A Multi-User Detection Implementation Approach For UMTS Uplink Channel

Makram TOUZRI, Samir SAOUDI, Sylvie KEROUEDAN, Patrick ADDE

GET / ENST Bretagne / PRACOM / CNRS-TAMCIC

CS 83818, 29238, Brest, cedex 3, France

Abstract—**In this paper, we introduce the first step for the implementation of a multi-user detection for UMTS uplink channel. We discuss the results of simulations performed with a single user detection and a Multi-User Detection.**

We compare performances of a Matched Filter vs. a Successive Interference Cancellation receiver in the synchronous channel and a RAKE vs. a SIC/RAKE receiver in the multi-path asynchronous case.

Simulation results are obtained without any channel encoding and compared in both real and integer computing.

Index Terms—**CDMA, Multi-User Detection, SIC / RAKE, quantization.**

I. INTRODUCTION

Third generation Universal Mobile Telecommunication System (UMTS) is based on Wideband Code Division Multiple Access (W-CDMA) air-interface using Direct Sequencing (DS) spread spectrum with a 3.84 Mcps chip rate and a QPSK modulation scheme to reach a theoretical peak data rate of 2 Mbps [1].

But in this air-interface, the Multiple Access Interference (MAI) significantly reduces the number of active users as a consequence of the multi-path channel which affects orthogonality of spreading codes.

To mitigate this limitation, acceptable results are obtained in most base stations with a single user detection process combined with channel encoding [2].

These performances are still not optimal particularly when the number of users is increased.

To this purpose, many Multi-User Detection (MUD) processes have been developed to overcome this limitation and the best theoretical detection performances are reached with an increased practical complexity of integration.

In this paper, we introduce the Successive Interference Cancellation (SIC) structure [3]-[4] in the synchronous case. We give some initial simulation results to show the gain of this MUD vs. the single user detection. Then, we discuss the quantization process. Afterward, we give some results for the quantized MUD depending on the number of SIC stages and the number of quantization bits. Finally, we present a SIC/RAKE structure as described in [4] and our first quantized results in multi-path asynchronous channel.

II. SUCCESIVE INTERFERENCE CANCELLATION

A. *Synchronous channel*

The SIC structure is an iterative process used to reduce MAI and to perform better sub-optimal MUD [4].

Its structure is composed of consecutive Interference Cancellation Units (ICU). Each ICU (Fig. 1.b) is composed of two blocks. The first one is a simple Matched Filter (MF). Its output is injected into the second block which is a Local Emitter. This dispreads the MF received result in order to regenerate an estimation of the user *k* emitted signal.

The output of the ICU is a residual signal *e* which is the difference between the received and the regenerated signal. This process is carried out successively for all users and repeated for *M* stages as shown in Fig. 1.a.

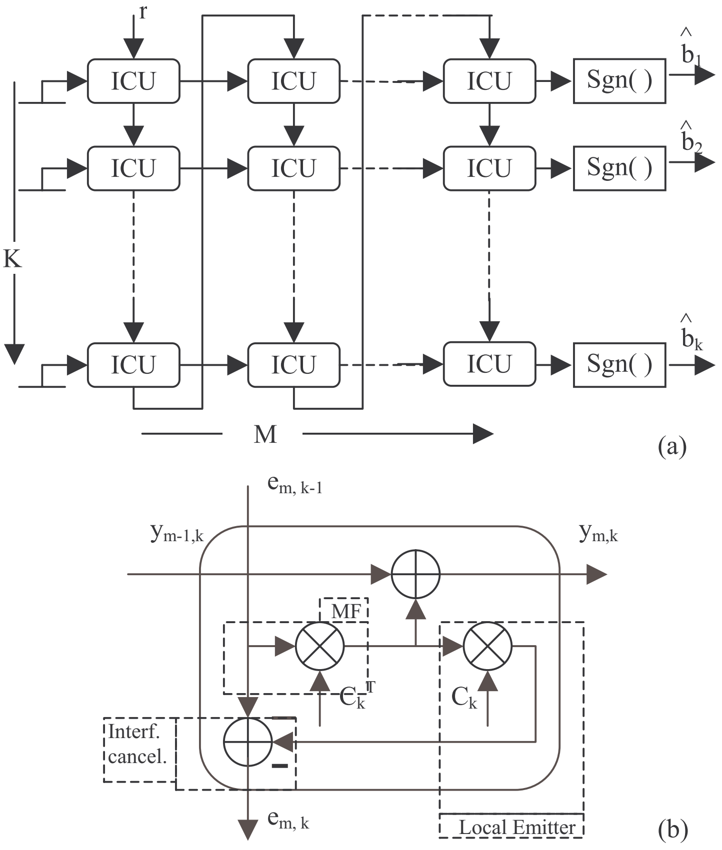

Fig. 1. Successive Interference Cancellation:
(a) General structure. (b) ICU structure

B. Simulation

The following simulations are made in the synchronous channel. Gold codes are used to separate users.

In order to allow an orthogonality default between codes, only a segment from the total length of codes is used.

Unless notified, the simulation parameters are fixed as Spreading Factor $SF=16$, number of users $K=8$ and number of stages $M=5$, giving a system loading rate of $K/SF = 50\%$.

All users are supposed to be received with an equal power level. The results in Bit Error Rate (BER) are given as an average of all individual users' results. However, a single user BER result can reflect the difference between the first and the last user who benefits more from the SIC process.

Depending on the stage number, the SIC process results converge from the MF curve to roughly approach the reference single user transmission curve (Fig. 3).

The optimal value of M depends on the loading rate K/SF.

III. QUANTIZATION

A. Quantization process

In a quantized mode, the algorithm is computing with values in an integer interval $(\pm 2^{n-1})$ bounded by the number of quantization bits n. This Analog to Digital Conversion is performed once at the beginning of the received signal as shown in Fig. 2. The two computing modes are done together to allow a results comparison between estimated bits $\widehat{b}_k$ from the real mode (Fig. 2a) and their equivalents from the integer mode (Fig. 2b).

The scale factor F is computed knowing the number of users K and the Spreading Factor SF.

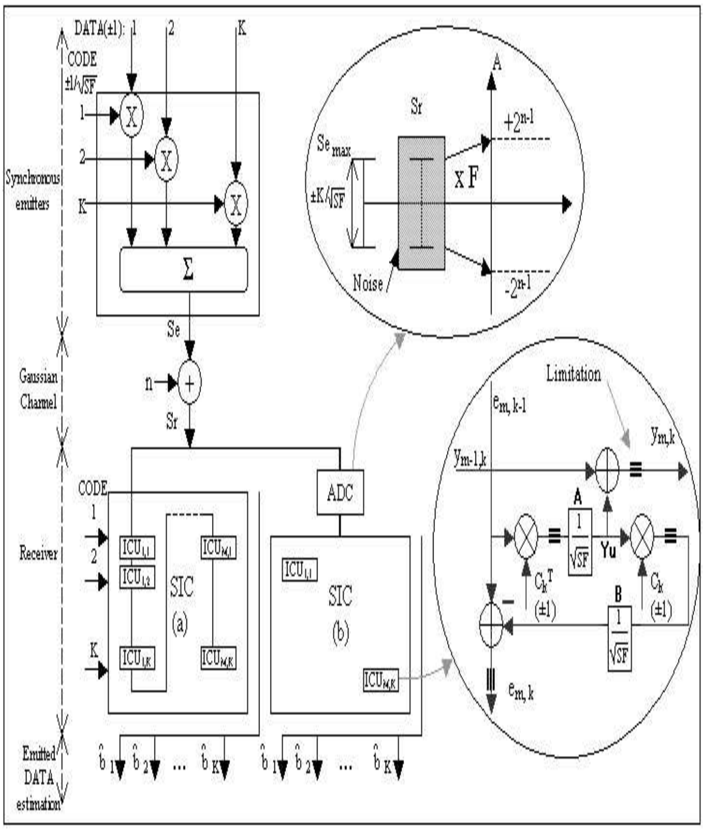

Fig. 2. Simulation process. (a) Real. (b) Integer.

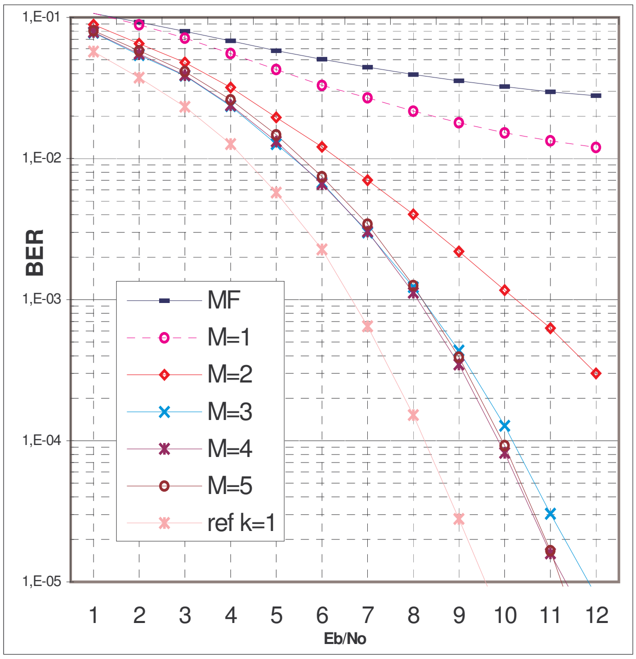

Fig. 3. Performance of SIC vs. matched filter.

B. Simulation

According to the simulation results (Fig. 4), the real curve can be reached from $n=8$, in the defined signal to noise ratio limit (around 8 dB).

Then, $n=8$ is selected for the following simulations in the synchronous case.

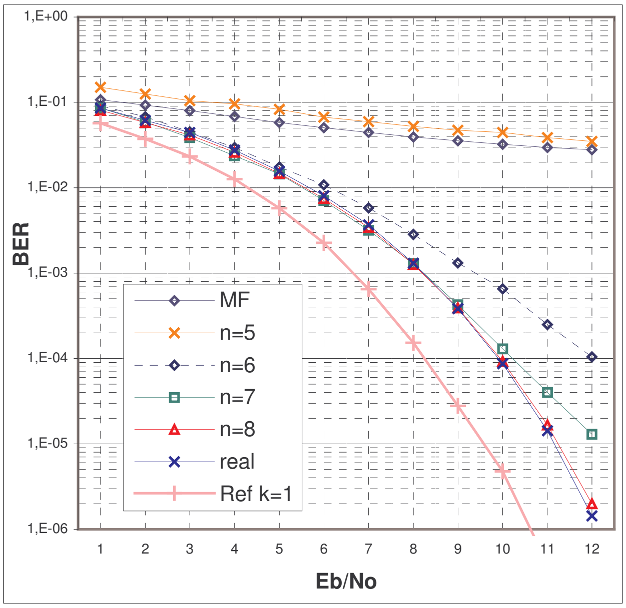

Fig. 4. Simulation results: real vs. integer.

During this simulation process, a constant quantization bit number n is used at each step of the ICU and during the whole SIC process.

Many approaches can be done to reduce arithmetic operations and quantization bit numbers during this SIC process.

In fact, Fig. 2 shows a division by $\sqrt{SF}$ carried out in order to normalize because in the quantized mode, codes are considered to be equal to ± 1, unlike in the real mode where codes are equal to $\pm 1/\sqrt{SF}$ [4].

Normalization in the quantized mode is done after multiplication by the code (twice in the ICU). However, to simplify operations, the two divisions by $\sqrt{SF}$ are combined to make a single division by *SF*.

This modification simplifies computing in the quantized mode while the spreading factor *SF*, is a power of two in the practical case. Consequently, the division of binary numbers by $SF = 2^C$ means a shift to the right by C bit cases.

But, where should this division by *SF* be carried out ?

After the matched filter (Fig. 2 *point A*) or after the local emitter (Fig. 2 *point B*) ?

Theoretically, it should be the same but in quantized mode, with the use of integers, the simulations give different results.

In fact, when placing the division by *SF* in point *B*, right after the local emitter, the simulations provide roughly the same results for integer and real computing in the defined signal to noise ratio limit. But these results do not remain constant when *M* (the number of stages) is increased due to amplified errors in estimation of transmitted data (Fig. 5).

Also, this emitted data estimation of user *k* inside ICU ($Y_{u,m}$) and at SIC outputs ($Y_{m,k}$) will have significant values and have to be quantized with *n* bits as in the whole SIC.

Now, when placing the division by *SF* in point *A*, directly after the matched filter of each ICU, the simulations provide roughly the same results for integer and real computing in the defined signal to noise ratio limit too. However, these results remain constant when *M* is increased (Fig. 5). Moreover, (Y_u, $Y_{m,k}$) will have small values and can be quantized with a lower bit number than the whole SIC.

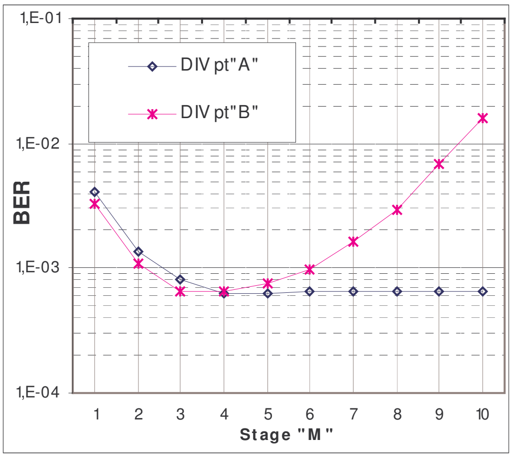

Fig. 5. Last user integer results vs. stages number. *Eb/No=8dB*

As practical results:
with *n=8bits*, and the division in pt. *A*, $Y_{m,k}$ can be quantized with *n'=6bits* and Y_u with *n"=4bits*.

Histograms are made for both cases and confirm that if errors occur, then the estimated value is near to zero with the opposite sign. Then , we can add a *mask* zone around zero and a second modification is proposed by proceeding as follows:

The MF output is a value whose sign gives us the estimation of the transmitted data.

Also, for a given *SF*, the higher the output of the matched filter, the more precise the estimation is. So, division made in the ICU can be removed and the local emitter input can take a positive or a negative constant value depending on the MF output sign. And to be in accordance with the estimation precision, the small values that indicate a weak estimation of the emitted data can be hidden and instead, a zero is injected to the local emitter which means no interference cancellation in this case.

This process is the same as a *Hard* interference cancellation combined with a *Mask* zone to inhibit SIC operation (Fig. 6).

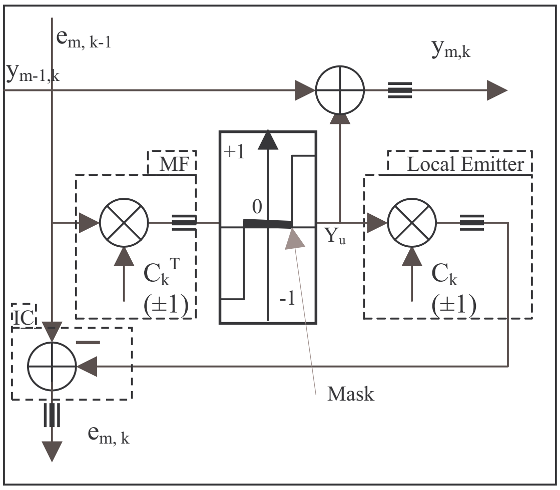

Fig. 6. Modified ICU structure

This same approach is applied to the real case and improves the modification too, but only in the defined signal to noise ratio limit (around 8 dB) (Fig. 7). The mask value used for this simulation in integer mode is limited by ± *2*.

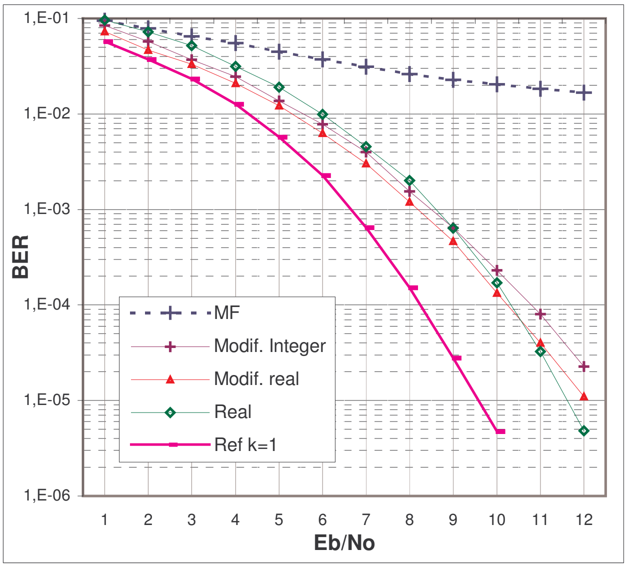

Fig. 7. Modified ICU results (Nc=20, K=10, n=8bits)

All tested approaches participate to reduce complexity and arithmetic operations during the SIC process. However, they affect system stability against power level variation between users.

In fact, with the use of these modifications, acceptable BER results for the first user can be reached while the power level ratio of other users vs. the first one do not exceed *4dB*.

IV. SIC/RAKE

A. Multi-path asynchronous channel

In this case, the external SIC structure is the same. But inside the ICU, a RAKE replaces the MF (Fig. 8) and complex multipliers are added to follow the UMTS process steps.

At least, two channels are used; the data channel In-phase and the control channel Quadrature-phase.

Also to be in accordance with UMTS norm:

- long scrambling Gold codes $C_k^{(s)}$ are used to discriminate between users.
- Walsh codes $C_{[I]k}^{w}$, $C_{[Q]k}^{w}$ are used to separate Data channels and Control channels respectively.
- Spreading factor *SF* for the control channel is constant and equal to *256*.
- The data channel *SF* can be *4* to *256*.
- *Clarke* model is used to simulate Rayleigh channel.
- Coefficients $C_{k,L}$ and delays are given knowing users speed, Doppler frequency and numbers of channels.

In reference [4], the supposed maximum delay is equal to $2 \times SF$ as a maximum of *SF* chips between users and a maximum of *SF* chips between paths. Then, optimal performances are obtained in [5]-[6] using a sliding window as a solution to this long delay.

B. Simulation

Changing to integer mode, two analog to digital conversions are made; one for the received signal and the other for the channel coefficients. The scale factor may be different for these two conversions.

In these simulations, channel coefficients and delays given by the channel estimator are supposed to be perfect. And during one control channel symbol, these coefficients are constant.

Also, the users *Vehicular_A* type (120 km/h) are used with *6* paths per user and a data channel *SF=32*.

Simulations give the first result (Fig. 9) which is obtained with one channel interference cancellation in the ICU, *n=8bits* is used and a limitation of ($\pm 2^{n-1}$) is applied only to ICU input and output.

With the use of different *SF* for data and control channels, interference cancellation cannot be done for these two channels at the same stage. Otherwise, using the control channel *SF=256* and due to information structure, interference cancellation for the control channel can be carried out once in the first stage. In all cases, slightly better results will be obtained by applying two interference cancellations with considerably increased complexity.

Both received signal and channel coefficients are quantized with *n=8bits*. But simulations prove that it is possible to reduce the quantized bit number for channel coefficients without significant degradation of results.

Simulation results (Fig. 9) show that the RAKE curve is the same for real and integer computing. That is because only the sign of RAKE output is taken to estimate transmitted data. But with the use of the SIC process, the value of RAKE output is used inside the ICU. And the real mode gives better precision to this value than the integer mode due to complex mode of operations, normalization and limitation. Consequently, the SIC process is slightly better performed in real than integer mode.

Fig. 9 shows two integer curves obtained with and without limitation of ICU input and output.

The first curve is used to observe and determine the maximum values for each parameter inside the ICU. In this case, and without limitation inside the ICU, values go to *n=16bits* (Fig. 8 dotted zone) due to multiplication of the received signal (*n=8bits*) by the channel coefficients (*n=8bits*). After channel coefficient normalization with β_k^{-1}, values go down to *n=8bits*.

To reduce these values dynamics inside the ICU, one solution consists in implementing this normalization not in one step after the RAKE output, but inside the RAKE. This modification gives place to 6 divisions (for the 6 paths used) and a reduction of the quantization bit to *n=12bits* inside the ICU. Fig. 9 (Integer lim. curve) gives the simulation result in this case and shows a slight degradation.

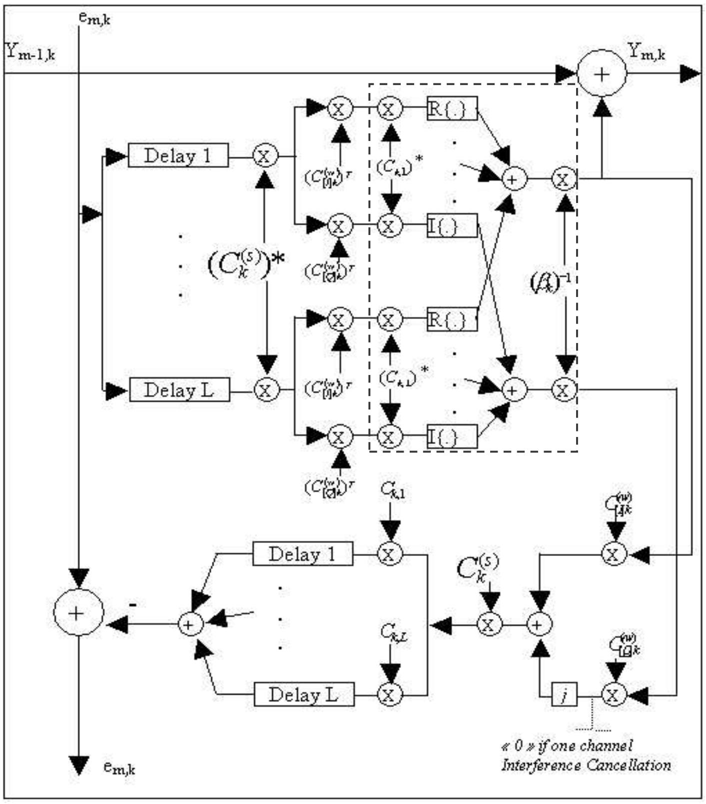

Fig. 8. SIC/RAKE ICU structure

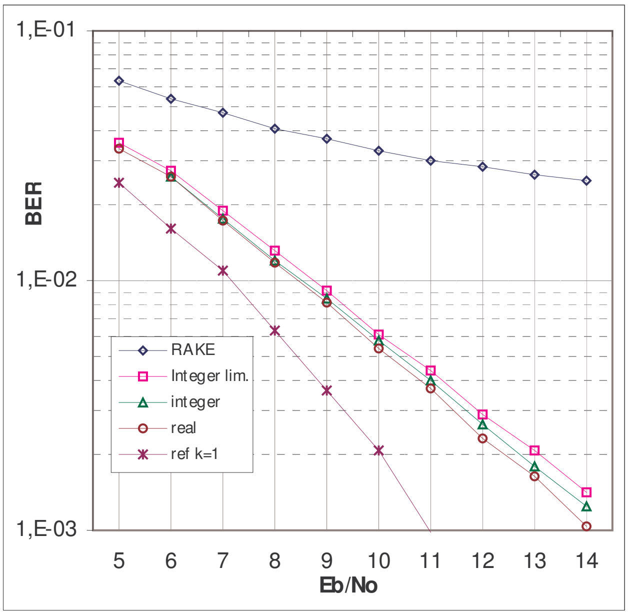

Fig. 9. SIC/RAKE first real vs. integer results
(SF.I = 32, SF.Q = 256, K = 8, M = 3, n = 8)

V. CONCLUSION

In this paper, we prepared the implementation of a multi-user detection to be integrated in the base station reception for UMTS uplink channel. We began by simulations in the synchronous channel to improve integer computing.

Then, we moved on to the multi-path asynchronous channel case.

After that, we applied limitations and modified the computing structure to reduce values dynamics within the ICU.

Promising results have been obtained with a reduction of quantization bit number used to reach the whole of the SIC/RAKE receiver process.

The next step is the complexity evaluation on silicon for the MUD architecture obtained.

Then, we aim to achieve the use of a Multi-User Detection and a Turbo-codes channel encoding combined structure. We will perform several configurations targeting better performances with fewer stages in MUD and fewer iterations in channel decoding.

Finally, a silicon evaluation will be made for the whole optimized receiver architecture.

VI. REFERENCES

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