Multiple Gateways Synchronous CDMA Access in the Framework of COMPOSE

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ABSTRACT

COMPOSE (Composition Of Mobile Pre-trip, On-trip SErvices) is a Research and Technology Development project co-funded by the European Commission and aiming to define the specifications of an innovative mobile service scenario for travelers and to demonstrate the effectiveness of new Location-Based and Broadcast/Multicast services. This goal will be achieved by means of a comprehensive service Test-Bed (the COMPOSE Demonstrator) combining the exploitation of terrestrial and satellite communication and navigation facilities together with Geographical Information (GI) contents. The full coverage of mobile users needs (both pre-trip and on-trip), combined with a single user access point to continuously broadcasted general information (finance, traffic, news and weather forecasting) and on demand information (messages, point of interest, route guidance, etc…) is the COMPOSE service concept. In the COMPOSE on-trip framework in particular, users will have wireless-link access to both broadcast/multicast one-way services through an S-UMTS (Satellite Universal Mobile Telecommunication System) standard compliant satellite link and point-to-point two-way location-based services through a GPRS (General Packet Radio Services) terrestrial link. This paper is mainly focused on the broadcast/multicast services provision and in particular on the synchronization strategy adopted and implemented in the COMPOSE demonstrator in order to synchronize the transmissions of two different gateways accessing the satellite facilities. This multiple gateway uplink architecture indeed is a very innovative approach extending the SKYPLEX concept, only conceived for operation in the DVB (Digital Video Broadcasting) context, to the S-UMTS CDMA (Code Division Multiple Access) technology environment.

COMPOSE BROADCAST/MULTICAST FRAMEWORK

One of the main objectives of COMPOSE (Composition Of Mobile Pre-trip, On-trip SErvices) is to demonstrate the provision of a set of Broadcast/Multicast Services identified in the framework of the project. From a technological point of view, these services will be provided through the utilisation of real satellite facilities (Artemis or Inmarsat 3F5) accessed from a Gateway Station located in Lario (Italy) and through the design and development of innovative ad-hoc equipment compliant to S-UMTS (Satellite Universal Mobile Telecommunication System) standards based on W-CDMA technology (Wideband Code Division Multiple Access). The COMPOSE vehicular User Terminal utilised in the demonstrations will be equipped with an ad-hoc developed S-UMTS module able to receive the aforementioned broadcast/multicast data and to store them in an Intermediate On-Board Unit (OBU). Broadcast data in the On Board Unit will be frequently refreshed as the broadcasted signal is received with a sufficient signal to noise ratio and will be accessed in a sort of “off line navigation” through a Personal Digital Assistant (PDA) opportunely connected to the storing device. Through the PDA the users will be able to select the broadcast operational mode between a local PULL Mode (users request information from the OBU) and a local PUSH mode (users receive information from the On Board Unit automatically, on the basis of a previous service configuration), and to personalize services. As far as Multicast Service is concerned, it allows Service Providers to deliver information to selected users on the basis of their position (location area code) or on the basis of pre-defined user group codes. Users addressed in COMPOSE will automatically visualize the messages on the PDA in a Push mode configuration. The broadcast/multicast services selected for demonstration in COMPOSE are the following ones:

- Weather Information Service: European, National and Local weather forecasting.
- News & Sports: European, National and Local news and sport including links to dedicated Internet Service Providers (ISP) for more detailed information.
- Cultural & Entertainment: National and Local cultural information including links to dedicated ISP for more detailed information.

- Financial Information: European and National financial information consisting of main stock price-trends and links to dedicated ISP for more detailed information.
- Traffic Information: National and Local traffic information including links to dedicated ISP for more detailed information.
- Generic Multicast Messages to restricted area and/or directed to a selected user group.
- Advertising Messages.

Two different CDMA channels will be utilised in order to provide the selected services, the first one providing Weather, News, Cultural and Financial broadcast services whilst the second one exclusively used for Multicast messages delivery in conjunction with broadcasted Traffic Information. The most important innovative concept objective in the framework of COMPOSE is the envisaged multiple-gateways up-link S-UMTS architecture as opposed to the current typical single-gateway up-link station arrangement of satellite broadcast systems. COMPOSE will extend the SKYPLEX concept, only conceived for operation in the DVB (Digital Video Broadcasting) context, to the UMTS CDMA technology environment moving the multiplexing node from the gateway on ground to a gateway in space and thus allowing each operator to have direct-shared access to the satellite transponder. In this way each operator would be able to deliver his contents without the need for terrestrial links to a centralised ground gateway, but using his own gateway. Small gateways will be in general required due to the small capacity needed by each operator and an efficient handling of satellite capacity can thus be achieved while avoiding the bottleneck for service providers to use costly satellite communications. In particular two emulated gateway stations (opportunely synchronized) accessing the real satellite facilities are envisaged within COMPOSE, each transmitting one of the two CDMA traffic channels needed for broadcast/multicast services provision. The overall architecture of the COMPOSE demonstrator for broadcast/multicast is shown in Fig. 1.

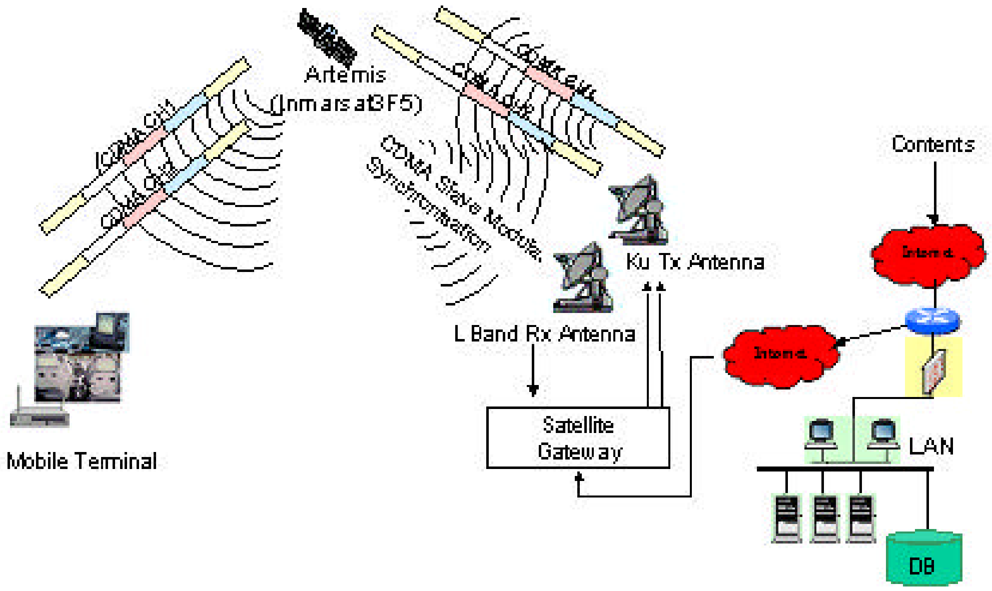

Fig. 1. High Level Architecture of the Satellite Communication Network

GATEWAYS SYNCHRONISATION

Multiple satellite-Gateway stations access will be emulated within COMPOSE through the transmission of DS-CDMA (Direct Sequence CDMA) signals onto a given channel frequency from two emulated Gateway Stations opportunely synchronized. Synchronisation at the satellite side among the up-link codes transmitted by the gateways is the challenging feature needed to avoid multiple-access interference. To achieve codes synchronisation, a closed-loop scheme will be implemented in COMPOSE. One of the two Gateway Stations (referred as Gateway Station 2 or Slave) controls the epoch of its transmitted codes relying upon feedback information derived locally through a comparison with signals transmitted from the other Gateway Station (referred as Gateway Station 1 or Master) and received through the satellite link. The Slave Gateway steadily adjusts the transmit codes epoch such that they appear synchronous in the down-link with the Master Gateway ones. The synchronisation approach adopted in COMPOSE is based on the utilisation of the Primary Common Control Physical Channel (P-CCPCH) envisaged in the S-UMTS standards [1], [2], [3]. Next Fig. 2 shows a simplified block diagram explaining the proposed synchronisation mechanism.

The Gateway Station 1 transmits a CDMA signal carrying the Walsh-Hadamard Code 0 (WH0) on the P-CCPCH. This signal is received at the Gateway Station 2 together with its own transmitted signal marked with the Walsh-Hadamard Code 2 (WH2). A Synchronization Error (code, frequency and timing differences) is then extracted and used to correct the signal transmitted by the Gateway Station 2. The master equipment at the Gateway Station 1 is just a free running CDMA modulator whilst the slave equipment at the Gateway Station 2 must be a complete MODEM (MOdulator/DEModulator) with both the receiving and transmitting parts. Both modulators (Master and Slave) transmit two CDMA channels, a P-CCPCH and an S-CCPCH (Secondary - Common Control Physical Channel). The P-CCPCH is used essentially for synchronisation and control purposes whereas the S-CCPCH is used to transmit broadcast/multicast traffic data. The main characteristics of the S-UMTS physical layer implementing the P-CCPCH and the S-CCPCH are reported in Tab. 1. The processing carried out by the master modulator after the radio frame formatting is shown in Fig. 3.

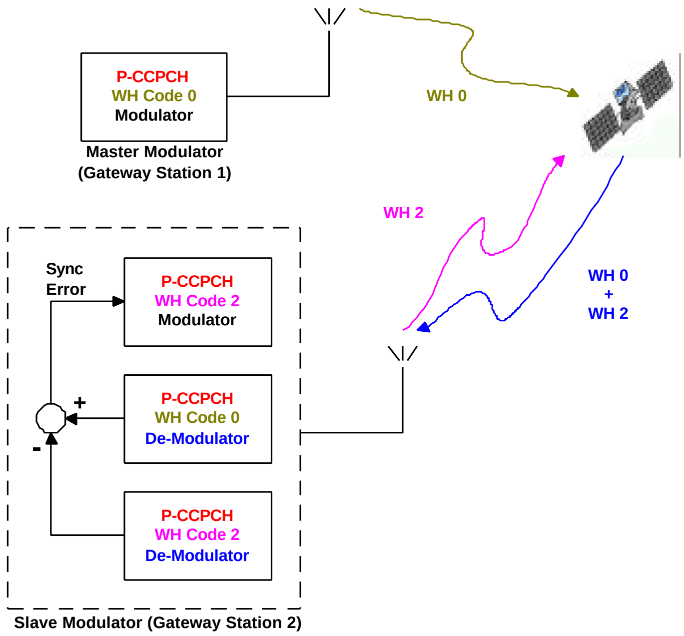

Fig. 2. Master and Slave Gateway Stations Synchronisation Approach

Tab. 1. Physical Channels Main Characteristics

Physical Layer Characteristic	P-CCPCH	S-CCPCH
Information Bit Rate	575 bits/sec	24 Kbits/sec
Interleaver Frame Length	184 bits	1920 bits
Interleaver Frame Duration	320 ms	80 ms
Coding	FEC 1/3	FEC 1/3
Channel Bit Rate	3.75 Kbits/sec	60 Kbits/sec
Radio Frame Length	300 bits	4800 bits
Radio Frame Duration	80 ms	80 ms
Chip Rate (UMTS Standard 3.84 MHz divided by 8)	480 KHz	480 KHz
Roll Off Factor	0.22	0.22

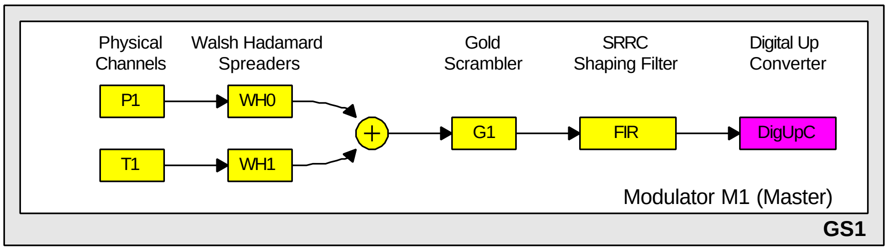

Fig. 3. Master Modulator Block Diagram

The two channels (P1=P-CCPCH and T1=S-CCPCH) are first spread using two different Walsh-Hadamard codes (WH0 and WH1) [4] [5] and then mixed and scrambled using a given Gold code (G1). Afterwards an SRRC (Square Root Risen Cosine) pulse shaping FIR (Finite Impulse Response) filter is applied, see also [6] and [7], and finally a digital up conversion is performed moving the central frequency of the signal to 52.88 MHz. After the digital processing, a digital to analog conversion at 122.88 MHz is carried out in order to obtain an image of the signal at 70 MHz (122.88 MHz - 52.88 MHz). This image is then selected with a Band Pass Filter (BPF) in the IF Interface, included in the modulator, up converted to Ku band and transmitted towards the satellite. The complete block diagram of the MODEM emulating the Slave Gateway Modulator is reported in Fig. 4. It includes two sections, the Slave Modulator and the Slave Demodulator. Only the P-CCPCH channels (shortly P1 and P2) are demodulated within the Slave Demodulator to carry out the synchronization between the Master and the Slave Modulators.

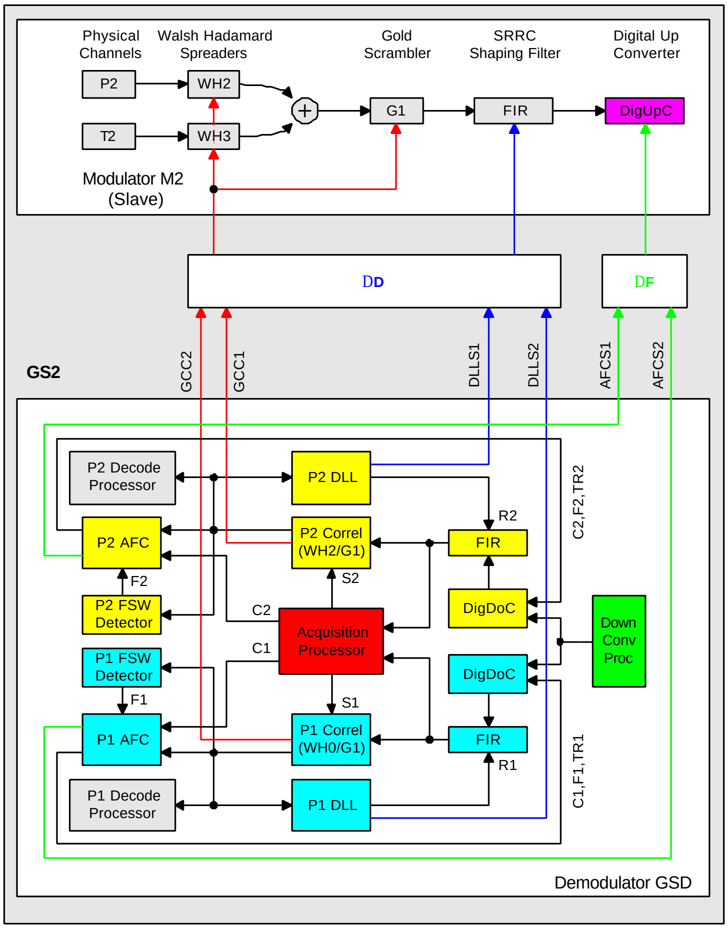

Fig. 4. Slave Modulator Block Diagram

The Slave Modulator section block diagram is almost identical to the Master Modulator one with only the following modifications to be taken into account:

- The pair P1/T1 must be substituted with P2/T2 (the Slave Modulator transmits a second P-CCPCH and a second S-CCPCH).
- WH codes must be set different (i.e. WH2 and WH3) in order to obtain four orthogonal channels (note that the Gold code remain unchanged).
- The WH and Gold code generators and the FIR must be able to accept corrections to modify the timing in order to achieve the synchronisation between the two Modulators.

The MODEM works as follow:

- First of all the incoming signal, carrying both the P1 and the P2 channels, is digitally down converted and filtered with a SRRC FIR filter in order to recover the base band signals;
- The FIR output is passed to an Acquisition Processor able to recover the Walsh-Hadamard and Gold codes synchronisation, in time division mode, for both the P1 and P2 channels;
- Then the "Correl" blocks, using the Acquisition Processor information, perform the Walsh-Hadamard de-spreader and the Gold de-scrambler processing achieving QPSK (Quadrature Phase-Shift Keying) symbols;
- The "Correl" blocks, together with the timing loop (Delay Lock Loop blocks, DLL), are used to extract the information concerning the time difference between P1 and P2; this information is sent to a discriminator (?D) in order to realise a via-satellite timing loop necessary to achieve the timing synchronisation between P1 and P2; the discriminator (?D) extracts the timing corrections filtering the timing difference between the signals P1 and P2;
- Finally the "AFC" blocks (Automatic Frequency Control) are used to carry out the frequency synchronisation: a discriminator (?F) extracts the frequency corrections filtering the frequency difference between P1 and P2;

The "Decode Processors" are used to check the correct reception of the channels P1 and P2. The correctness of both channels can be controlled before the beginning of the synchronisation process. Timing corrections are carried out updating the FIR coefficients of the Slave Modulator and modifying the chip counters of the Walsh-Hadamard and Gold code generators. The frequency correction is obtained modifying the value of the numerical controlled oscillator used in the digital up conversion.

NUMERICAL SIMULATIONS

Numerical simulations have been carried out to analyse the control loops on which the synchronisation mechanism is based [8]. Since a GEO satellite will be used in the experiment, it is necessary to take into account, at our latitude, a distance of about 38000 Km. The implicit delay of the loop is then about 252 msec and therefore the loop bandwidth have to be opportunely tuned in order to obtain a stable and, at the same time, effective control. The results presented here are based on a bit true simulation in Gaussian environment forcing an Eb/No of 0 dB. The timing synchronisation has been achieved through a first order loop whose behaviour has been analysed controlling the evolution of the two state variables of the DLLs used to lock separately the channels P1 and P2. We forced the Slave modulator to start with an initial delay of 18.8 chips with respect to the Master Modulator. The behaviour of the Slave Modulator DLL is reported in the Fig. 5.

The Slave Modulator recovers, using a given loop constant, the timing gap in about 7 millions of samples corresponding to 3.65 seconds (the sample rate is 1.92 MHz). The slope of the curve is then about 5 chips/sec so the worst case (1280 chips corresponding to half Gold Code) is recovered in about 256 seconds. A similar approach has been also used to control the results of simulation concerning the frequency synchronisation. The two state variables of the AFC loops used to lock separately the channels P1 and P2 have been plotted and analysed. We forced an initial carrier frequency error on both the modulators respect to the digital intermediate frequency of 480 KHz. The central frequencies of the Master and Slave Modulators were respectively 480125 Hz and 480450 Hz. During a first acquisition phase the AFC loops lock separately to their frequencies (i.e. 480125 Hz and 480450 Hz) then the Slave Modulator evolves toward the central frequency of the Master one reaching it (i.e. 480125 Hz) in about 4 million of samples (about 2 seconds). Fig. 6 shows the behaviour of both the AFC loops.

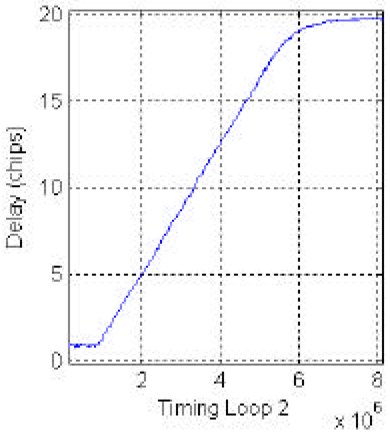

Fig. 5. Slave Modulator DLL Evolution

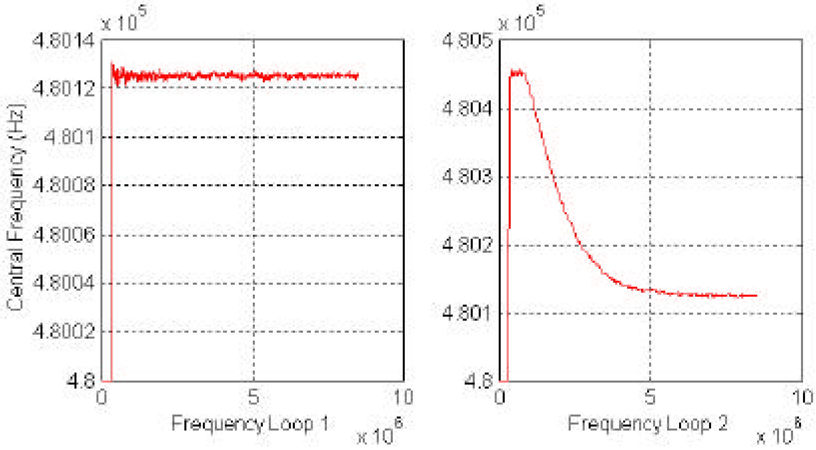

Fig. 6. Master and Slave Modulators AFC Evolution

Extensive simulations have been done to obtain BER (Bit Error Rates) curves in both asynchronous and synchronous situations. After reaching the synchronisation between the modulators the expected gain has been obtained as shown in Fig. 7.

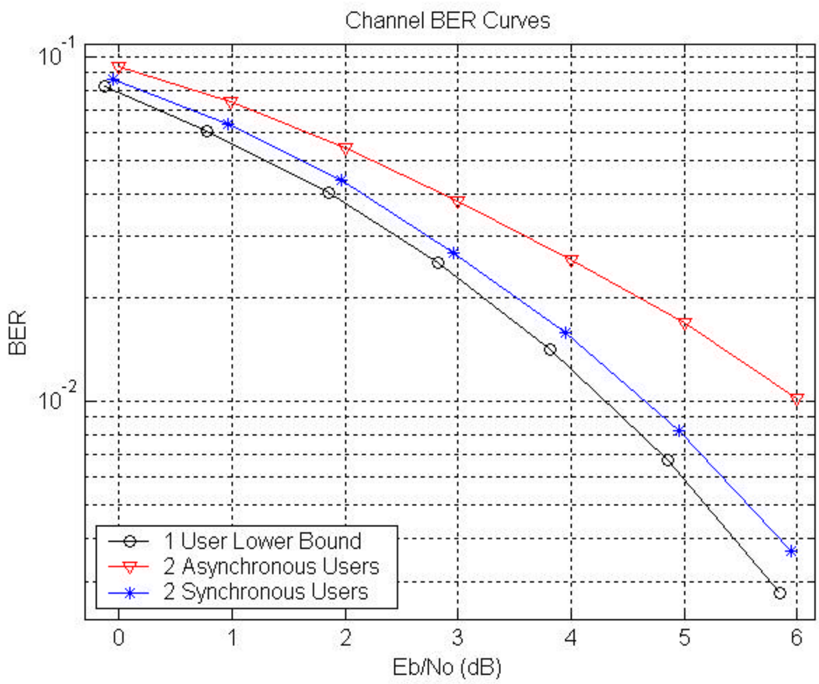

Fig. 7. BER Curves

The implementation loss of the curve "2 Synchronous Users" respect to the lower bound is less than 0.5 dB at 6 dB of Eb/No and it is due essentially to three factors:

- The fixed point implementation affected by truncation and rounding errors;
- The not orthogonal interference caused by the primary channels (transmitted at the same Eb/No used for the traffic ones but with less power being their bit rate lower than the bit rate of the traffic channels);
- Residual timing and frequency errors;

The curve "2 Asynchronous Users" is the result of the simulation obtained disabling the synchronisation process. As we can see the implementation loss is about 1.7 dB at 6 dB of Eb/No.

CONCLUSIONS

In this paper the synchronization mechanism selected for implementation in the framework of the IST COMPOSE project in order to synchronize two different gateways accessing real satellite facilities (emulated through two different but co-located S-UMTS compliant modulators ad-hoc developed in the framework of the project) has been described. The results of preliminary simulations indicating the effectiveness of the aforementioned approach and the advantages obtained in terms of reduced interference have been moreover presented.

ABOUT THE AUTHORS

P.Balletta is the COMPOSE program manager. His main contributions concern the overall system definition. M.Albani contributed in defining the COMPOSE Demonstrator communication infrastructure and the UMTS-like satellite link. E.Rossini defined the algorithms of the physical layer and carried out the numerical simulations.

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