INITIAL SYNCHRONIZATION PROCEDURE IN S-UMTS NETWORKS FOR MULTIMEDIA BROADCAST MULTICAST SERVICES

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Abstract - W-CDMA and SW-CDMA air interfaces require that a user equipment in a given cell acquires slot and frame synchronization, and identifies the primary scrambling code used by the target cell before starting communications. This synchronization procedure is identified as cell search procedure in W-CDMA and beam search procedure in SW-CDMA. Notwithstanding the extensive commonalities between the two air interfaces, the two procedures are actually different. This paper aims at the evaluation of the false acquisition probability achievable by the two procedures in a scenario in which the receiver may experience both satellite and terrestrial radio propagation conditions. This is a sensible evaluation scenario since in the delivery of multicast-broadcast multimedia services, the satellite UMTS network represents an efficient complement to terrestrial UMTS, since its coverage is extended to indoor and urban areas through, for example, the use of terrestrial intermediate repeaters. In the paper, Rayleigh fading, Rice fading, and vehicular multipath propagation channels are used for the performance assessment.

Keywords - IMT-2000, CDMA, Fading channel, Code Acquisition, Satellite Networks, Multicast/Broadcast Multimedia Services

I. INTRODUCTION

Multicast and broadcast of multimedia services (MBMS) will play a fundamental role in future 3G mobile systems, as confirmed both by the activity in the standardization groups [1], [2] and by the papers recently appeared in scientific literature [3]. The delivery of such services through a satellite network is much more convenient, in terms of system capacity, than the delivery through a terrestrial network. In fact, in a terrestrial network the same information must be repeated in all cells where at least a subscriber is located, thus using different radio resources (i.e. frequency, time slot, or code) for retransmitting the same information flow. In a satellite network, the large coverage area of the antenna beams can be efficiently exploited to reach all subscribers with minimal radio resources. However, the necessity of having an unobstructed line-of-sight to close the link budget and the consequent absence of coverage in indoor environments and dense built-up areas, effectively hinder the straightforward use of the satellite to deliver MBMS to mobile users. One of the recently proposed solutions to solve this problem is the adoption of terrestrial intermediate repeaters. These intermediate repeaters, also known as boosters, gap fillers, or intermediate module repeaters (IMRs), are located in line of sight to the satellite, and extend its coverage area by repeating, in the MSS (Mobile Satellite System) frequency bands, an amplified version of the received signal.

In this framework, the European IST founded project SATIN (SATellite UTMS IP-based packet Network) [4], aims exactly at evaluating the feasibility and the impact on the radio interface design, of the MBMS delivery through a satellite network, based on the Universal Mobile Telecomunication System (UMTS). Urban and indoor coverage is here achieved through the use of transparent terrestrial IMRs. In this scenario a user equipment (UE) may receive the signal through a direct link with the satellite, through an indirect link via IMRs, or through a combination of the two. Since the rationale behind the SATIN project is that the satellite system should operate as service enhancer in close cooperation with the terrestrial system, the target radio interface is the Wideband Code Division Multiple Access (W-CDMA) Frequency Division Duplex (FDD), or IMT-2000 DS-CDMA [5]. The adoption of this air interface will in fact allow the exploitation of the economy of scale to keep the terminal costs and dimensions at a minimum level. However, it is worthwhile noting that although an UE experiences terrestrial propagation conditions when connected to an IMR, the presence of satellite links cannot be neglected. Therefore, evaluation of satellite ad-hoc developed air interfaces, that may show advantages in the foreseen scenario, shall be carried out. To this aim, due to its inherent commonalities with W-CDMA, Satellite W-CDMA (SW-CDMA), also known as ITM-2000 SAT-A [5], is considered within the SATIN project.

In this paper, the results of the analysis carried out in this research area are reported. In particular, the initial synchronization procedure adopted by the two radio interfaces is addressed. This procedure is performed to obtain chip, slot and frame synchronization, and to detect the scrambling code used in the cell (or in the beam in the case of satellite transmission). Notwithstanding the numerous commonalities between

W-CDMA and SW-CDMA, initial synchronization differs in the two radio interfaces. W-CDMA uses a three step procedure [6], [7], whereas SW-CDMA reduces it to a two step procedure plus frame synchronization word (FSW) detection [8], [9]. Two different architectures are hereafter proposed and evaluated on Rayleigh and Rice single path channels and on the multipath channels described in [10]. Detection and false alarm probabilities for each step and for the overall process are obtained through simulations keeping into consideration the presence of the terrestrial IMRs.

The paper will be organized as follows. In Section II the addressed synchronization procedures are briefly introduced and the synchronization subsystem described. The evaluation scenarios are detailed in Section III, while numerical results are reported in Section IV. Finally, conclusions are drawn in Section V.

II. System model

A. Cell/beam search procedures

In the downlink of W-CDMA and SW-CDMA air interfaces physical channels are arranged into 10 ms radio frames, which consist of 15 slots of 0.67 ms each, corresponding to 2560 chips, i.e. 3.84 Mchip/s. Two levels of spreading are applied. First, Orthogonal Variable Spreading Factor (OVSF) Codes are used to differentiate physical channels transmitted by the same Base Station (BS). Then, BS specific scrambling codes are used to mitigate intercell interference. There are 8192 available scrambling codes, arranged into 512 sets, containing $1 + 15$, one primary and 15 secondary, scrambling codes each. The 512 sets are grouped into 64 *scrambling code groups*. Information about used OVSF and scrambling codes are delivered through the broadcast channel, which, however, is scrambled itself with the cell primary scrambling code. Hence, an UE willing to place a phone/data call in a cell must acquire the used scrambling code along with timing synchronization. The cell/beam search procedure aims exactly at this. However, being an user equipment (UE) dependent procedure, cell/beam search is not specified in the standards, which only provide the physical channels that can be exploited by the UE to acquire the initial synchronization and the primary scrambling code. In particular, these physical channels are different in W-CDMA and SW-CDMA as hereafter described.

According to [6], in W-CDMA air interface, three downlink physical channels are provided for the initial cell acquisition: the Primary Synchronization Channel (P-SCH), the Secondary Synchronization Channel (S-SCH), and the Primary Common Pilot Channel (P-CPICH). The channel structures are reported in Fig. 1.

P-SCH is provided for slot synchronization. It consists of a bursty repetition, at the beginning of each slot, of the same 256-chip pseudonoise sequence, the Primary Synchronization Code (PSC). Once PSC synchronization is acquired, the slot boundaries are identified as well. The P-SCH structure is reported in Fig. 1; PSC is denoted as C_p. PSC is a generalized hierarchical Golay sequence [7], and is common to all the cells in the system.

S-SCH is provided for frame synchronization and BS scrambling code group acquisition. S-SCH consists again of a bursty transmission, at the beginning of each time slot, of a 256-chips sequence, the Secondary Synchronization Code (SSC). In this case, however, SSC changes from slot to slot and repeats at a frame level. The macro-sequence of 15 SSC repeated at a frame level, is BS specific and identifies the particular scrambling code group used by the serving BS among all the 64 scrambling code groups. The 64 macro-sequences belong to a 16 level Reed Solomon code and they are chosen so that their cyclic-shifts are unique, i.e., a non-zero cyclic shift of any of the 64 sequences is not equivalent to any cyclic shift of any other of the 64 sequences, nor to any cyclic shift, less than 15, of the sequence itself [7]. In this way, once the macro-sequence is identified, the frame boundaries and the scrambling code group are identified as well. The S-SCH structure is reported in Fig. 1; $c_s^{i,k}$ indicates the SSC, being $i = 0, 1, \cdots, 63$ the number of the scrambling code group, and $k = 0, 1, \cdots, 14$ the slot number. SSC are complex values with identical real and imaginary parts and are constructed from position wise multiplication of an Hadamard sequence and a sequence z defined in [7].

P-CPICH is provided for scrambling code acquisition. It is a fixed rate (30 kbps, spreading factor 256) downlink physical channel carrying a pre-defined symbol sequence. P-CPICH is always coded by the same OVSF channelization code and scrambled by the primary scrambling code of the serving BS. Once the pilot symbol sequence is correctly detected, the primary synchronization code is identified. The frame structure of the P-CPICH is reported in Fig. 1. There is one and only one P-CPICH per cell and it is broadcast over the entire cell.

In the SW-CDMA air interface proposed by ETSI for the satellite component of UMTS, only two physical channels are envisaged for for the beam search procedures: the P-SCH and the Primary Common Control Physical Channel (P-CCPCH).

P-SCH is provided for slot synchronization purpose, and is identical to the W-CDMA one. P-CCPCH is provided for both frame synchronization and primary scrambling code acquisition. The P-CCPCH structure is shown in Fig. 2. P-CCPCH is always coded by the same OVSF channelization code and scrambled by the primary scrambling code of the serving beam. The peculiarity of this channel is that it contains a 60 symbol unique word differentially modulated and spanned all over one entire frame. Each slot of a frame contains 4 symbols of this unique word. Thus, once the unique word is correctly detected, the primary scrambling code and the frame boundaries are known as well. Consequently, the unique word is called Frame Synchronization Word (FSW). Notably, no scrambling code group identification is possible. Hence, after slot synchronization, UE must search through all the scrambling code uncertainty area to acquire the appropriate primary scrambling code. This will be reflected in the acquisition subsystem architecture and complexity.

B. Synchronization subsystems

In Fig. 3 and Fig. 4 the block diagrams of the synchronization subsystems analyzed in this work are reported. The first step represents the classical problem of chip synchronization in spread spectrum systems, and it is identical for both W-CDMA and SW-CDMA. For this problem, a coherent accumulation, non-coherent post detection integration acquisition architecture and MAX decision criterion is adopted [11] [12].

Let L be the code length, i.e L=2560 for the P-SCH, the time uncertainty region is divided into $N \times L$ *cells*, $N = 1, 2, 4, ...$, each of which represents a timing hypothesis. In the proposed scheme this is achieved by upsampling the output of the chip matched filter (a square root raised cosine, SRRC, filter with roll-off 0.22), to obtain N samples per chip. For each cell a test variable is then built through non-coherent post-detection integration of order M [13].

The architecture used for the second and third steps of W-CDMA, is reported in Fig. 3. In the second step the SRRC output is sampled in order to have a single sample per chip. The sampling device is driven by the output of the first step. The received sequence is non-coherently correlated against each one of the 16 SSCs; notably, at this stage the non-coherent approach is mandatory since no phase reference exists before the third step is completed. The located macro-sequence of 16 SSCs spots out the code group used by the serving cell. Actually, a shorter correlation can be used, since it is possible to verify that a sequence of 3 SSCs is sufficient to identify both the code group and the frame bounds. As a matter of fact, each sequence of three SSCs in a macro-sequence associated to a code group is never repeated in any other macro sequence, thus allowing code group determination, nor in the same one, thus allowing frame bound localization. In the third step the downsampled sequence is descrambled with each one of the 8 primary scrambling code belonging to the scrambling code group determined in the second step and despread with the orthogonal variable spreading factor (OVSF) code. The pilot data symbols are then non-coherently detected to determine which one of the scrambling code is used.

The architecture adopted for the second step of SW-CDMA, is reported in Fig. 4. In the second step the SRRC output is again sampled in order to have a single sample per chip, descrambled with each one of the primary scrambling codes, and despread. Then hard detection on the FSW takes place.

III. Evaluation scenario

The two proposed architectures are evaluated in the framework of the IST-SATIN project [4]. As stated in Section I, to efficiently deliver MBMS through a satellite network, it is proposed to use transparent terrestrial repeaters, IMRs to achieve urban and indoor coverage. Hence, an operating UE may receive the satellite signal through a direct link with the satellite, through an indirect link with IMRs, or through a combination of the two. In this scenario the UE may thus experience both satellite and terrestrial radio propagation conditions. In the numerical results this will be reflected by considering four different propagation conditions: Additive White Gaussian Noise, Single Path Rayleigh Fading, Single Path Ricean Fading, and Multipath Rayleigh Fading channel. In order to keep results as much general as possible, propagation parameters are derived from the standardization documents. Hence, a mild Rice factor, K, is used (K=5 and 15 dB), and the multipath channel is the 6 taps vehicular one suggested in [10]. Accordingly, power delay profile is the one reported in Table 1. Finally, different UE speeds are considered to evaluate the fading correlation effects on system performance. UE is supposed to move at a medium speed of 50 km/h, at a high speed of 130 km/h, and at a very high speed of 200 km/h.

IV. Numerical Results

Fig. 5, 6, 7, and 8 show the false alarm probability of the three different steps of the W-CDMA cell search procedure. The false alarm probability is reported as a function of the ratio of the energy per chip, E_c, over the noise power spectral density, N_0, for the considered propagation channels and speed values. In particular, in Figs. 7 and 8 the false alarm probability is reported for the third step in two different synchronization hypotheses: the ideal correct chip and slot synchronization, indicated as *ideal*, and the real synchronization hypothesis provided by the first and second steps, indicated as *real*. Finally, Fig. 9 shows the detection probability, the missed detection probability, and the error probability for the second step of the SW-CDMA beam search procedure as a function of the FSW detection threshold, i.e. the number of tolerated symbol errors on FSW. In this case, ideal performance of the first step is assumed. It is worthwhile to note that in the case of the multipath radio channel, correct acquisition is assumed when the receiver is correctly aligned with any one of the six paths.

V. Conclusions

In this paper, the cell/beam search procedures employed by an UE to acquire initial synchronization in a W-CDMA and SW-CDMA air interface based system were considered. In particular, performance of two proposed architectures were evaluated in a sensible scenario, in which the satellite coverage is enhanced in urban and suburban environment through the use of terrestrial intermediate repeater.

Acknowledgements

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Tap	Relative Power (dB)	Relative Delay (ns)
0	0	0
1	-1	310
2	-9	710
3	-10	1090
4	-15	1730
5	-20	2510

Table 1
Multipath power delay profile used in simulation

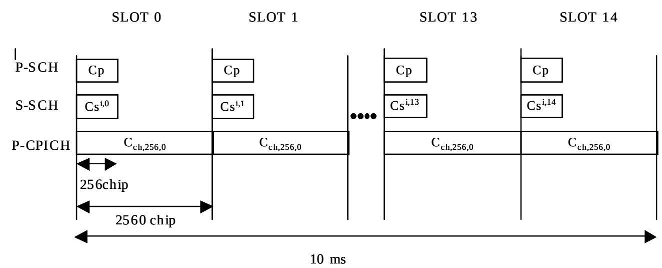

Fig. 1. Structure of the physical channels used for cell search, W-CDMA air interface

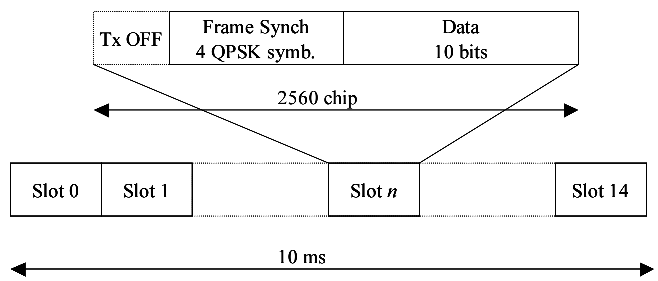

Fig. 2. Structure of the P-CCPCH used for beam search, SW-CDMA

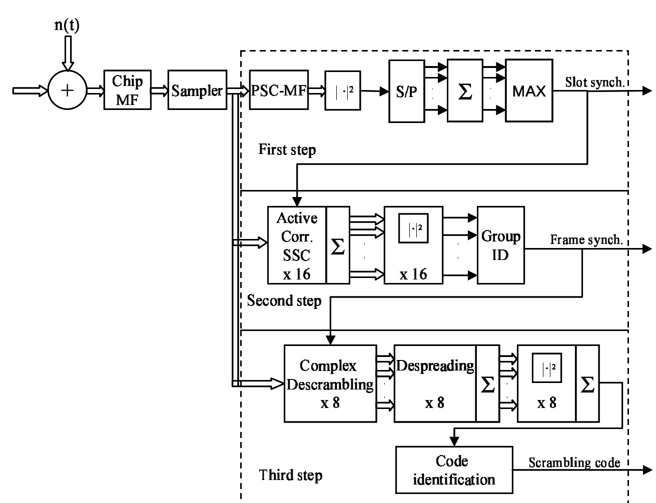

Fig. 3. Synchronization subsystem used for W-CDMA cell search

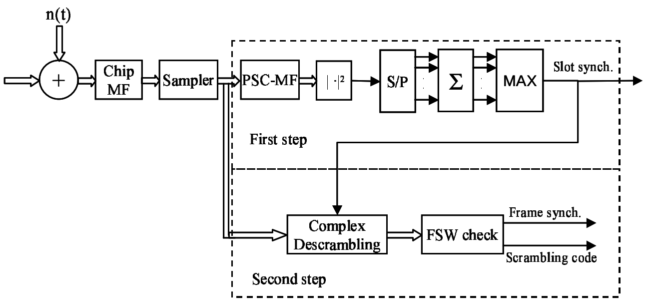

Fig. 4. Synchronization subsystem used for SW-CDMA beam search

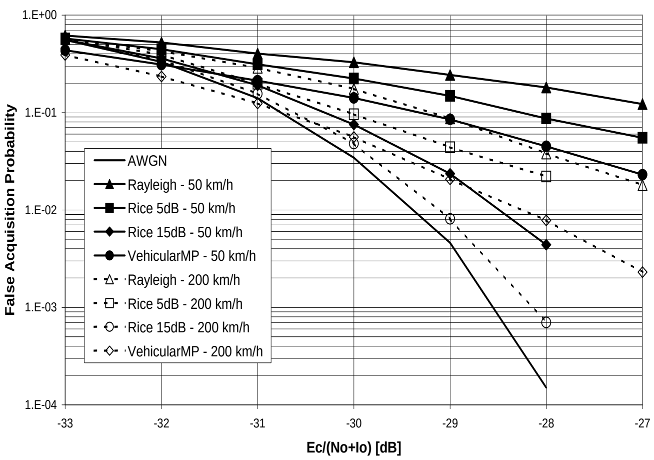

Fig. 5. False Acquisition probability vs. Ec/No, W-CDMA air interface, step 1

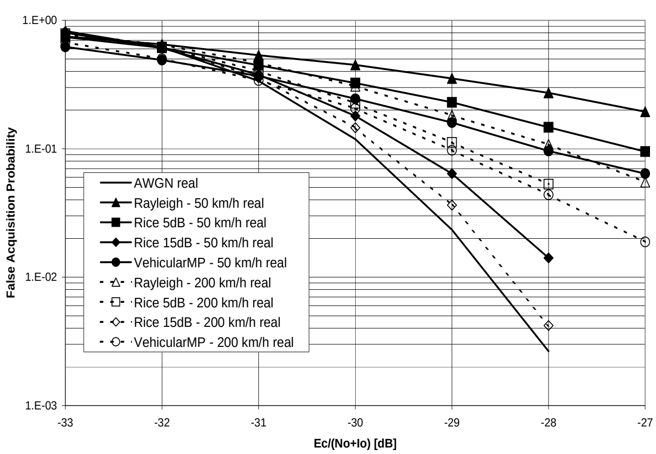

Fig. 6. False Acquisition probability vs. Ec/No, W-CDMA air interface, step 2

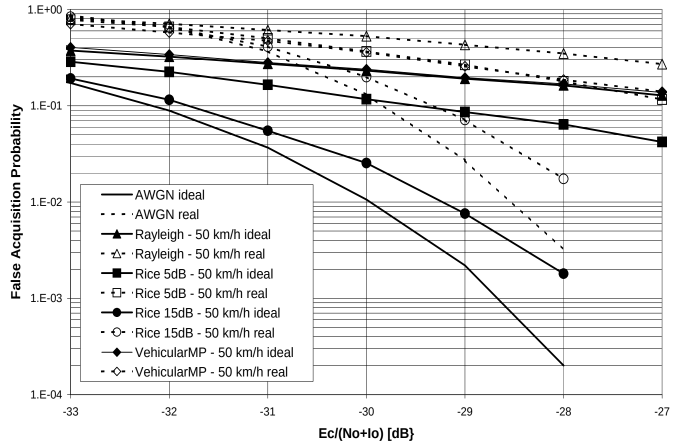

Fig. 7. False Acquisition probability vs. Ec/No, W-CDMA air interface, step 3, 50 km/h

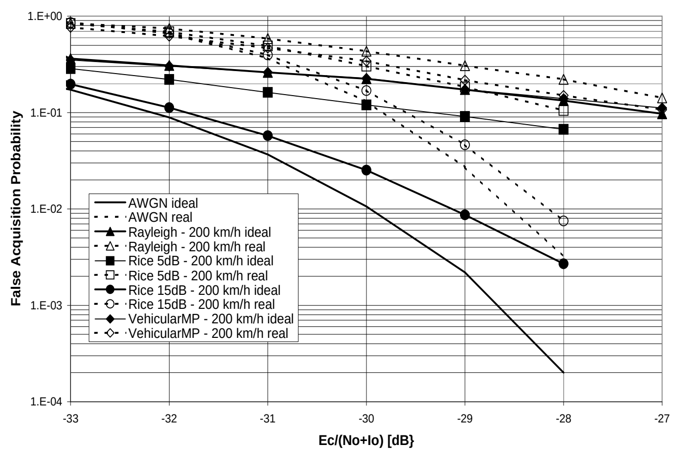

Fig. 8. False Acquisition probability vs. Ec/No, W-CDMA air interface, step 3, 200 km/h

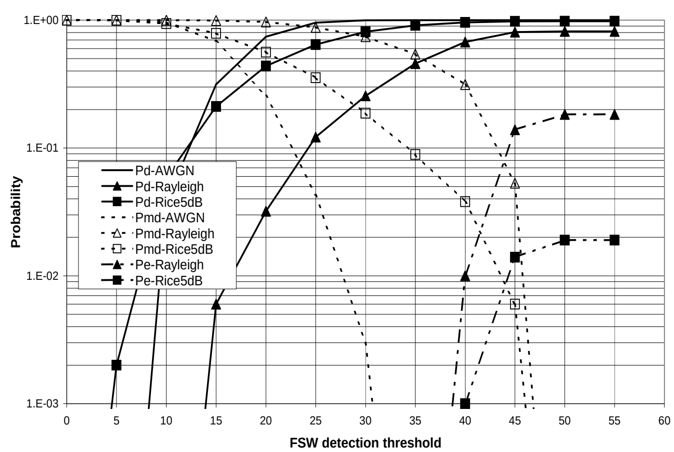

Fig. 9. Detection, Missed detection, and Error Probabilities vs. FSW detection threshold, SW-CDMA air interface, step 2, 130 km/h