A DSP-BASED DS/CDMA MODEM FOR MULTIMEDIA APPLICATIONS OVER GEO-STATIONARY SATELLITE NETWORKS

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ABSTRACT

Multimedia services over satellite networks require a large amount of bandwidth for the delivery of variable-bit-rate video and audio signal with adequate quality of service. Hence, the bandwidth allocation has to be efficiently managed. In such sense, CDMA is a flexible multiple access technique since it allows a dynamic configuration of the resources allotted to the users of the system. This paper[1] aims at describing a DSP-based DS/CDMA satellite multimedia system for multimedia applications, working in geo-stationary (GEO) satellite networks. The DSP implementation of the satellite modem is described in detail, both for what concerns the hardware section and the signal processing algorithmic section. The developed prototype, whose test is expected during year 2001, should be considered as a basic platform for developing flexible software radio-based architectures for satellite communications.

1. INTRODUCTION

The continuous development of telecommunication systems able to satisfy the demands of a growing number of users, asking for a continuously increasing range of multimedia services, has yielded to study more and more advanced and efficient transmission techniques. In particular it has been considered the development of satellite transmission with receivers that are able to demodulate many different kinds of information coming from different sources [1]. The satellite environment allows one to overcome some limitation inherent to the terrestrial networks mostly in terms of available bandwidth and coverage area. In particular, the increasing request of providing residential users spread over wider and wider areas with different kinds of multimedia services (video, voice, INTERNET browsing, distance learning, remote land surveillance etc.) involves the necessity of integrating wide coverage networks, such as the satellite ones, with terrestrial wireless and wired networks (e.g.: cellular phone GSM and UMTS networks, coaxial cable networks, POTS networks, fibre networks, etc.), which are characterised by local coverage of relatively small areas. The integration of heterogeneous networks involves a bi-directional transmission from earth stations (connected with terrestrial networks) to satellite of different kinds of information related to several multimedia services, each characterised by its own specific bit-rate, traffic typology and quality of service requirements. In such perspective, the flexibility and the software reconfigurability of the transmission link depending on the quality-of-service requirements is a key issue in the effective design of new generation multimedia systems. This aspect is particularly important for the satellite link, where the on-board payload cannot be modified after the orbit launch. To this aim, the ad-hoc implementation approaches, followed in the recent past, seem to be quite inadequate. On the other hand, Digital Signal Processing (DSP) architectures [2] and software radio architectures [3] allows the implementation of flexible communication systems that can be easily updated by means of remote downloading of software tools [3]. This is possible by means of the software implementation of advanced digital signal processing techniques for telecommunications. Today many signal-processing functionalities in digital transmission systems are implemented via software up to intermediate frequency (IF) stage with lower costs than hardware realisation and controlled accuracy. The final target of the software radio technology is the implementation of multi-mode and multi-bandwidth telecommunication systems with characteristics defined by software over all protocol layers. This means a multi-mode radio with software dynamic characteristics defined in all protocol stack layers, included the physical one. The present work is inserted in such a challenging technological framework. The HW/SW realisation of a DSP-based DS/CDMA satellite modem for multimedia applications over Ka-band (20-30 GHz.) geo-stationary (GEO) satellite networks has been investigated within the scope of the ASI/CNIT project: "Multimedia Services on Heterogeneous Network connected via Satellite". The project started in 1998 and is funded by the Italian Space Agency (ASI)

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and by the Italian Inter-University Consortium in Telecommunications (CNIT). The final target of the project is the implementation of a test-bed platform for future experiments on advanced signal processing algorithms for optimal detection in DS/CDMA-based satellite communications. In the presented prototype, currently under hardware assembling, almost all the signal processing functionalities at the receiver side are software-implemented (i.e. carrier recovery, PN acquisition and tracking, PN de-spreading, and CDMA multi-user detection). The actual prototype test is foreseen at the beginning of 2001 year. In the present paper, the detailed analysis of the proposed HW/SW modem architecture is presented. A global system description is matter of Section 2. The hardware DSP architecture of the modem is described in Section 3. The software part of the modem related to DS/CDMA signal-processing algorithms is presented in Section 4. Finally paper conclusions are drawn in Section 5.

2. GLOBAL SYSTEM DESCRIPTION

The project ASI/CNIT is aimed at analysing most parts of the problems related to a satellite or terrestrial/satellite interconnection [4]. The paper focuses on some problems met during the work and the solutions envisaged for various application scenarios. The ASI/CNIT project considered different applications scenarios in order to highlight the most important factors that influence the delivery of a TCP/IP service over a satellite network [4]. At the same time, innovative configurations and services are also considered, in order to exploit the real advantages of a satellite system. The scenarios considered in the project are listed as follows:

1. Point-to-point IP satellite network;
2. IP Multicast satellite network;
3. Point-to-multi-point satellite IP network (ISDN return link);
4. Point-to-multi-point satellite IP network (satellite return link);
5. Satellite TCP/IP network
6. Satellite TCP/IP network (Multiple Access).

The scenario #6 perhaps represents the most ambitious target of the project since it completes the system with a multiple access technique to the shared satellite resource.

This scenario, described in Figure 1, employs a multiple access protocol to manage the access to the shared satellite channel. This configuration solves two considerable problems existing in the previously listed scenarios, i.e.: not scalability issue due to the multi-hop nature, and low utilisation of the satellite channel since its broadcasting characteristic is not exploited.

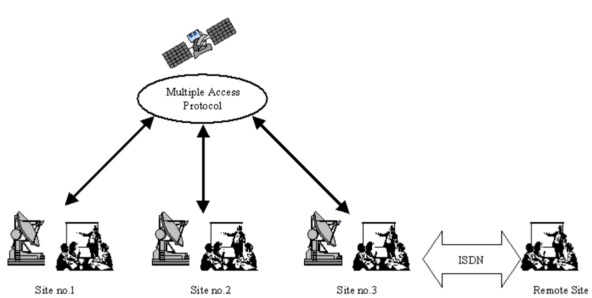

Fig. 1. Satellite TCP/IP network with multiple access to the shared channel

Among the different kind of available multiple access techniques (i.e. slotted ALOHA, TDMA, CDMA)- particular interest gained the DS/CDMA technique which allows the software realisation of different network topologies by multiplexing several logical channels over the same physical channel. This result has been obtained with a joint effort in the field of network research and in the DSP-based realisation of a satellite modem, as dealt in the following sections of the paper.

3. DSP-BASED MODEM ARCHITECTURE

A block diagram of the architecture of the multi-code DS/CDMA modem considered in the present dealing is depicted in Figure 2. The modem architecture schematised here can provide a maximum upstream bit-rate equal to 64 Kb/s x 6 = 384 Kb/s (corresponding to $\boldsymbol{m} = 6$ PN encoders enabled to transmit). The multiple access protocol chosen is the *fully asynchronous CDMA* [5], with upstream transmission allowed to each user without any bandwidth or time restriction. Such a choice is motivated by the intrinsic asynchronicity of the multimedia application considered for the actual use of the modem (i.e. interactive videoconference). The digital modulation employed is the QPSK one [6] and the selected spreading factor N is equal to 63, corresponding to an occupied signal bandwidth equal to about 4.12 MHz.

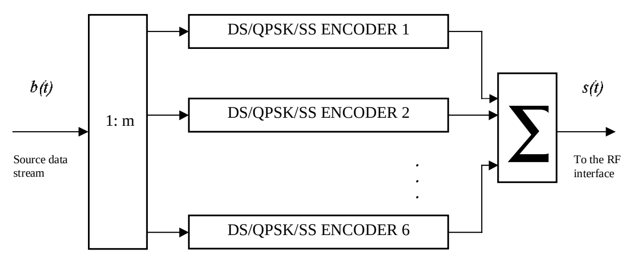

Fig. 2 Transmitter modem scheme

The receiver architecture, depicted in Figure 3, is made up by a bank $\boldsymbol{m}$ of DS/QPSK/SS decoders; each of one devoted to recovering the signal components transmitted by the encoders enabled for each user. The de-modulation and de-spreading blocks implement the carrier recovery, PN acquisition and tracking algorithms required in order to ensure the correct receiver synchronisation. After de-spreading, a multi-user detection (MUD) block is considered in order to reduce the amount of MAI.

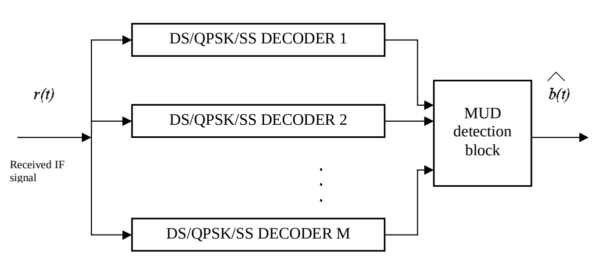

Fig. 3. Receiver modem scheme

The hardware architecture implementing the modem schemes of Figure 2 and 3 is depicted in Figure 4.

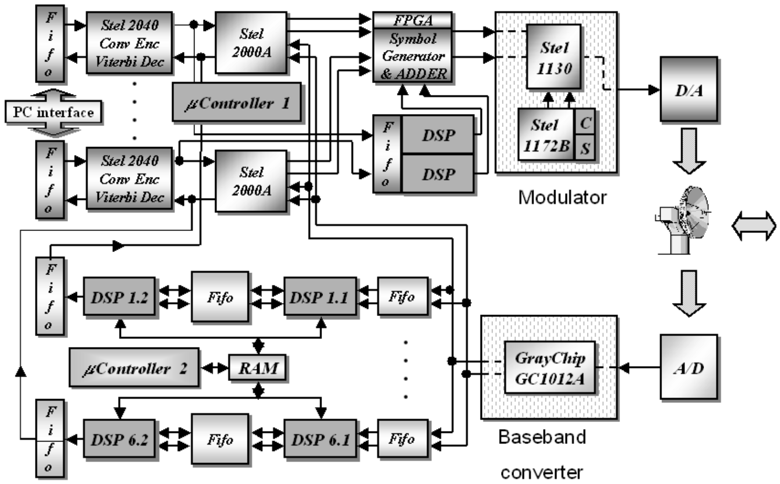

Fig. 4. Hardware modem architecture

The hardware architecture of the DS/CDMA modem can be subdivided into two main sections:

- *Custom ASIC device section*, implementing basic data transmission functionalities, such as convolutional FEC coding and Viterbi decoding at rate = 1/2 (ASIC component employed: STEL2040) and single user DS/SS transmitter/receiver (ASIC component employed: STEL2000A). The custom ASIC device section also includes a micro-controller HITACHI H8/3067 managing a single PN encoder together with a FIFO memory with serial output used for loading data to be transmitted and memorising the received data. This side, with a fully operating transmitter and receiver, will allow the development of a high performance, DSP device side. In this way, limited performance of single user (conventional) receiver, implemented by the STEL 2000A Spread Spectrum transceiver will be sensibly improved by the multi-user detection algorithms hosted on the DSPs.
- *Programmable DSP device side*, based on DSP, supports both conventional (single user) and multi-user detection. As shown in the Figure 4, 14 DSPs are present in this board: 2 DSPs will be used to give higher flexibility to the transmitter side, (variable length preamble, and other future developments) and the other 12 DSPs, (2 in each of the 6 channels), are employed to implement the multi-user algorithms.

The modem device can operate in three different modes: a *custom mode*, a *hybrid mode* and a *DSP mode*. In the first one the transmitter and the receiver are implemented by the Custom side. In the hybrid mode the custom side, and the 2 DSPs in the transmitter, are used to produce a flexible modulated signal while the other DSPs implement a multi- user detector. In DSP mode the DSPs work both to transmit and to receive.

4. SIGNAL PROCESSING ALGORITHMIC SECTION

The implementation of the DSP section (depicted in the lower part of Figure 4) has been completed and the debug and test phase initiated at the time of this writing. One of the challenges of this project is represented by the DSP realisation of all the functional blocks of the modem in a general-purpose DSP processor. The main feature of the proposed communication device is the ability to be reconfigured by software commands but at the same time; to implement technically advanced receiver structures. The above considerations led to the development of a two-processor modem card, whose block diagram is depicted in Figure 5. A fully scalable architecture has been designed around the base modem card, allowing the stack assembly of two or more cards to increase the processing power of the device. Each modem card can act as a multi-code CDMA transmitter or a multi-code multi-user detection receiver. When used for reception, the micro-controller loads the DSP 1 with the synchronisation and tracking program code, while the DSP 2 is loaded with the multiuser CDMA receiver program.

The transmitter is achieved with the same card but loading the DSP 1 with the frame formatter and spreader and the DSP 2 with the pulse generator and eventual transmission power control algorithms. As concerns the signal processing code for the receiver a series of multi-user detectors have been evaluated in the design phase. The receivers elected for implementation are:

- LMMSE CDMA multi-user detection algorithm [7];
- "Blind" (minimum output energy) multi-user detection [8] with two variants introduced to fight the constant phase error introduced by the synchronization stage: a differential encoding and a trained carrier phase estimation.

The DSP board has been equipped with two TMS320C6201 DSP processors and a Hitachi micro-controller. The system clock will be set to 250 MHz. From an deep analysis of the receiver complexity the selected algorithm has been implemented and optimized for the selected target architecture. A single DSP processor contains the 6 LMMSE decision-feedback reception sub-algorithms with the selected specifications. The performances of the selected receivers have been simulated with the C++ IneSiS [9] tool over a large variety of operating conditions. The detailed results of the simulations are not reported in this paper, however an overall comparison of the receivers performances for the expected operating environment is shown in Figure 6 for 6 earth stations at full load (6 codes per station).

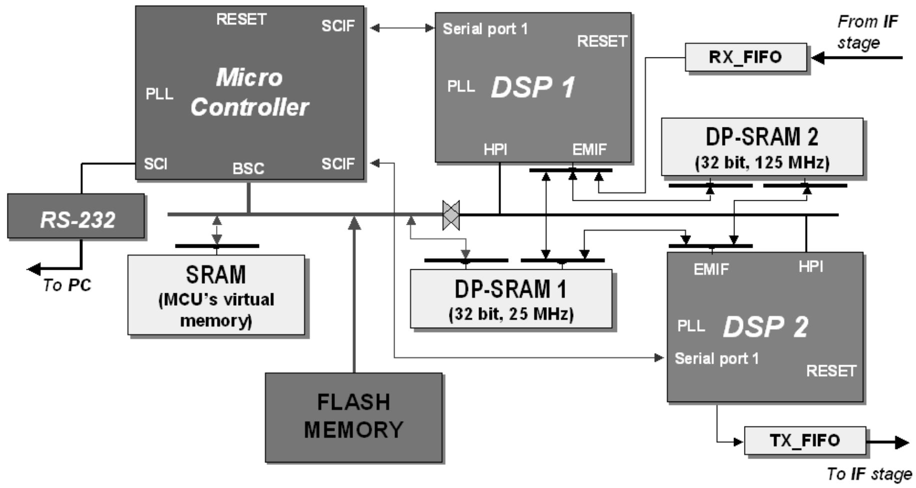

Fig. 5. Modem base card

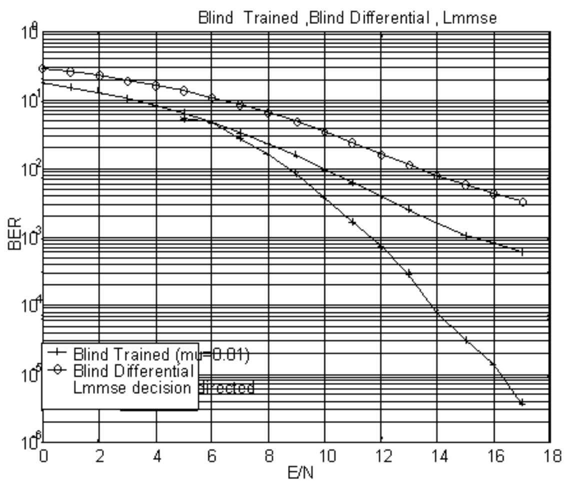

Fig. 6. Comparison of the Selected Receivers

5. CONCLUSIONS

In this paper is presented one of the main targets of an ongoing project (Integration of Multimedia Services on Satellite Heterogeneous Network): the realisation of a satellite CDMA modem on DSP architecture. The design phase, carried out from a national research team, has shown the feasibility of a fully programmable DSP implementation of complex receiving and signal processing structures for satellite VSAT transmission on the Ka (20-30 GHz band). The modular architecture currently under development will provide an useful transmission test-bed for advanced CDMA communication system preparing the migration towards the full DSP definition of the transmission chain, widely envisaged for future generation communications systems.

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