Adaptive PPM Acoustic Detection in very Shallow Water Reservoir

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***Abstract*—Underwater acoustic communications can be used for several applications. When the underwater link is related to a reservoir, applications can go from water monitoring, both in terms of pollution and physical characteristics, as for example, temperature. Another class of applications can be the remote control of small vehicles/vessels. Due to the limited depth, this kind of underwater acoustic connection suffers from delay spread and, in a wider sense, intersymbol and/or interpulse interference. In this work we analyze the problem of delay spread and test the performance in terms of BER for single link in a reservoir when 16-PPM is used according to Desert Star Systems LLC SAM-1 Modem. We propose also an adaptive detection scheme so as to reduce bit error rate. Last we compare the performance of the modem in the receive mode with a hybrid receiver characterized by hardware/software operations.**

***Index Terms*—PPM, modulation, adaptive, detection, delay.**

I. Introduction and Goals of the work

During the last decade underwater acoustic communications regain a lot of attention from the scientific community since new applications are requested and new technology is available. Dealing with applications, both optical and acoustic communications are the focus of new research both for gliders control [1], water monitoring, pollution measurements [2] and Tsunami alarm [3]. Regarding the technological advances, piezo-electric devices are starting to spread due to the transducer (electrical to mechanical and viceversa) price decrease. Different still open problems are currently evidenced by the research in this field. Specifically, one of the challenges of underwater communications is multipath with or without fading that rises as an effect of the propagation environment [4]. In fact, multiple reflections off the water bottom and the sea surface, as well as scattering from non homogeneity in the water, result in multiple replicas of the transmitted signal at the receiver. These multiple arrivals superimpose on each other and deform the signal in amplitude and phase. This effect is strongly limiting from a performance point of view in very shallow water [5] since the replicas, close in time, present low attenuation so they are comparable in energy with the main components, that is, the information signal. We show the performance of Pulse Position Modulation for a modem able to transmit and detected signals and we propose also an implementation of a hardware/software receiver based on signal acquisition via the use of a hydrophone so as to process the samples with Matlab. The final goal is to improve performance in terms of bit error rate (BER) in a reservoir.

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This work is partially supported by AMOUR-AQUALAB project.

The remainder of the paper is organized as follows. In section II we present the system model and the SAM-1 modem essentials both for transmission and detection. The adaptive receiving scheme is then detailed in section III while the performances are detailed and commented in section IV. Last, the paper conclusion is reported in section V.

II. System model

The data communication features of the SAM-1 modem developed by Desert Star Systems LLC is based on the segmentation of the message into 2-character blocks, and then the transmission of the blocks in sequence. SAM-1 encodes each new data block with an independent group of 6 acoustic pings. The first ping does not carry data since it it is used for synchronization purposes by the receiver since it establishes the time frame reference for the pulse window. Each of the remaining five pings represents a 4-bit chunk in the data block and each 4-bit group is mapped according to a 16-PPM (not orthogonal) modulation. Hence, the 20 bits of the data block are encoded by six *ping* pulses contained in a pulse window as shown in Fig. 1. Pulse position modulation was

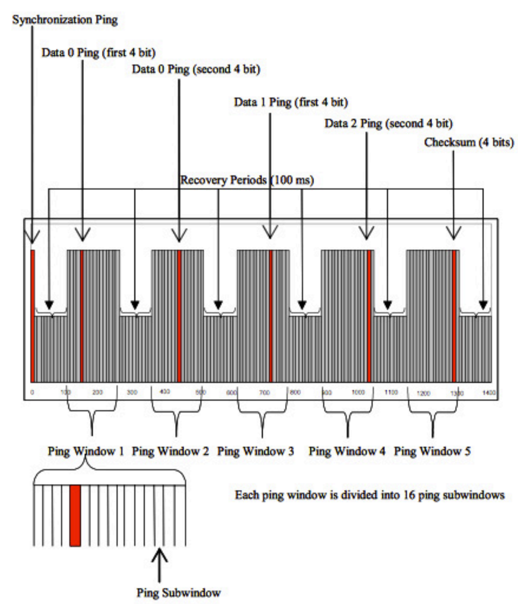

Fig. 1. Modulation Scheme as reported in [6].

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chosen for the SAM-1 system because it is a very energy efficient modulation format [7],[8]. This means that there is a specific window of an assigned time duration in which each of the data pings must occur. As illustrated in Fig. 1, a PPM time frame for SAM-1 contains five fixed duration data ping windows sandwiched with recovery periods. Each data ping window is evenly divided into 16 sub-windows. One ping will be transmitted during one of these sub-windows. Which sub-window the ping is in determines the four-bit value that the ping represents. In other words, the value of 0000 is associated with the first sub-window, 0001 with the second, and so on. It is important to note that the pulses are not separated in time and the receiver may suffer for error detection due to multipath. Analytically speaking, the signal received in the i-th ping sub-window of the k window can be written as

$$r_{k,i}(t) = s_{k,i}(t - jT_s) * h(t) + n(t) + w(t) \tag{1}$$

where $s_{k,i}(t - jT_s)$ is the symbol j carrying the PPM time shift ($j \in \{0, 1, ..., 15\}$) and T_s is the possible shift. More $h(t)$ represents the channel impulse response and it is responsible for possible reflections (multipath) while $n(t)$ is the acoustic noise and $w(t)$ is the thermal additive white Gaussian noise. About detection, the SAM-1 receiver, once set a threshold (that can be chosen by the operator in a set of 99 possible values) operates by preliminary check for the synchronization ping on the basis of a threshold. This task if fundamental since it gives the timing and also the time distance of the pings is regulated on the basis of the synchronization. Modem symbol detection works according to the following rule

$$\hat{s}_{k,i} = \arg \max_{j=0,1,...15} y_{k,i}(j) \tag{2}$$

where

$$y_{k,i}(j) = \int_{jT_s}^{jT_s+T_p} r_{k,i}(t) s_{k,i}(t - jT_s) dt \tag{3}$$

T_p being the pulse duration of $s_{k,i}(t)$. This approach is really sensible to phase rotation and attenuation as well as multipath.

III. Adaptive detection

When the channel is minimum phase, like for example in line-of-sight (LOS) propagation, usually it is expected that the first path presents lower attenuation with respect to the others. This is mainly true in RF application while in acoustics it may happen that the first path is comparable in amplitude (i.e., attenuation) with others. This happen when the difference of path length (that is the difference of the length of two *propagation rays*) is low. In other words, this is is equivalent to have a pulse duration larger than the time difference of arrival of two signal replicas. The key elements for detection are the syncrhonization, channel knowledge and external interference. The first one gives a reference for transmission frame, the second one is responsible for interpulse (channel delay spread inducing confusion among symbols) and/or intersymbol (channel delay spread inducing confusion among symbols of different frames) interference while the third one is a colored, and in general sporadic, noise.

A. The role played by synchronization

When the receiver is waiting for the synchronization pulse, it may happen that this latter is attenuated and the detection fails. More reasonably a *confusion* can incur. That is, the receiver recognizes some peaks as they are synchronization pings (see Fig.2). Since the shape of the synchronization ping is known, a cross-correlation can be operated as in (3). However, despite of the shape of the channel, we store the peaks exceeding a threshold. In the non-realistic case of ideal channel, we have only one peak while when channel presents multipath, more that one peak is expected. So, if we have, for example, L different values exceeding threshold, we store those values both for amplitudes and delays. In the case of LOS channel those values are descending sorted while if NLOS is considered not specific rules are followed. So, for each of the L values we have

$$\tilde{h}(j) = \frac{1}{E_s} \int_{jT_s}^{jT_s+T_p} r_{k,i}(t) s(t) dt, \tag{4}$$

subject to having

$$\tilde{h}(j) \geq \theta_h \tag{5}$$

θ_h being the threshold. Hence, the reference time for synchronization is

$$\tilde{\tau}_{sync} = T_c \arg \max_{j=1,...,L} \tilde{h}(j) \tag{6}$$

T_c being the sample time.

B. The role played by channel knowledge

Under the sufficient realistic assumption of channel not changing within a frame, that is, six pings, we can use the information acquired during synchronization phase so as to proceed to data detection. In fact, since the receiver knows where in time the pilots are placed it can evaluate the right symbol even though the receiver can experience possible symbols that are close in amplitude. In the presence of ideal channel the solution would be trivial since L=1 and only one path is present so the receiver as in (2) will perform very reliably. In the more general case of $L >$1, we know where the main component is present, even if this last can be due to path overlapping. This allows to take a *new temporal reference* for detection by starting from the above estimated $\tilde{\tau}_{sync}$ in (6). This is equivalent to consider the conventional 16 receiving windows (since 16-PPM is used) since the time reference has been changed, we look for

$$\hat{s}_{k,i} = \arg \max_{j=q,q+1,...q+15} y_{k,i}(j) \tag{7}$$

where q equates $\tilde{\tau}_{sync}/T_c$. Although this scheme solves the problem of interpulse interference since it realigns the time axis, it fails to work with interpulse interference. However, due to signaling time, and by considering the specific application scenario, we can affirm that no intersymbol interferene occurs (among different frames) while interpulse interference is very frequent.

C. The role played by external sounds

External interference is really an issue since, depending on the operating bandwidth, undesired signals can be present at the receiver. We anticipate here that, during detection, we experience the presence of sounds coming from canoeists rowing in the reservoir. An example is depicted in Fig.2. The signal acquired has been also band-pass filtered with a bandwidth of 10 khz.

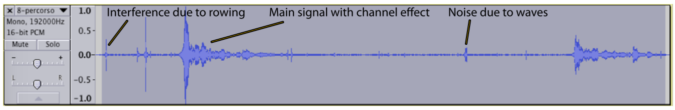

Fig. 2. Example of data signal plus noise due to canoists.

It is possible to recognize the effect of undesired signals both due to rowing and waves generated by wind. Also the effect of channel is evident. The problem related to this kind of noise is that the receiver may interpret the first peak, as that depicted in Fig.2 as the first synchronization ping so leading to drop all the consecutive data.

IV. Test Results

We use the following setup for tests. The transmitter operates in a 2.5Khz bandwidth around 33.8 khz and the bit rate is 13 bit/sec. The transmitted power is 189 acoustic dBs. The receiver sensitivity is 95 dB with reference to 1 μPa (see [7] for additional details). We perform direct detection for the modem as detailed in (2). So, we transmit the following text -*Adaptive PPM Acoustic Detection in very Shallow Water Reservoir AMOUR-AQUALAB Project ICT Lab University of Rome 'La Sapienza"*-. Since we deal with measurements, we detail the BER values achieved in a map, by reporting the Google Earth map with colors in Fig.3. About the colors, those range from green to yellow and red represent a low BER increasing till to values (red) as 0.5. It is possible to note that in Fig.3, after few meters, the color shifts from green, that represents a low BER value, to red. More, the red region is the largest since it deals with the coverage offered by the modem. We can also argue that the behavior with respect to distance is monotonic thus meaning that by increasing distance, BER increases. We detail the BER map for the detection operated with an acquisition with the Hydromic device [9] able to sample the signal at the hydrophone with a bandwidth of 192 Khz with 16 bit per sample. After we used the acquired file (in the .wav format) for be processed with Matlab software. After a band pass filtering, in order to reduce additional noise, we implement the detection rule detailed in (7) and draw the BER map. By comparing the two figures (Fig. 3 and Fig. 4) it is possible to argue that the here proposed approach is able not only to outperform the modem detection but, more, to extend coverage from 100 meters (at BER=0.05) till to 200m. This gain can be explained in two different ways, since two are the elements that allow such a gain when the receiver operates with a hardware/software approach. First, the threshold mechanism to *understand* where the pilot symbol is located allows to synchronize the transmission in a more reliable way. Second, the analysis carried out about interpulse interference, allows to reduce BER. To be more precise, we can state that increasing the coverage, where this latter is defined as a function of the obtained BER, means not only to increase the received signal strength but, mainly, to increase the signal to interference noise ratio.

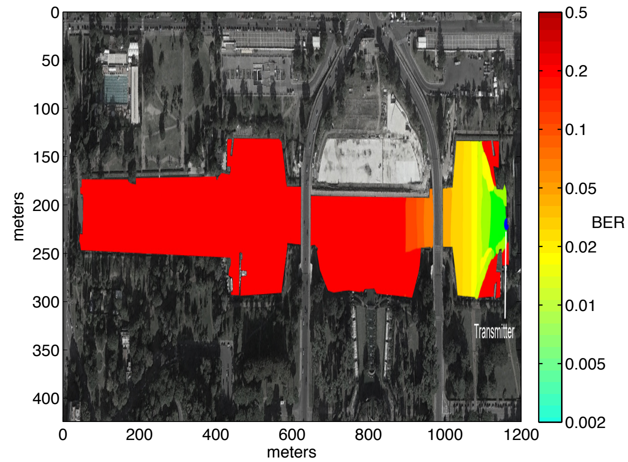

Fig. 3. BER map for communication with direct detection as in (2) with longitudinal transmission.

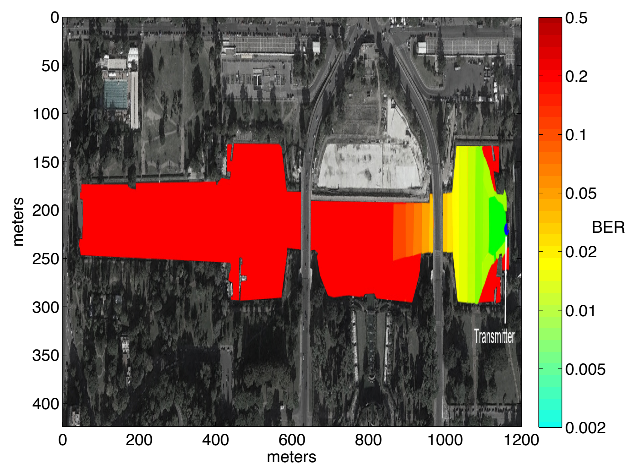

Fig. 4. BER map for communication with detection as in (7) with longitudinal transmission.

The second experiment deals with the positioning of the transmitter on the side of the reservoir (transverse transmission) with the modem and hydrophone located on a small pedalo. We transmit the following text -*Welcome to IEEE Oceans 2015 University of Rome "La Sapienza" Adaptive PPM Acoustic Detection in very Shallow Water Reservoir*-. As for the previous experiment, we detail the BER performance, as a map, both for modem hardware detection and software/hardware one. We report in Fig.5 the BER map of modem hardware detection. The performance rapidly decreases with the increasing distance and at 30 meters the BER achieves 0.1. The behavior is monotonic and the BER rapidly achieves values that are not admissible. As an example, the modem detection recognizes only two ASCII characters out of 156.

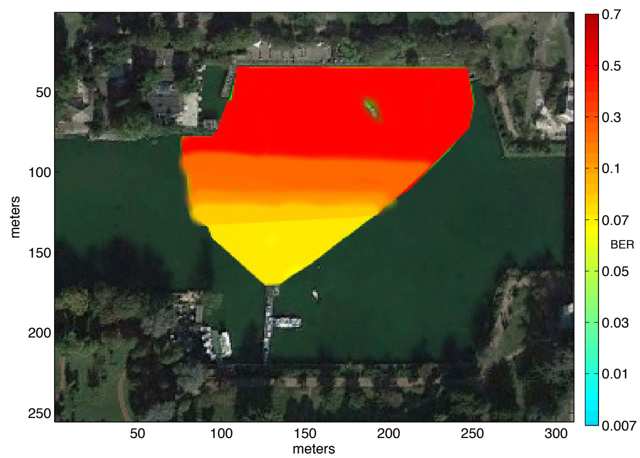

Fig. 5. BER map for communication with detection as in (2) with transverse transmission.

More interesting is the behavior of the hardware/software detection detailed before. In fact, in Fig.6 it is possible to appreciate that the BER achieved is considerably lower since the color representing BER does not become red so giving evidence of the performance gain. Additionally, the behavior

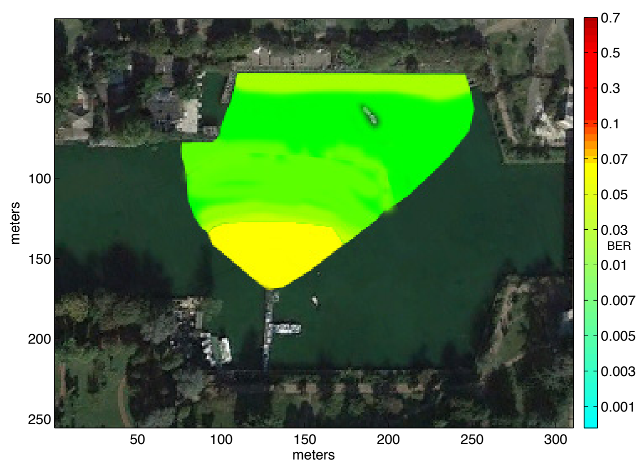

Fig. 6. BER map for communication with detection as in (7) with transverse transmission.

of the BER is not monotonic with the distance. In particular we can recognize three different zones. The first one, closer to the transmitter, is essentially yellow, the second one is green and the third one yellow/green. Since the lake-floor is 1.6 meters there (see [10]), the amplitudes due to reflections are comparable with the main path and the delay of such a path is of the order of few ms. So, the BER loss is essentially due to interpulse interference. The second zone, the green one, present very good BER levels since the effect of interpulse interference is mitigated even though the distance decreases the signal level with respect to the previous zone due to a larger distance. Last, the third zone is yellow/green since the signal level decreases and the effect of attenuation is dominant with respect to the BER behavior.

V. Conclusion

We test the communication reliability of an acoustic underwater link in a very shallow water reservoir in two different configurations. The first one simply consider the transmission and reception operated by the SAM-1 modem when a text is sent. The second one takes into account the same transmission scheme by applying detection via hydromic receiver, that is, a hardware/software integration. The main result is that the second scheme we consider is able to improve reliability since it is more robust with respect to channel impairments, that is, inter-pulse interference.

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