km in low power mode despite unusually large levels of ambient noise in the area. Communication breakdown for short ranges was found to be caused by long reverberation times, easing with range. When the propagation path was near vertical, modem reception was at the highest possible level. Results from this trial conclude multipath interference to be the dominant source of communication breakdown, as modems were able to operate over long ranges in low SNR environments.*

Keywords: *Underwater, Acoustic, Modem, Subsea, Communication, Telemetry, Multipath*

1. INTRODUCTION

Acoustic communication is a major contributor to subsea wireless telemetry, owing to the partial conductivity of seawater preventing efficient electromagnetic wave propagation. In many cases it has been used in relatively short range applications such as sub-sea sensor networks [1, 2], involving vertical transmission from the sea-bed to sea surface buoys. Data transfer to shore generally involves transmitting above the surface using radio waves due to its high speed and reliability.

This study seeks to aid in research for the oil and gas industry which is attempting to discard traditional forms of off-shore resource extraction methods by submerging all facilities. For this reason, conventional methods of system, environmental and pipeline monitoring need complete revision as RF transfer above the sea surface is no longer an option. This places a significant demand on the horizontal performance of acoustic modems to be used either primarily or as a backup system should an umbilical link fail.

The propagation of high frequencies involved in acoustics is complicated for horizontal transmission due to recurring reflections from the sea surface and sea bed arriving at unpredictable times compounded by refraction throughout a water column [3]. Data communication techniques have advanced considerably over the last decade to better adapt to these effects. However, emerging modems tend to use different principle encoding techniques and filtering, based mainly on the effects of the specific environment they are built for. It is even anticipated that this may compound problems further as an underwater communication standard is yet to be developed, creating the potential for modems in proximity to interfere with each other.

This study investigates the performance of an underwater acoustic modem designed for horizontal communication using frequency shift keying (FSK) techniques. By simultaneously measuring environmental parameters during telemetry, it aims to characterise the various mechanisms affecting transmissions.

2. TRIAL METHOD

For this study, the AQUAmodem from Aquatec Group Ltd was deployed to assess its performance for shallow water horizontal data transmission. Accompanying the modems during the deployment was external hardware built specifically to control and assess the modems during transmission. This included a Silicon Labs microcontroller used to communicate with modems via RS232 and added interfaces for integration with high level control via a PDA. This allowed high frequency recording of the signal using a high speed ADC, writing directly to USB flash disk. Whilst capable of recording at 192 kS/s, recordings for the deployment occurred in 20 minute blocks at 96 kS/s as the AQUAmodem utilises a low frequency range (7.5 - 12 kHz).

The trial was performed using a receiving modem deployed on the sea bed for the duration of the experiment with the omni-directional transducer facing directly upwards. The accompanying software recorded ambient noise whilst awaiting an acoustic command from a transmitter. All modem events were also recorded onto internal PDA memory. When the correct sequence was received, the modem responded with a similar short burst of acoustic data. The primary transmitting modem was configured to send an acoustic request every 20 seconds. Accompanied by a CTD profiler, this was lowered to typically half the water depth for approximately 10 minutes at various positions.

The deployment focussed on shallow water and was performed approximately 10km off the coast of Perth, Western Australia. The main transect was located over a 30m north-south depth contour. For investigation of modem performance over rugged terrain, the modems were also placed on either side of a collection of reef and rocks protruding from the sea surface. This is shown in Fig. 1. By using known bathymetry data for the area, the two dimensional propagation paths were extracted for each test position (TP). This is also shown, demonstrating the propagation paths for TP9 and TP11. The sea-bed substrate for the majority of the deployment was sand covering limestone. The maximum range was attempted at TP9 with a modem separation of 11.2km.

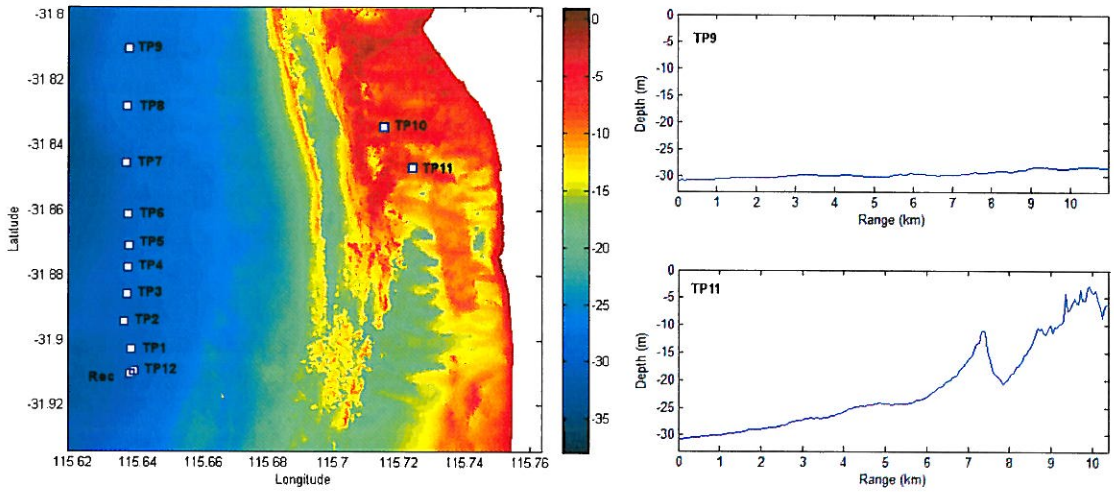

Fig.1: Trial area showing deployed positions of the receiver and subsequent testing positions for the towed transmitter (left). Extracted 2d propagation path (right).

3. COMPARISON MODELS

Acoustic modems typically operate over a limited bandwidth between 1-50 kHz. These relatively high frequencies simplify computational predictions by allowing the application of Ray Tracing [3]. The ray code used in this study was Bellhop, written by Mike Porter at HLS Research. In addition to typical ray code, Bellhop considers each ray as a Gaussian beam of energy decaying over its path. This gives predictions of transmission loss at a receiver position and is particularly useful to predict multipath propagation. After extracting the bathymetry for TP11 as shown in Fig. 1, ray tracing was used to simulate a 9 kHz signal transmitted through the two dimensional model. Rays for the shallow water environment are concentrated, giving transmission loss depicted in Fig. 2.

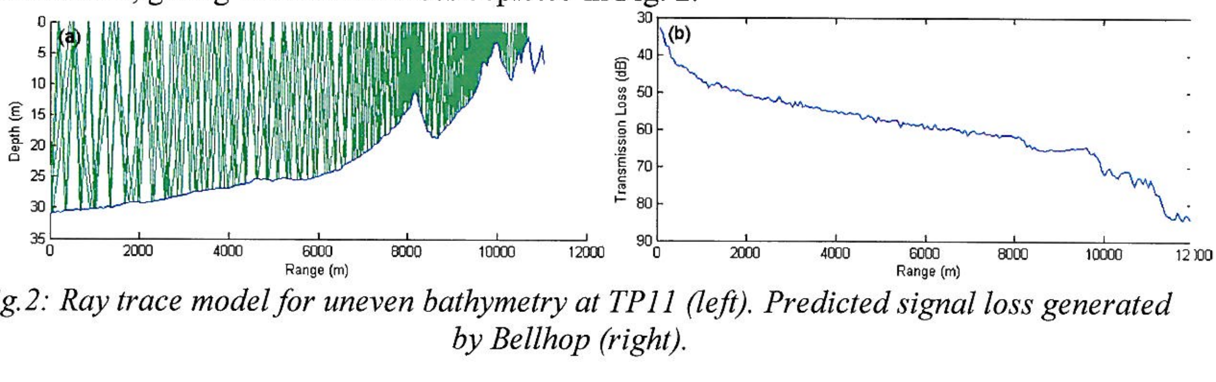

Fig.2: Ray trace model for uneven bathymetry at TP11 (left). Predicted signal loss generated by Bellhop (right).

Despite the long ranges, ray concentration at peaks shown in Fig. 2 (a) indicates signals converging at the receiver would place high demand on internal digital signal processing to correctly compensate with the effects of multiple arrivals. Transmission loss computation for receiver depth of 5m shown in Fig. 2 (b) indicates relatively uniform transmission loss throughout the shallow water environment typical of cylindrical spreading at range, despite the terrain.

4. RESULTS

During the trial, the transmitting modem did not report any successful communication with the receiving modem on the sea floor even when in close proximity and with signals clearly audible to the crew on deck. Whilst data was effectively transmitted to the sea-bed receiver, it was discovered that the response was not successfully decoded by the transmitter, resulting in a half-duplex communication link. A possible cause for this could be interfering vibration from the aluminium mounting plate on the sea-bed modem, as the systems were otherwise identical.

When analysing the reception at the sea bed, it was found that when transmitted horizontally, the signal was mostly undecodable by the receiving modem. However, as the range increased, telemetry resumed successfully. The success rate of the modems for each test position is shown in Fig. 3.

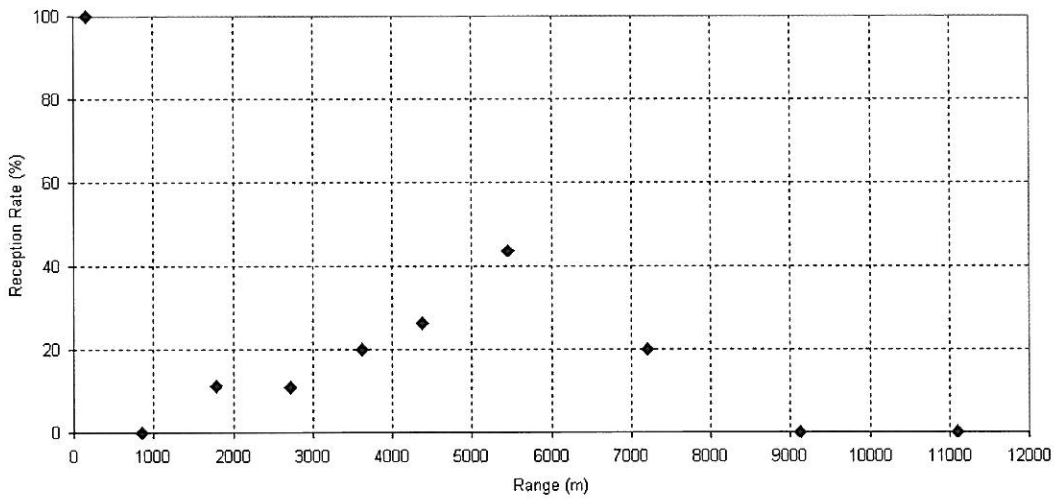

Fig.3: Reception rate for modem deployed on the sea-bed.

With the exception of near-vertical communication successfully receiving every transmission, performance of the modems gradually improved with increased range. The drop in reception beyond approximately 7km was followed by complete failure at further ranges.

Recordings from the sea-bed equipment were analysed to assess acoustics of the environment over the deployment period. It was discovered that several noise sources were present during the deployment, dominated by unusual amounts of vessel noise towards the end of the day. This was most likely due to deploying in close proximity of a local shipping channel, as well as a rare influx of recreational vessels in the area. Accounting for the drop in performance at TP7, the ambient noise level is depicted in Fig. 4 to exceed received signal strength over time during the communicating period. A summary of signal and noise levels is also shown.

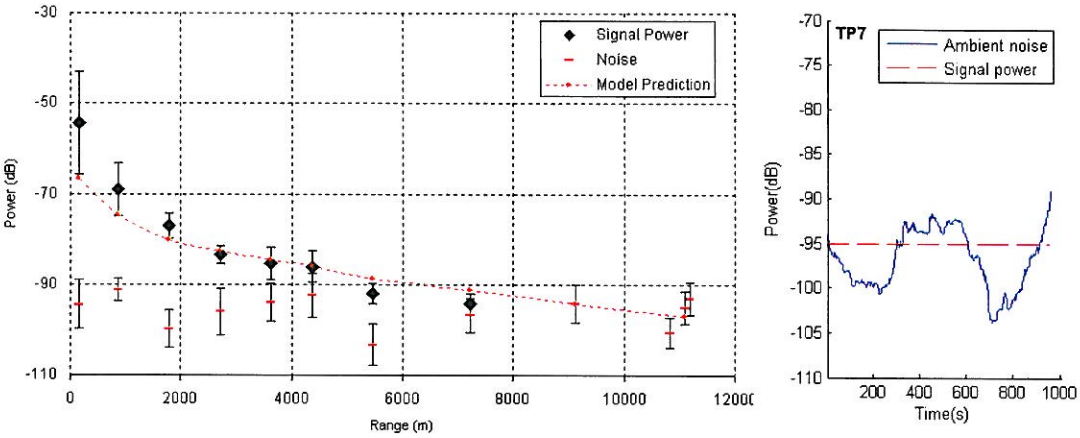

Fig.4: Summary of received SNR compared with model prediction for full transect (left). Noise trend during TP7 showing significantly varying SNR levels (right).

An expected drop in signal strength is exhibited as the modems were placed further apart, following the predicted trend. These results demonstrated SNR levels sufficient for successful transmission at ranges up to 7km, consistent with the modem reception rate. Additionally, the FSK modem performance is shown to be effective in low SNR environments. The modem performance drop for close range communication was found to be unrelated to SNR, also inferring multipath propagation interference at close range.

Signal reverberation was investigated by analysing the tail of received signals. In normal operation over the deployment, modems transmitted for 1.27 seconds. The time taken for the transmitted signal power of known length to decrease to one standard deviation above the noise floor was measured. Shown in Fig. 5, the reverberation time is shown to decrease with range, a negative correlation with successful communication.

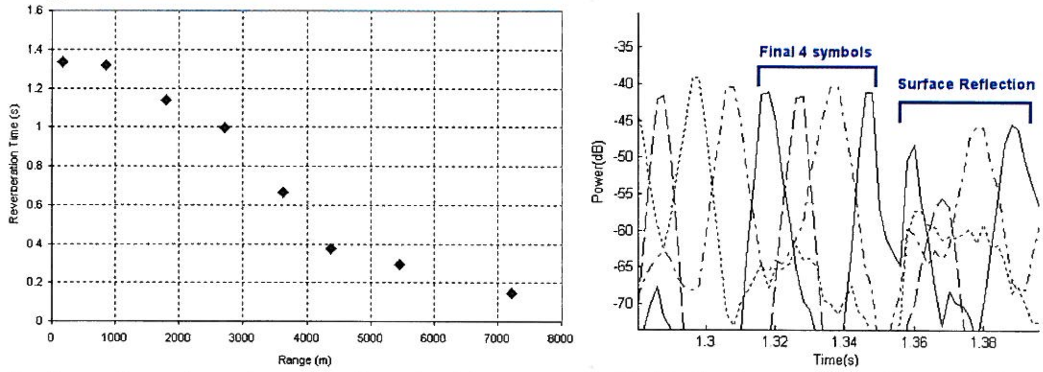

Fig.5: Reverberation time for signal with range (left). Tail of transmitted signal from sea-bed modem (right).

Maximum reverberation time during vertical transmission is expected, as reflections occur directly between the sea surface and sea bottom. As range extends beyond the depth of the water, it is shown that the column acts more like a waveguide and reception is minimally affected by long reverberation times. This significantly reduced inter-symbol interference, and modems were able to communicate effectively.

Upon closer analysis of signal patterns, the depth of water could be acoustically confirmed using the first reflection from the sea surface after a sea-bed transmission. Also shown in Fig. 5, following a signal termination, four symbols are clearly echoed in the same sequence as the final four symbols of the packet. The measured time delay of 42ms correlates with a depth of approximately 30m.

5. CONCLUSIONS

The shallow deployment of the devices caused significant multipath interference which was shown to decrease with range. Nearby vessel noise impacted modem performance throughout the trial, although successful reception was possible at ranges up to 7.2km with the AQUAmodem low power setting. No signals were detected by the ambient noise recorder at testing positions beyond this range. It is expected that given the unusually high ambient noise levels particularly during the later part of the day, successful communication may have been achievable at further ranges. Despite this, the modems have been shown to operate in very low SNR environments. However, inter-symbol interference at short ranges in shallow water has been shown to significantly inhibit performance.

By accessing debug information from the internal modem memory, data regarding both the bit error rates and raw recordings can be analysed to determine modem performance over the duration of the deployment. This can help confirm multipath interference as the primary cause for lack of modem communication in low ranges. Furthermore, by analysing modem recordings for similar transmissions, the cause of half duplex communication can be determined.

Future deployments will involve longer transects and deeper waters to help assess performance and characterise effects of other oceanographic parameters. Specifically, a long term deployment in deep water will give insight into the impact of wind noise and changes in sound speed profile. Eventually, effective characterisation of the parameters affecting successful underwater telemetry will aid in ensuring reliable subsea links, wherever needed.

Whilst analysis is ongoing, preliminary results have given strong indication that for shallow water deployments, multipath propagation causes significant inter-symbol interference. Environments close to shore have also been shown to exhibit high levels of man-made ambient noise. Although the modems in this trial were not designed for shallow water environments, they have been shown to operate effectively at long ranges where inter-symbol interference is reduced.

6. ACKNOWLEDGEMENTS

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