N94-22801

First Satellite Mobile Communication Trials Using BLQS-CDMA

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Abstract

In this paper, technical results obtained in the first MSBN Land mobile technical trial are reported. *MSB-N* (Mobile Satellite Business Network) is a new programme undertaken by the European Space Agency (*ESA*), to promote mobile satellite communication in Europe, including in particular voice capability. The first phase of the MSBN system implementation plan is an experimental phase. Its purpose is to evaluate through field experiments the performance of the MSBN system, prior to the finalisation of its specifications. Particularly, the objective is to verify in the field and possibly improve the performance of the novel satellite access technique *BLQS-CDMA* (Band Limited Quasi-Synchronous-Code Division Multiple Access) ([1]), proposed as baseline for the MSBN.

1. INTRODUCTION:

The first series of MSBN Land Mobile trials were successfully conducted in June/July 1992, and followed up by some additional tests in January 1993. The tests were carried out using the Marecs-A satellite, existing infrastructure (ESA Villafranca C-band station) and BLQS-CDMA prototype terminals (one mobile and one fixed), developed within the European Space Agency's Advanced System Technology Programme (ASTP) by SAIT Systems (B).

The objectives of the trial were the testing of the technical performance of the system (with particular reference to the new access scheme BLQS-CDMA described in [1]), and the implementation of user oriented tests and demonstrations.

Overall, this first Land mobile trial has been very successful. It has not only enabled the acquisition of a large amount of important technical information, but it has also raised the confidence of ESA in the general system performance, and proved the viability of the new system in providing good quality communications.

The paper is divided into six sections (this is Section 1):

Section 2 includes a general description of the MSBN system concept ([4]). In Section 3, the main trial objectives are outlined. The overall test set-up is described in Section 4, together with the different facilities/equipment involved in the trial. In Section 5, the technical results are reported, of particular importance is the return link synchronization. Overall conclusions are drawn in Section 6.

2. DEFINITION OF THE MSBN CONCEPT:

The basic MSBN concept represented in Figure 1 shows that a fixed user has direct access to his own mobile fleet through the satellite transponder. The FES (Fixed Earth Station) is a VSAT station which operates in the Ku-band frequencies, and

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the MES (Mobile Earth Station) operates in the 1.5/1.6 Ghz frequency band (or L-band).

In the basic scenario, a pair of channels (one Forward Common Channel (FCC), and one Return Common Channel (RCC)) is permanently allocated to each network: a network consists of an FES and a set of MES's organized in a closed user group as a *star network.* The overall system is controlled by a Network Management Station (NMS) which has the capability to transmit and receive in both frequency bands (Ku and L-band).

The access technique is based on Code Division Multiple Access (CDMA). Therefore, several networks operate over the same frequency band (typically 1 Mhz), the various networks using a different set of codes. With the newly developed BLQS-CDMA scheme, both network terminal *synchronization*[1] and carrier frequency control[2] are required for optimum performance ([1]). This reduces intra-system interference (self-noise) with respect to conventional CDMA and simplifies the MES receiver design.

To achieve more easily synchronization, a common clock and frequency reference is broadcast by a master station (the NMS or alternatively one of the FES's) on a dedicated *pilot* signal, produced by direct sequence modulating a precise frequency reference. All signals transmitted by the FES's or MES's are synchronized with respect to this common reference signal.

Bandlimitation is achieved with Nyquist chip pulse shaping with no degradation compared to the unfiltered case.

In practice, BLQS-CDMA possesses all the intrinsic advantages of CDMA, but has an efficiency comparable to orthogonal transmission systems like FDMA and TDMA.

3. TRIAL OBJECTIVES:

As pointed out above, BLQS-CDMA relies on chip clock and carrier frequency synchronization for optimum performance. Chip clock synchronization is straightforward in the forward link (ie from the fixed station (FES) to the mobile one (MES)) while it is more problematic in the return link (ie from the MES to the FES). Due to this, one of the main objectives of the trial has been the verification of the return link synchronization.

In general, the key objectives of this first trial can be summarized as follows:

1. the verification of the *return link synchronization* algorithms of which two, one called "Dzung algorithm" ([3]) and the other called "Sait algorithm" ([2]), were implemented.
2. the verification of the global system performance in different environments (voice quality of the various vocoders, antenna tracking capability..)
3. the implementation of user oriented tests and demonstrations.

4. TRIAL CONFIGURATION:

4.1. Experiment Scenario:

A block diagram showing the configuration during the experiment is given in Figure 2.

The MSBN system is planned to be operational early 1995 and will use *EMS* (European Mobile Satellite). Due to the unavailability of EMS, the Marecs A-satellite was used instead, although the feeder links are at C-band (instead of Ku-band).

As shown in Figure 1, the following signals were transmitted/received:

- *The C-Band uplink signal*, transmitted from Villafranca (FES) to the MES terminal, was composed of two signals:

  1) *the Spread Spectrum (SS) pilot signal or FRC (Forward Reference Channel)* and,
  2) *the Spread Spectrum (SS) traffic signal or FCC (Forward Common Channel).*

  The baseband data entering the FES SS modulator can be selected between the vocoder output (voice mode), or a random data generator (data mode). All the satellite tests were performed in voice mode, as these provided the greatest feedback of system performance.

- *The C-band received signal or RCC (Return Common Channel)*, transmitted from the

[1] By synchronization event, we mean that all the transmitter code epochs and frequencies are quasi-aligned at the satellite transponder input. The error shall be less than ± 0.3 chips

[2] within a range of say $\pm\ 6.10^{-2} R_b$, R_b being the uncoded bit rate.

MES terminal to Villafranca (FES), consisted of *the MES Spread Spectrum (SS) signal*, which after down conversion was acquired and demodulated via the FES (SS) demodulator. Recovered baseband data was routed to the vocoder (voice mode), since, as already mentioned, all the satellite tests were performed in voice mode.

The maximum signal bandwidth was 1.2 Mhz.

4.2 Description of facilities/equipment involved in the experiment:

4.2.1 The Marecs-A satellite:

The Marecs-A is a geostationary satellite located 22.3 degrees East; its present inclination is i≈ 5°.

In general, the geostationary orbit inaccuracies (ie satellite's inclination) induce a doppler shift on both the carrier and chip frequencies of the MES signal received by the FES. This doppler has to be accounted for within the return link synchronization process.

4.2.2 The Agency's Payload Monitoring Station at Villafranca:

Situated close to Madrid (Spain), this station is the dedicated Marecs-A TT&C and payload-monitoring station. The station is fully equipped for payload testing with sophisticated computer-driven test equipment, 12 m C-Band dish, 4 m L-band dish and L-band standard gain horn for precise EIRP measurements. The main parameters of the C-band facilities are:

- Max C-Band EIRP: <= 80 dBW (6.4 Ghz).
- C-Band G/T: 32.4 dB/K

As shown in Figure 1, the interface between the *fixed terminal (FES)* and the C-Band station in Villafranca (S) was at IF (70 Mhz).

4.2.3 Description of FES & MES equipment:

4.2.3.1 Main characteristics:

The newly developed (MES & FES) prototype terminals include fully digital multirate modems using the BLQS-CDMA access technique. BLQS-CDMA is a direct sequence modulated CDMA (D-S/QPSK) that makes use of quasi-synchronized signature sequences (*preferentially phased Gold codes*[3]) belonging to an almost orthogonal sequence set.

The modem flexibility permits operation in several modes, depending on the selected chip rate (from 150 Kchip/s to 1.2 Mchip/s), bit rate (from 2.4 Kbit/s to 19.2 Kbit/s) and, spreading factor (from 31 to 511). Convolutional coding (r=1/2, K=7) may be applied to further enhance the system efficiency.

Both voice and data transfer are possible. Nevertheless, as mentioned above, only the voice mode was tested during the satellite trial. The voice is digitized using the SVQ (Spectral Vector Quantization) voice coding technique. Three different speech coders (operating[4] at 6.4 Kbit/s (Inmarsat-compatible), 3.0 Kbit/s & 1.8 Kbit/s respectively) are implemented.

4.2.3.2 MES equipment in Trial Vehicle:

The mobile set-up can be described as follows: the antenna was mounted on the roof of the trial vehicle (Renault Espace), whilst the HPA/LNA (High power amplifier/Low noise amplifier) module, MES terminal (developed by SAIT and interfacing at IF= 70 Mhz with the HPA/LNA module), and other supporting equipment were installed inside the vehicle and powered by a 12 V battery module.

The antenna used for the trial was a mechanically steerable prototype, developed within the European Space Agency's Advanced System Technology Programme (ASTP). It has a tracking capability and a gain of about 10 dBi. An omnidirectional antenna was also used to perform some tests at the lowest bit rates. Finally, a GPS antenna was mounted on the roof rack of the vehicle to allow GPS data recording during the mobile trials.

All relevant information regarding the state of both the mobile and static terminals could be visualized in real time graphically during the experiment and/or recorded in a capture file on the PC for further post-processing (MMI facility).

5. PRESENTATION OF RESULTS:

5.1 Test routes:

Tests were first carried out *in a fixed set up* between Villafranca and Brussels to ensure the system was functioning correctly; following this, the vehicle was fitted with the mobile terminal and verification of the system was again undertaken. The system was then ready for satellite testing in

[3] Gold codes all having mutual cross-correlation R_{xy}= -1 for Δ= two-sided maximum timing offset= 0.

[4] including error protection.

		Sequence Length (chips/symbol)				
		31	63	127	255	511
Symbol	9.6		X(*)	X(*)		
Rate	4.8	X		X(*)	X(*) (Mode 1)	
(Ksymb	2.4		X		X(*)	X(*)
/s)	1.2					X(*)

Notes:

(1) Mode 1 is the nominal mode.
(2) X indicates the possible modes of operations.
(3) (*) indicates the modes tested during the trial.
(4) During the satellite tests, the highest vocoder rate was always used for any given symbol rate.

Table 1: Modes of Operation.

earnest.
Most of the *mobile tests* were carried out on a section of the Brussels/Paris motorway to the south of Brussels, the surroundings were much the same for the entire length of motorway used. That is to say the sides of the motorway were lined with a mixture of high trees and bushes with the occasional open area while the central reservation was mainly clear of obstructions.

5.2 Modes of Operation:

As already pointed out, different modes of operation are possible, depending on the selected chip rate (from 150 Kchip/s to 1.2 Mchip/s), bit rate (from 2.4 Kbit/s to 19.2 Kbit/s) and, spreading factor (from 31 to 511). Table 1 shows all the possible combinations (indicated by X in Table 1). The majority of tests were carried out using mode 1 (from now on called the "nominal mode"). However to establish correct operation of the other modes, additional tests were also performed (indicated by (*) in Table 1).

5.3 Result Discussions:

For each mode of operation, a set of parameters were recorded at both fixed & mobile sites. Since it is not practical to present all the analyzed results from the trial, only some representative statistics covering the main parameters are presented in this paper. All of them refer to the nominal mode.

5.3.1 Acquisition/Reacquisition times:

During the mobile tests, it was not possible to measure accurately the acquisition/reacquisition times, however they were observed to be very fast and proved to be crucial in maintaining communications in a land mobile environment. Under Lab conditions, acquisiton was typically accomplished in less than 1 sec at Eb/No= 0.5 dB, whilst reacquisition times of less than 0.2 sec were achieved at Eb/No= 2dB and after a coasting time of 1 minute.

Generally, the tracking of the antenna performed extremely well even when the vehicle was turning at 30 deg/s. The angular sensor (added to the antenna during the January 93 tests) helped to a large extent to maintain correct antenna pointing during periods of blockage.

5.3.2 Performance of the RTN Link synchronization:

5.3.2.1 Definition of the RTN Link synchronization concept:

The goal of the RTN Link synchronization is to synchronize the code phase of the Return Common Channel (RCC) with the one of the locally generated reference at the FES (FRC). The RTN Link synchronization is accomplished in two phases: during the *acquisition phase*, both code phase and chip frequency errors are estimated by the FES and transmitted to the MES which adjusts its transmit code phase and chip frequency accordingly. During the *tracking phase*, the FES tracks the return link code phase error by comparing the code phase of the mobile terminal (RCC) with the code phase of the pilot (FRC) and commanding the necessary corrections in the MES. This operation is repeated at regular time intervals (To= 1 second).

Two different tracking algorithms, called "Dzung algorithm" and "Sait algorithm" respectively, were tested during the trial. The "Dzung algorithm" ([3]) can be described as "a phase correction based method", since the corrections sent by the FES to the MES represent code phase correction values. In contrast, the "SAIT algorithm" ([2]) is a "frequency correction based method". The FES compares now the chip frequency of the mobile terminal (MES) with the chip frequency of the pilot and uses the forward link to command the chip frequency corrections within the MES.

Both algorithms were tested during the satellite trials in both static and mobile conditions; all the mobile tests were carried out on the same section of the Brussels/Paris motorway to the south of Brussels, the surroundings were much the same for the entire length of the motorway used. In all cases, speeds of up to 120 Km/h were reached and both hard acceleration and breaking conditions were tested. Each recording session lasted for a duration of 10 minutes. The results are presented below.

5.3.2.2 Results on RTN Link synchronization:

The results on the RTN Link synchronization are shown in Figure 3. Both "Dzung" and "Sait" algorithms show similar performances in a mobile environment: in both cases, the mean of the steady-state code phase error is < 0.02, and the standard deviation is not greater than $\pm$ 0.08 chips. Concerning the D-DLL's jitter[5], the values are slightly worse for the "Dzung algorithm" than for the "Sait algorithm"; this difference in performance may be due to the different code phase control procedures (discrete or continuous) each algorithm applies. The "Dzung algorithm" is based on code phase corrections: the D-DLL has to accept every second code phase jumps of f(t).To, where f(t) is the residual[6] chip frequency deviation (in chips/s), and To (=1 sec) is the time correction interval. The D-DLL reacts to these jumps within a transient time that decreases with the D-DLL bandwidth.

On the contrary, the "Sait algorithm" is a method based on chip frequency corrections; this means that the code phase is updated continuously (ie Rb code phase corrections per second at the MES, where Rb is the bit rate), and the D-DLL smoothly tracks the code phase evolution without any transient.

5.3.3 Subjective voice quality:

The voice quality provided by each of the three vocoders implemented in the terminals (6.4, 3.0 & 1.8 Kbit/s) was evaluated during the trial. For all of them, both continuous transmission and voice activation were tested. The speech quality of the vocoder was, under favourable conditions, felt to be good at 6.4 Kbit/s and 3 Kbit/s, while at 1.8 Kbit/s, the quality degraded somewhat.

A demonstration was organized at ESTEC the last day of the trial, when more than 20 people attended experiencing with satisfaction the new system. People appreciated the fact that the voices of individuals could be recognized.

6. CONCLUSIONS:

During this first series of MSBN Land Mobile trials, the use of BLQS-CDMA for mobile applications has been positively demonstrated. The results obtained were very encouraging and will allow further enhancements of the system performance.

Main achievements can be summarized as follows: both 6.4 Kbit/s & 3.0 Kbit/s speech coders provided good voice quality (for the 1.8 Kbit/s, the quality was somewhat degraded), and was found to be insensitive to the vehicle speed. The initial acquisition and reacquisition after blockages was very fast (an estimation of the latter being in the order of those measured under lab conditions). Generally, the tracking of the antenna performed extremely well even when the vehicle was turning at 30 deg/s. The angular sensor (added to the antenna during the January 93 tests) helped to a large extent to maintain correct antenna pointing during periods of blockage. The return link synchronization was tested with a variety of doppler shifts and doppler rates and found to work quite well; in mobile conditions, code phase errors $< 0.02 \pm 0.08$ chips were achieved.

References

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[2] M. Dothey, C. Van Himbeeck, I. Deman, B. Wery, *Final report on "Baseband Processor for Reconfigurable Mobile Terminals"*, ESTEC contract no. 8909/90/NL/RE.

[3] W.R. Braun, D. Dzung, P. Eglin, G. Mastner, P. Rauber, *Final report on "Definition of the Mobile Network Synchronization Experiment"*, ESTEC Contract No. 8728/90/NL/RE, November 1990.

[4] A. Jongejans et al., *"The European Mobile System"*, also included in the Proceedings of the IMSC'93.

[5] Digital Delay Lock Loop of the FES traffic demodulator
[6] ie after the acquisition phase

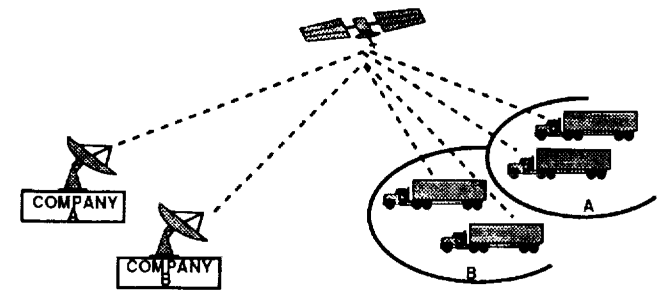

FIGURE 1: MOBILE SATELLITE BUSINESS NETWORK CONCEPT

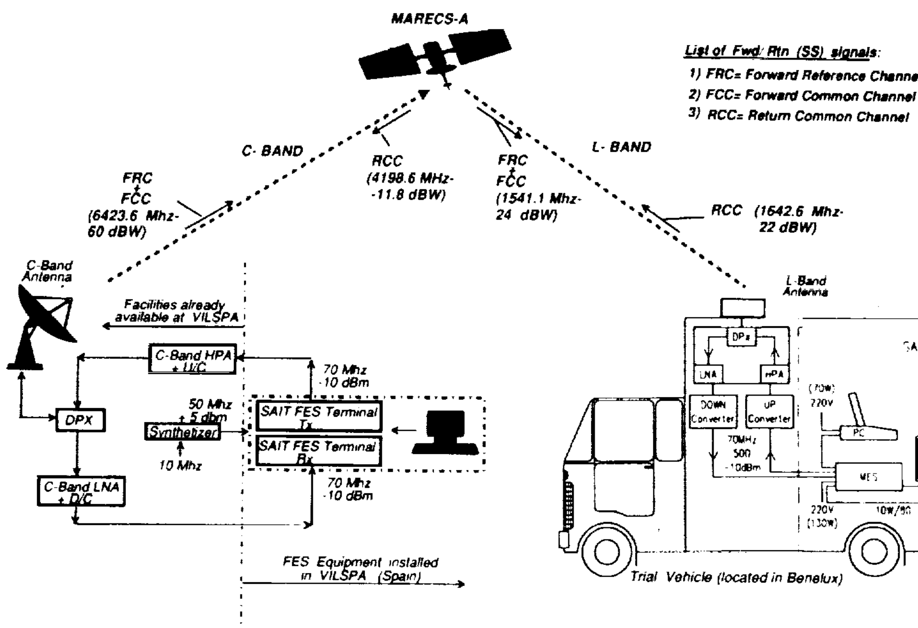

FIGURE 2: EXPERIMENT CONFIGURATION

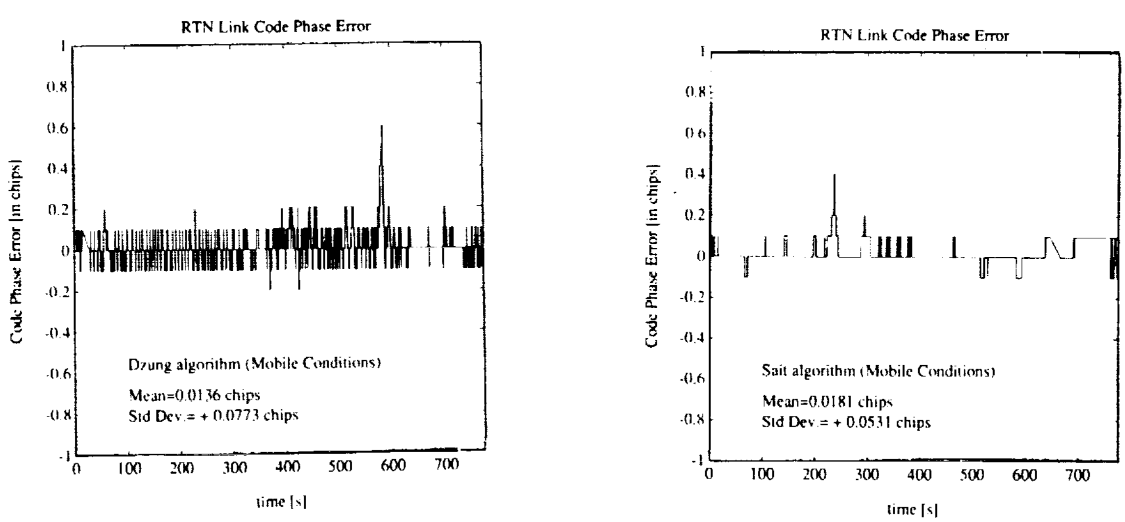

FIGURE 3: RTN LINK CODE PHASE ERROR IN TRACKING MODE.