-- TALISMAN --
An innovative tool using time varying channel model to evaluate performances of an acoustic link

Gérard LAPIERRE[♣], Christine LE BRUN[♦], Christophe VIALA[♠]
[♣]G.E.S.M.A. (Groupe d'études sous-marines de l'atlantique), BP 42, 29240 BREST NAVAL, France
[♦]IPSIS, 3 square du chêne Germain, 35510 CESSON SEVIGNE, France
[♠] SEMANTIC TS, 39 chemin de la Buge, 83110 SANARY SUR MER, France

Abstract : This paper describes the development in progress of a simulation tool to model acoustic digital communication over time-varying channels. Based on a modular structure, this tool is constituted by the description of an emission, channel and reception part. Physical parameters characterize time varying channels by integration of static parameters (kind and form of sea surface or sea bed) and variable ones (celerity, receiver moves…). This software is suitable for testing all configurations (provided rays propagation is available) and signal processing techniques for message recovery and is able to deal with time variant impulse response. Performances of acoustic link could be evaluated on the one hand from a statistical point of view by simulation of representative series of symbols. On the other hand, the quality of the link can be visualized by transmission of pictures, sounds or text files. Results are suitable by conventional tools (eye-pattern, I-Q constellations, BER, SER or display of decoded symbols).

1- Introduction.

This paper presents a tool to evaluate the performances of acoustic links. This software called TALISMAN (i.e. Transmissions Acoustiques sur Liaisons Sous MAriNes) is built starting from two software packages, COMSIS, digital communications simulator and RAYSON, acoustic propagation model. The first part of the article reviews some contributions indexed in the field of simulators of underwater acoustic communication. The second part is dedicated to COMSIS software more specifically. The third part presents the different functionalities of RAYSON. Finally, the integration of these two software within TALISMAN is described and an example concludes the paper.

2- A quick review of underwater acoustic channels (UWA) modeling.

UnderWater Acoustic (UWA) channels are characterized by multipath phenomenon whose characteristics are time-varying. This speed of variation is partly due to the medium (change of celerity, nature of the sea-bed, form of surface) but also to the instruments (movements, immersion depth...). The performance evaluation of a transmission in simulation thus requires to take into account variability in order to estimate the robustness of treatments. Current work in this field thus rests on the characterization of this time and frequency dispersion and on their consequences on transmissions [1],[2].

Whatever the degree of modeling could be, simulation cannot perfectly represent the reality (due to insufficient knowledge of the environment, erroneous modeling...). However, this tool can be of a great utility in the preparation of sea trials (optimization of instrumental positions, comprehension of global phenomena...). This is one of the reasons why GESMA wishes to obtain such a tool.

A first possible approach to model these disturbances is to let physical phenomena and model the whole transmission link by the discrete equivalent model. The impulse response is modeled in this case by a 2-D random process synthesizing the sum of N contributions shifted in time, out of phase and attenuated in amplitude.

$$h(t,\tau) = \sum_{i=1}^{N} \alpha_i(t).\delta(t-\tau_i(t))$$

Synthetic time–varying channels with certain shapes of fading (Rayleigh, Rice channel) can be modeled by the application of laws of variations on amplitudes α_i delays τ_i and phases. A second level of description consists in linking the main characteristics of the channel to the physical phenomena. Then, the application of simple geometrical laws allows to define multipaths and to determine main characteristics of various rays. A first contribution [1]described such a reception. Some modeling are refined by taking into account temporal variations of the medium due to changes of instruments [4]. The modeled channels in this way are often characterized by what one calls the scattering function which allows the visualization of the dispersion of energy both in time and frequency. Interest rests on the integration of realistic order of magnitude in the fluctuations of these models.

The author's contribution is based on the fusion of two existing software in order to offer the sufficient modularity to build an acoustic link as a whole and to evaluate its performances. With this intention, a block diagram is defined by:

1. The emission part. It includes messages generation, the source and channel coding and modulation of signals
2. The channel part. The impulse response is determined by the preliminary definition of configuration of transmission (celerity, nature and form of surface and sea bed, movements of the transmitter and the receiver...).
3. The reception part. It includes all operations of filtering, demodulation and classic treatments (matched filters, equalization...).

Formal parameters can be defined in order to determine statistical curves (error rate versus signal-to-noise ratio...)
Lastly, the module of analysis allows the visualization of the whole characteristics of signals (in time, frequency, constellations, eye pattern, sound loss field, impulse response...).

Thus, TALISMAN can be used upstream of an experimentation to simulate awaited disturbances and downstream like processing station on collected signals. In situ signals and measured noise can also be integrated on any part of the link.

3- COMSIS simulator

COMSIS [5] is a telecommunication systems simulator, aimed at the development, study and evaluation of any analog or digital transmission link, in various areas such as optical fiber telecommunication, mobile telecommunication, satellite links… It is developed by IPSIS, France and helps designers in their task of developing transmission systems, by simplifying the study of various configurations, of influence of several parameters on the system performances and thus targeting the best solution for a given situation.
In COMSIS, the system is represented by a block-diagram, interactively built by the user (Fig. 1).

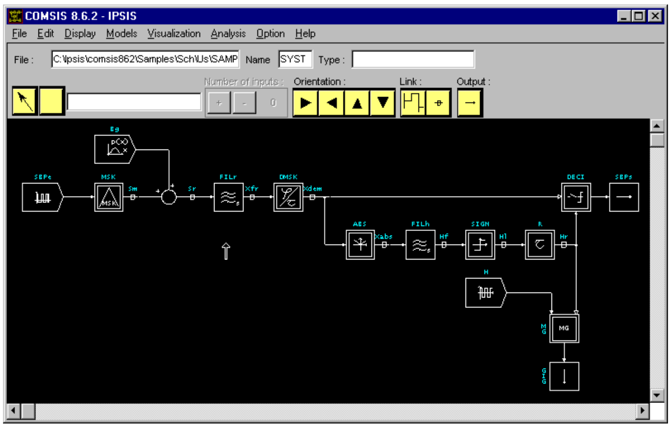

Fig. 1. Block diagram representing a telecommunication system with clock recovery in COMSIS

Each block represents a component or a function in the system. COMSIS includes models for encoders and decoders (RZ, CMI, dicode, error correcting…), analog and digital modulators (including user-defined digital modulator), filters (analytic, synthesized, or file-defined), propagation channels, logical and mathematical functions, combiners… Each model has its own definition interface whose characteristic parameters have to be defined. Some generic models allow to introduce and process experimental data within the simulation: the input/output characteristic of an amplifier, the frequency response or the time-domain response of a filter, the input signal… Models also take into account of non-linearities and noise effects.
COMSIS is a time-domain simulator, i.e. signals on each point of the link are represented by time-domain samples. Moreover, the user can choose any time step to represent the signals. COMSIS always suggests an appropriated time-step for the whole system, according to Shannon theorem. Also, the filters are simulated using FFT algorithms. COMSIS uses the complex envelope representation for modulated signals. This enables to sample the signal according to the bit rate rather than the carrier frequency and greatly improves the calculation time.

COMSIS performs a complete analysis of the system and stores the signals obtained on each point of the link. Then, a complete performance assessment menu gives access to visualization of results (time domain, power spectral density, eye pattern, statistics, scatter diagram…), calculation of Q factor, of signal to noise ratio (SNR), of mean power, of bit error rate (BER)… Three different methods allow to calculate the BER. Parametric studies can easily be run, to plot BER versus SNR.
Fig. 2 shows some plots obtained from the performance assessment phase.

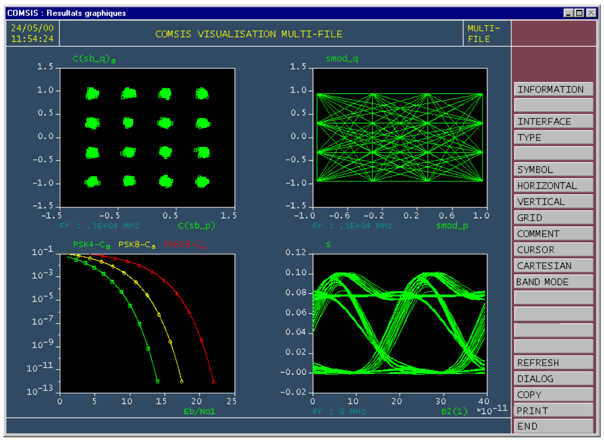

Fig. 2. Visualization of results from the performance assessment: scatter diagram, vector diagram, BER vs. SNR curve, eye pattern.

Although COMSIS already includes specific libraries for GSM, UMTS or optical transmission system simulation, it had never been used for underwater acoustic links analysis. However, its modularity makes it very appropriate to the TALISMAN project. The models of digital modulators (direct PSK, transition PSK, QAM, MSK) already exists, just as several models of encoders and decoders, noise, filters, decision…. New models, specific to this domain have been developed. Some of them have been implemented using the COMSIS Builder, a tool for the integration of models written in C/C++, that any user may also use to introduce his own models in COMSIS. So we developed a Knudsen noise model, a matched filter model, WAV, TXT and JPG file-defined input signals, and several models of equalizers among which linear or decision feedback one. These equalizers could be adapted with a trained sequence or piloted by decision directed strategy. One can also choose the adaptation algorithm (LMS or RLS). For all equalizers, the phase recovery is optional.

4- RAYSON : Acoustic Rays Program in Ocean Medium

RAYSON [Réf] program is able to predict acoustic field using a ray method based on a simplification of Helmholtz equation valid in areas of high frequencies. This differential equation defines the trajectory of a ray taking into account local values of sound velocity and its gradients. When the medium is range independent (that means that vertical sound speed profile is the same across the range) this equation presents analytical solutions which are parts of circles. When the medium is range dependent no general analytical solution exists, even in the case of simple profiles of celerity. Ray equation is then solved numerically with a Runge-Kutta scheme of the order 4, moving forward along the range axis. This program has been realized in C++.

RAYSON is able to take into account various realistic environments:
- Range independent medium: horizontally homogeneous
- Range dependent medium (2D description (range, depth) of sound speed field. The number of celerity profiles is just limited by the processor memory.
- Bottom profile and type dependent on range in propagation loss calculations. Type of bottom is chosen among: sediments, sand, mud, rock, fluid bottom, fixed bottom (loss in dB is constant)
- Space-time dependent surface: Propagation times underline temporal dispersion that can reach some hundred milliseconds after some fifty kilometers of propagation. Two rays that have been sent from the source at the same moment will hit the surface in such different places and times that surface cannot be considered as stationary. A dynamic model is then necessary to deal with surface effects on acoustic propagation.

RAYSON offers several functionalities:
- Shot of a bundle of rays devoted rays trajectories studies
- Calculations of eigenrays (connecting source to a (set of) receiver(s)): memorization of trajectories and arrival angles, time and intensity for each eigenray.
- Calculations of propagation loss fields: vizualisation with 2D map of coherent, incoherent and maximal losses.
- Calculations of propagation losses fields is made through a systematic insonification from the source; calculations area is regularly discretized in range and depth; losses due to divergence and/or surface and bottom reflexion are determined in each mesh.
- Calculations of impulse responses: for a source and a set of receivers.

The program has a procedure of Monte-Carlo type that allows automatic and systematic statistical numerical simulations: determination of ray characteristics and their intensity for a set of speed profiles, moving surfaces, or unknown bottoms whose description files are present in a directory. All the characteristics are available in a file of results. Calls for parameters and the processing of files are automatized; human actions and manipulation errors which constitute a real problem when the number of realizations is high, are minimized; this authorizes parallelization of calculations and therefore optimization of processor efficiency. The method allows to dispatch calculations over a set of data between several processors of a network.

For the needs of TALISMAN tool, RAYSON has been adapted to take into account source receiver directivity and receiver trajectory. Fig. 3 shows the receiver trajectory in the receiving area.
Impulse response is interpolated on the receiver trajectory point as shown on Fig. 4 by knowing it in each point of the receiving area.

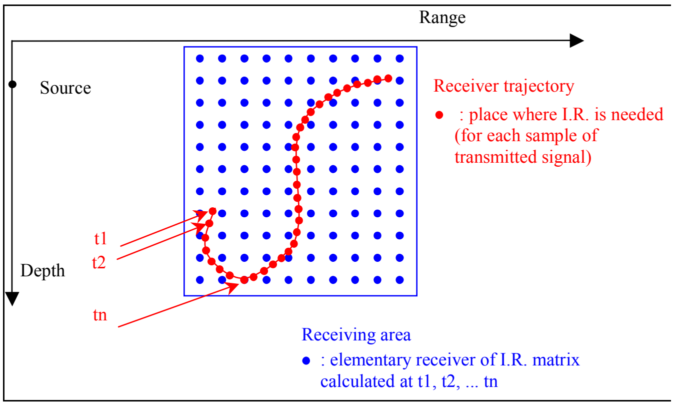

Fig. 3. Places where I.R. (Impulse Response) is needed

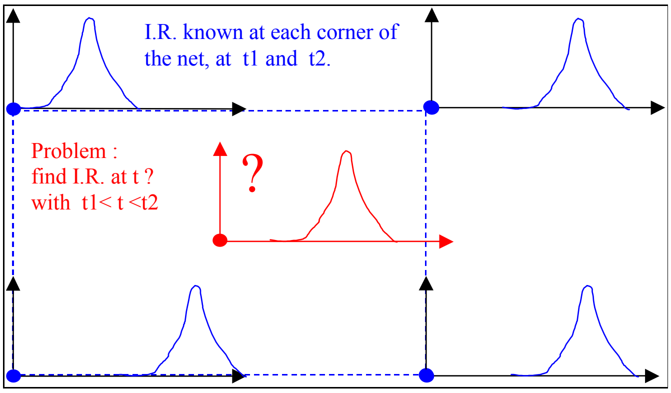

Fig. 4. Impulse Response interpolation

Once impulse response is determined for each receiver place RAYSON calculates propagated signal.

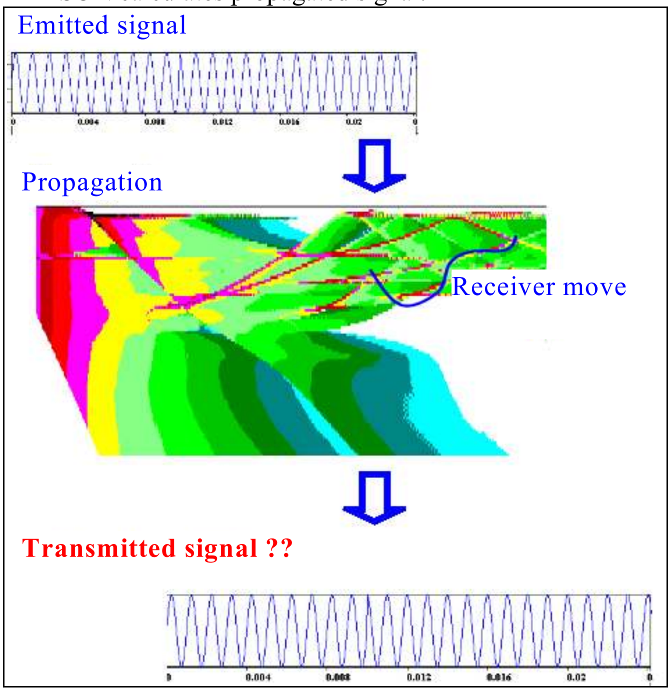

Fig. 5. Transmitted signal

5- TALISMAN: Integration of COMSIS and RAYSON

For the TALISMAN project, the two software COMSIS and RAYSON had to be interfaced. TALISMAN looks like

COMSIS, in terms of graphical user interface, integrates all standard COMSIS' models for the modelling of the transmission link. Then, a specific underwater acoustic model library has been created, and in particular, a specific block representing the underwater acoustic channel (RAYSON) has been included. This block has one input and N outputs (representing N receivers). Through the definition interface, one can select an existing RAYSON project (i.e. sound speed profile, bottom profile, configuration of receivers…) or create a new one. RAYSON can be opened from COMSIS definition interface. This allows for example to visualize the impulse responses characterizing the channel before launching the complete simulation. In this case also, the loss field is calculated and it will not be necessary to re-process it for the simulation.

In COMSIS, each intermediate signal of the transmission link is represented in the time-domain, as samples defined in double precision. RAYSON, manipulates data represented in the WAVE file format.

Fig. 6 represents a synoptic of the transmission link and the sharing out of the elements between COMSIS and RAYSON.

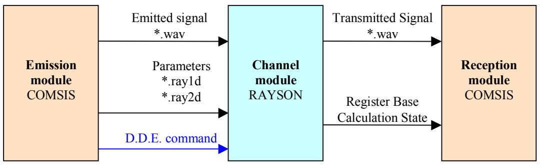

Fig. 6. Synoptic of the link in TALISMAN

The whole emission module (generation of signal, encoding, modulation, filtering) and the whole reception module are constructed and simulated by COMSIS. In-between, the acoustic channel is simulated by RAYSON. Thus, at the input of the underwater acoustic channel, the signal coming from COMSIS is converted into a WAVE file that can be processed in RAYSON. Since COMSIS may use complex envelope representation of the signals within the link, the signal may be converted from complex to real representation first. Then, the RAYSON program is called with the WAVE file created and the project file defined trough the definition interface. Since RAYSON is written in C++ and COMSIS also partly in C++, the communication between the two programs is made through DDE (Dynamic Data Exchange). RAYSON calculates the impulse responses and deduces the transmitted signals. COMSIS then recovers a WAVE file containing as many channels as receivers, and has to convert each corresponding signal into the COMSIS format and redirect each channel toward the corresponding output of the model. Then, these transmitted signals can be processed in the reception module. The simulation then goes through the performance evaluation process.

6- Example: simulation of a PSK transmission in TALISMAN

A PSK transmission is simulated. The binary input signal has a 1 kb/s bit rate and is 2-PSK modulated (direct-PSK) with a carrier frequency of 5kHz. The acoustic channel is defined by the impulse response given on Fig. 7. in a typical case of Atlantic ocean propagation, over 15 km, from a source at 80 m to a receiver localised at 94 m and on a flat bottom (146 m).

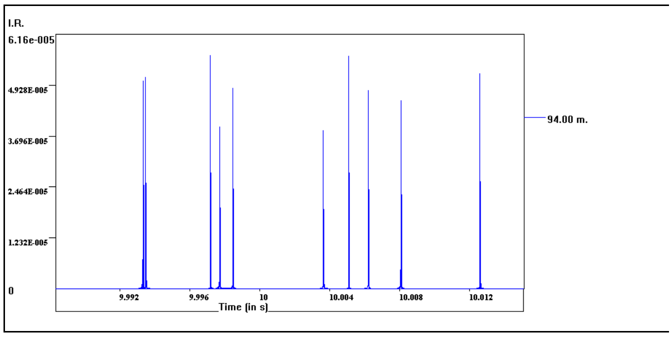

Fig. 7. Example of Impulse Response

Hereafter (Fig. 8), we show the scatter diagram at the output of the underwater acoustic channel.

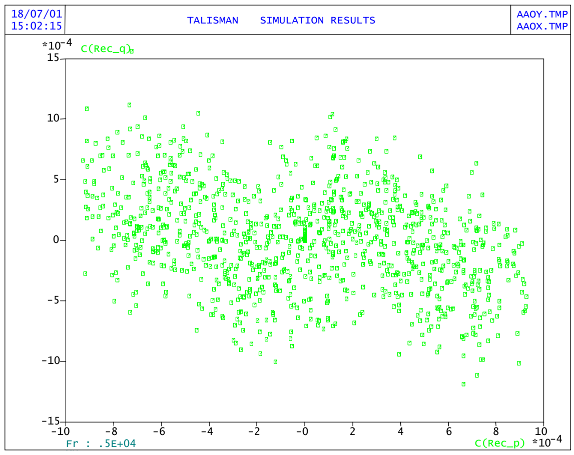

Fig. 8. Scatter diagram at the output of the UWA Channel

7- Conclusion

An acoustic communication simulator is presented. Fusion of two dedicated software (COMSIS and RAYSON), this software TALISMAN is presented as a tool which enables to evaluate performances, prepare sea-trials or process recorded signals. TALISMAN offers the possibility to insert or to extract the signals whatever place in the acoustic link.

Different aspects justify the interest of such a tool. On the one hand, it takes account medium variability or receiver moves. On the other hand, the great number of integrated libraries and its modularity offers a large range in terms of design of acoustic links. As a consequence, time series of data can be generated and transmitted through a time varying multi path channel. Propagated signal is received on an array and processed by the reception part of TALISMAN.

The last version of TALISMAN is planned for the end of 2001.

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