ON-AIR TESTS RESULTS FOR HF XL WIDEBAND MODEM

Catherine Lamy-Bergot*, Sébastien Herry*, Jean-Yves Bernier‡ and Frédéric Ngo Bui Hung*
(*) THALES Communications & Security
4 avenue des Louvresses, F-92622 Gennevilliers Cedex

(‡) THALES Belgium
Rue des Frères Taymans 28, B- 1480 Tubize

Abstract

This paper presents over the air (OTA) transmission results obtained with a multi-narrow band HF modem operating over noncontiguous 3 kHz bands spread over a 200 kHz wide sub-band. It is shown that for the considered Cholet-Coulommiers (~350km) link, the observed throughput was regularly over the 64 kb/s throughput of satellite INMARSAT-B circuits and can reach up to 138 kb/s.

Key words

HF transmissions, high data rate, wideband HF communications, IP over HF, adaptive waveform.

I. INTRODUCTION

Historically used for long haul fixed frequency low data rate communication such as voice applications, HF communications have known several evolutions since the last three decades. First, higher data rates have been introduced with the use of new modulations (PSK, QAM), allowing to reach throughputs up to 9600 b/s [3][4] in 3 kHz. Second, automatic link establishment (ALE) procedures [6][8] have been generalized to provide the end-user automatically with a usable frequency. Finally automatic repeat request (ARQ) solutions [6][8] have been proposed to make the HF link reliable.

Nevertheless the throughput offered by these existing waveforms remains too limited for many modern usages such as large files transmissions or IP connectivity. Consequently, several efforts have been made to try to reach higher bitrates over the HF channel. First solutions, such as the use of multiple separated modems proposed in [9] while illustrating the principle of higher throughput transmissions, were not considered realistic for use on the field due to their requiring several radios for a unique transmission. A more recent solution is the one described in the US MIL-STD-188-110C appendix D [5] which proposes single carrier waveforms from 3 kHz to 24 kHz. This modem solution has been integrated into a tactical equipment, and it was shown able to reach bitrates in excess of 64 kb/s. Nevertheless, some discussions are currently on-going on the possibility to find adequate free HF bands of 12 to 24 kHz to allow the use of this modem in real conditions. This is why another proposal was made recently [1], of an adaptive wideband HF waveform called “HF XL”, which relies on the usage of several non-contiguous 3 kHz channels. Expanding on the well-known high performance of the serial tone modem technology standardized in STANAG 4539 for 3 kHz sideband to conjugate a plurality of channels in a multi narrow band (MNB) waveform, this approach can be seen as an extension of the US MIL-STD-188-110C appendix F “ISB”, with the addition of specific redundancy capabilities to provide resistance to the highly variable HF channel conditions. With a linear complexity with respect to the 3 kHz sideband STANAG 4539 version, the HF XL approach allows to select the best channels in terms of expected signal to noise ratio for the transmission in a wider 200 kHz bandwidth. As illustrated in Figure 1, these channels do not need to be contiguous, which allows to select only good quality and authorized channels. With 8 to 16 channels, obtained throughput is easily over the 64 kb/s throughput of satellite INMARSAT-B circuits and can reach up to 138 kb/s.

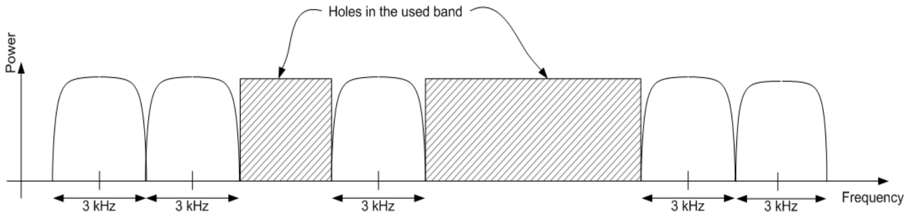


Figure 1 – HF XL multiple carrier principle.

This paper presents the demonstrative set-up developed to validate the HF XL concept and to establish its performance over the air. In particular, the considered transmission chain is described in section II, from the wideband tunable antenna prototypes to the modem itself. Next, in section III, the considered trial conditions are presented. These trials were a week-long one between the two French cities of Cholet and Coulommiers, distant of ~350km. Finally, results in terms of obtained throughput are presented in section IV and lastly conclusions are drawn in section V.

II. TEST BED DESCRIPTION

The test-bed set up to validate the HF XL modem is presented in Figure 2. Operated as a simplex transmission system, it consists of prototypes (wideband tunable antennas, PC modems), commercial test equipment (for ADC and DAC conversions, and frequency transpositions), and of existing Thales equipment (high power amplification, antenna tuning unit (ATU), wideband receiver equipment).

More precisely, on the transmission side, one finds:

- a Linux PC hosting the test-bed interface, the modem and filtering operations, delivering its stream at a sampling frequency of 1 MHz,
- a commercial test card ICS 564 from ICS Ltd implementing digital to analog conversion thanks to its 14-bits DAC and the transposition to HF frequency,
- a modified TRC3700 Thales exciter, whose role is both to tune the wideband antenna and to pre-amplify the signal before it enters the power amplifier,
- a 400W ALA 176 Thales HF power amplifier,
- two different antenna prototypes: the first one, corresponding to a tactical configuration, being a 15m high dipole tuned by a Thales AEA309 ATU, designed for near vertical incidence sky wave (NVIS) operation, and the second, corresponding to a naval configuration, being a combined monopole (low band)/dipole (high band) tuned by a Thales AEA400 ATU.

On the reception side, one finds:

- a wideband reception antenna (Thales ANT107),
- a wideband Thales REC107 receiver (electronic warfare product)

- a commercial test card ICS 1555 from ICS Ltd realizing the analog to digital conversion thanks to its 16-bits ADC and the frequency transposition from HF frequency to baseband,

- a Linux PC hosting the test-bed interface, the modem and filtering operations, receiving the digital stream at a sampling frequency of 1 MHz.

Additionally, a perfect return link between the two Linux PC can be emulated, in order to test the adaptation capability of the modem (as presented in [1]). This link is implemented via two 3G Internet keys, its sole purpose is to transmit the measurements done at the reception side, of the quality of the different channels in the 200 kHz subband, for the transmission side to take them into account. This 3G link is never used to transmit any acknowledgment or help the modems to do their task, nor does it transmit from the TX to the RX side.

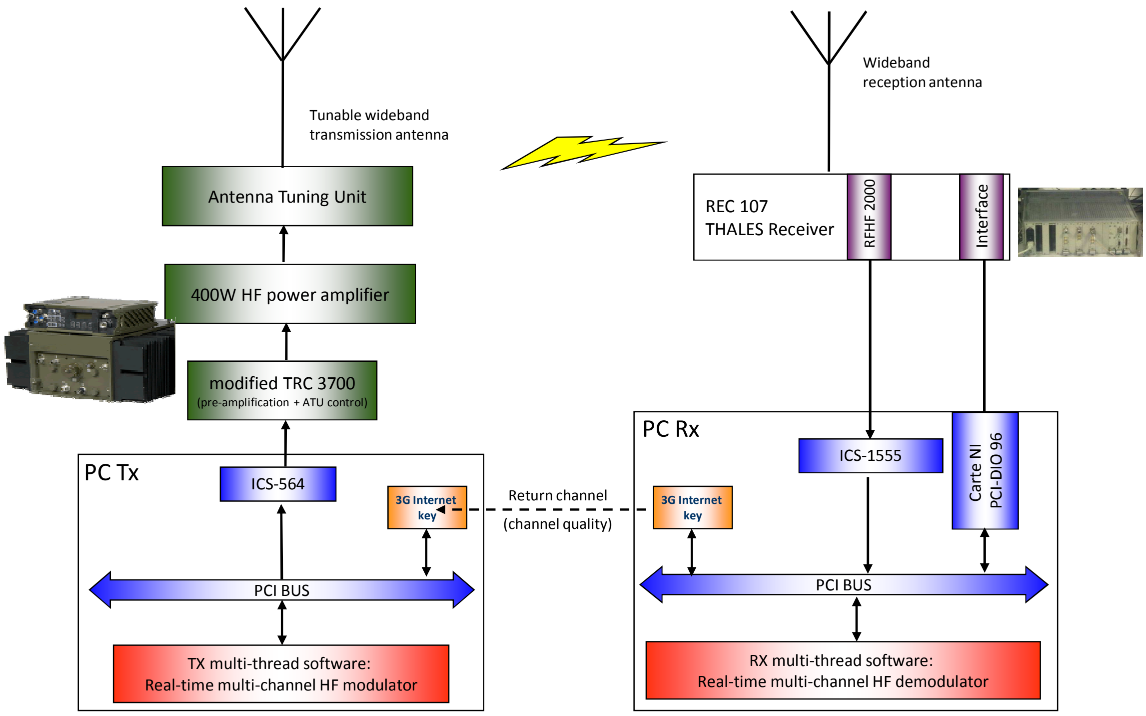
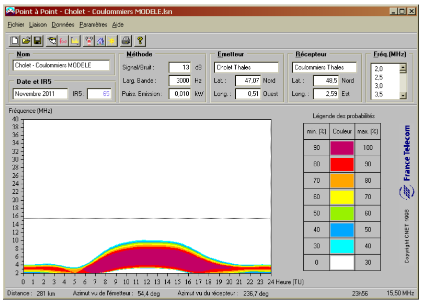


Figure 2 – Test-bed settings: TX (left) in Cholet and RX (right) in Coulommiers.

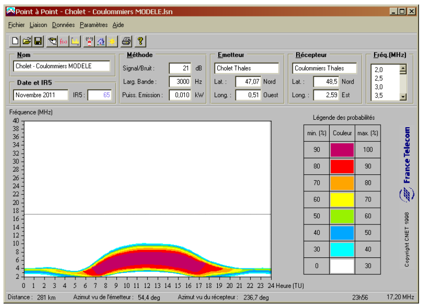
III. CONSIDERED TRIALS CONDITIONS

The trials were carried out during five consecutive days in December 2011 between the emission site of Thales Cholet (N47°04'01'', W0°51'25'') and the reception site of Thales Coulommiers (N48°50'46'', E2°59'4''), corresponding to a ~350km link. Various HF XL waveform configurations, including the number of combined channels used, as well as the modulations employed on each of those channels were tested, as well as regular 3 kHz transmissions to evaluate the link quality at different central frequencies. In all cases, the transmissions consisted of series of superframes of duration ~9s, and only trials with a minimal of 10 superframes (ie. 90 seconds) were considered valid for resul analysis, in order to present a minimal coherence.

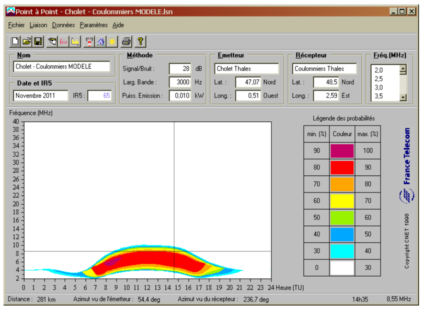
The probability of link establishment was first evaluated using the prediction software "Point à Point" developed by Telecom Bretagne [2] and regularly used by the French Army. Beside the antenna models, this software requires the following data: solar activity index, year and month considered, and power per 3 kHz channel. In our case, considering a power amplifier of 400W, the back-off induced by the multi-carrier waveform, and the power repartition between the different carriers (supposed in the simulation to be equally shared among channels), the considered power per channel was set to 10W, corresponding to a use of 12-15 channels. Figure 3 and Figure 4 present the circuit establishment probabilities for both antenna configurations. As foreseen, the tactical configuration, using a near vertical incident skywave (NVIS) antenna is more favorable and will allow for better throughputs than the naval configuration for the considered link.



(a)

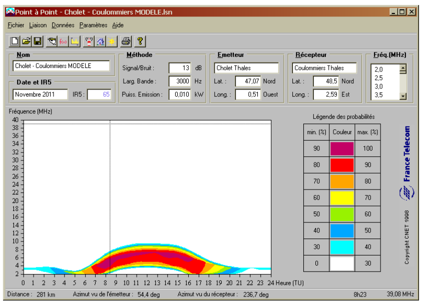


(b)

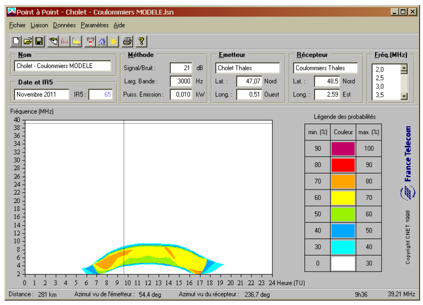


(c)

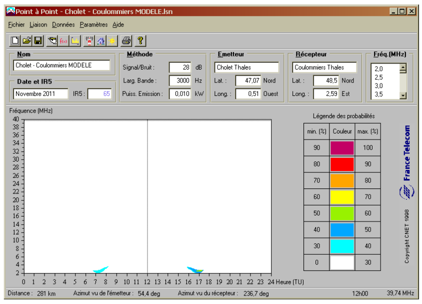
Figure 3 – Propagation prediction for channel bitrate 3200 b/s (a), 6400 b/s (b) and 9600 b/s (c) with the tactical antenna configuration.



(a)



(b)



(c)

Figure 4 – Propagation prediction for channel bitrate 3200 b/s (a), 6400 b/s (b) and 9600 b/s (c) with the naval antenna configuration.

IV. OBSERVED RESULTS

Various configurations were tested and recorded, each corresponding to:

- a given central frequency, selected based on the circuit establishment predictions for the considered daytime,
- a number of channels used (from n=1 to 15), and their location in the 200 kHz subband,
- the modulation choices for each channel (from QPSK to 64-QAM)
- and the power distribution over the composite signal have been tested, with a total power of 400W.

The first lessons from the trials consist of the throughputs achieved with the multiple carriers HF XL waveform. In this part of the trials, known sequences were used, in order to measure the quality of the transmission. The recordings were post-processed to measure the effective received throughput, taking into account the absence of any automatic repeat request (ARQ) mechanism, which led to occasionally remaining errors in transmitted superframes. This post-processing consisted in eliminating from the throughput count any superframe whose frame bit error rate (BER) is greater than a threshold. As a consequence, an observed throughput of 64 kb/s can be the result of an actual 64kb/s transmission without error, or a transmission at higher rate with erroneous frames dropped. Figure 5 and Figure 6 present the results of two BER thresholds: 10^{-3} and 10^{-4}, for various configurations (with both transmission antennas) corresponding to a total of more than 5 hours of compiled transmissions. Peak values obtained were of 138.8kb/s (error free 15 channels using 64-QAM modulations), but also half of transmissions were found to reach a throughput greater than 64 kb/s (25% for BER<10^{-4}).

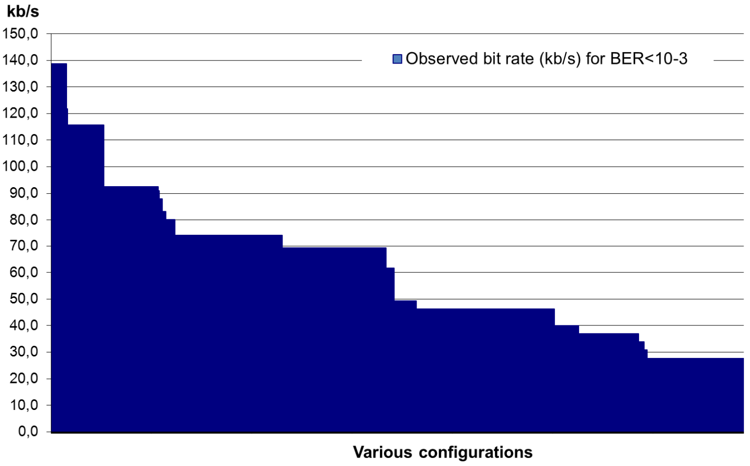


Figure 5 – Observed bit rate, BER<10^{-3}.

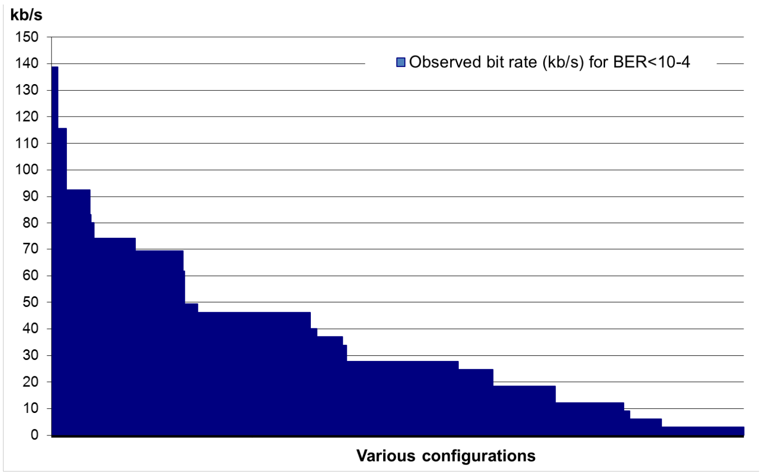


Figure 6 – Observed bit rate, BER<10^{-4}.

In a second step, the recorded transmissions were also used to estimate the band occupancy in the instantaneous 200 kHz band considered, to determine the maximal free bandwidth in contiguous and in non-contiguous configurations. The measurement was made over all transmissions (about 20 hours of recordings) made during the trials, including the regular 3 kHz circuit link quality establishment tests. Figure 7 presents obtained results, considering that a 3 kHz channel is free when the power level inside is less than 2dB greater than the lowest one (estimated noise floor). For this threshold, non-contiguous 24 kHz band has a 95.6% availability, compared to a 27.2% availability for contiguous band. Similar results for a 1dB threshold are of 42% for non-contiguous to 2% for contiguous 24 kHz.

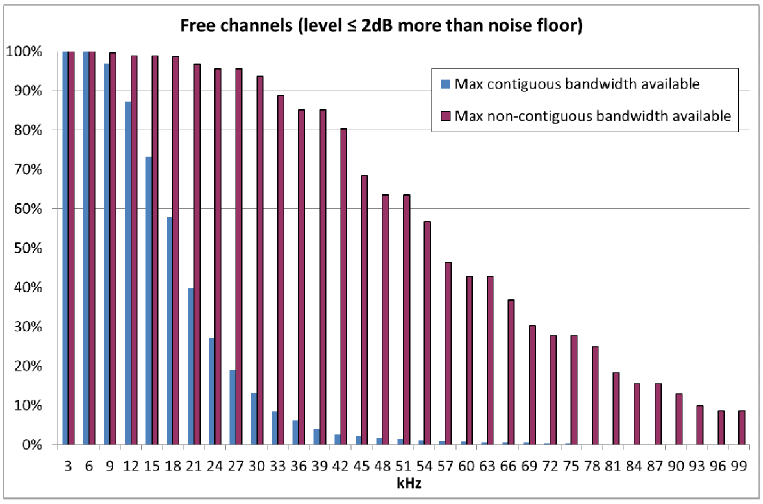


Figure 7 – Estimation of possible channel use in contiguous and non-contiguous mode.

The results obtained when activating the automatic adaptation of the system to the channel conditions are presented in [1].

Finally, the last part of the trials consisted in realizing a video transmission over the HF link. As illustrated in Figure 8, where nine different channels were used with a 32-QAM modulations each, the test-bed allowed to reach a throughput greater than the needed 64kb/s for the video link.

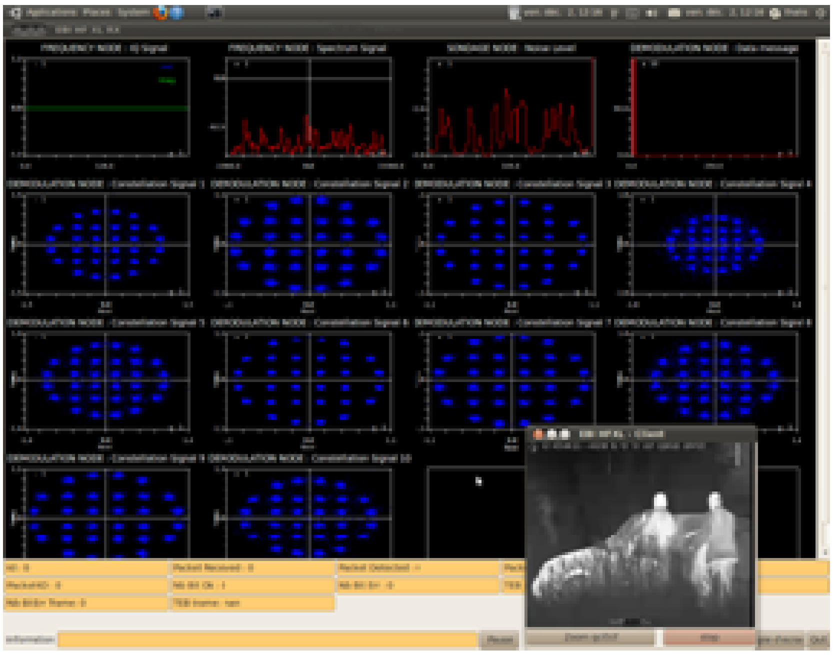


Figure 8 – Video over HF transmission using a 9x32QAM configuration.

V. CONCLUSIONS

The experimental trials carried out by the Thales team between the two French sites of Cholet and Coulommiers using a 200 kHz wide HF radio have allowed first to show the feasibility of non-contiguous multiple carrier transmissions and second to demonstrate the interest of considering wideband reception front ends. As a matter of fact, using wider front ends allows for adaptive transmissions thanks to the constant monitoring of channels others than those used for the transmission. This approach allows for much quicker adaptation to the channel variations, and should consequently permit to operate closer to the channel limits, offering higher throughputs to the end-user.

Future works will focus on the integration of the return link over HF, and automatization of the adaptation system, as well as prototyping an integrated radio board.

ACKNOWLEDGMENT

The authors thank the French MoD representatives for their interest in the project and their support to obtain frequency allocations necessary for the trials.

REFERENCES

[1] C. Lamy-Bergot, J-B. Chantelouve, H. Diakhaté, J-L. Rogier and J-Y. Bernier, "HF XL: adaptive wideband HF transmissions", Proc. of Nordic HF'13 conference, Fårö island, Sweden, August 2013.

[2] Telecom Bretagne. Software "Point à point". URL: http://www-iono.enst-bretagne.fr (link visited May 2013).

[3] STANAG 4285, Nato standardization agreement: characteristics of 1200/2400/3600 bits per second single tone modulators/demodulators for HF radio links, Feb. 1989.

[4] STANAG 4539 (Ed. 1), Nato Standardization Agreement: "Technical Standards for Non-hopping HF Communications Waveforms", (June 2005).

[5] MIL-STD-188-110C, Military Standard: interoperability and performance standards for data modems, September 2011.

[6] STANAG 5066 (Edition 1), NATO standardization agreement: profile for maritime high frequency (HF) radio data communications, Jan.2004.

[7] MIL-STD-188-141 A, Military Standard: interoperability and performance standards for medium and high frequency radio systems, March 1999.

[8] STANAG 4538, NATO standardization agreement: Technical Standards for an Automatic Radio Control System for HF Communication Links, annexe C, 2005.

[9] M.B. Jorgenson, R.W. Johson, K.W. Moreland, W.M. Bova and P.F. Jones, "Meeting military requirements for increased data rates at HF", IEEE Milcom'00, vol.2, pp. 1149-1153, October 2000.