COMPUTING RESOURCES IN FLEXIBLE RADIO ENVIRONMENTS

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ABSTRACT

It is well known that in future mobile communication systems the variations over the communication parameters - channel characteristics, radio resources availability, user service requirements - will be more significant for satisfying the capacity demands due to the coexistence of different radio access technologies within a heterogeneous environment. Software Defined Radio devices are suitable for meeting such demands by the means of software and reconfigurable hardware platforms. The need of a dynamic management of resources is crucial for the success of such implementation due to the relationship between the radio resources and the resources in terms of processing power and memory. This work introduces the concept of resource management framework which includes computing resource management cooperating with the radio resource management strategies. The goal is to dynamically seek to minimize computing costs but assuring certain Quality of Service constraints.

1. INTRODUCTION

Wireless communications are some of the most computationally demanding technologies due to the operational time and space - variant environments that characterize them. Mobile devices must deal with the constraints of available resources and offered services. Furthermore, the coexistence of different radio access technologies (RAT's) will demand a high level of flexibility by mean of partial or total reconfiguration of both terminals and network elements.

Software Radio or Software-Defined Radio (SDR) appears as the suitable concept which can handle the diversity of existing and future mobile systems by enabling the physical and link layers to be modified to best meet the current conditions. The aim of using software radio is to exploit reconfigurable hardware platforms to execute the processing chains of radio communication standards programmed by means of software [1] – [2]. This means that SDR enables implementation of different air interfaces standards as software modules. Thus appropriate software modules can be chosen to run depending on the current requirements. Nevertheless this scenario introduces a new dimension into the resource management problem due to real time limitations and its relationship with the required computing resources of the radio application.

Traditional network design involving physical layer to meet the expected worst case conditions would result in poor resource management. In the first instance, spectrum scarcity, inefficient bandwidth usage and limited interference tolerance are major reasons for efficient radio resource allocations. Advanced Radio Resource Management research aims to solve the problematic regarding spectrum management of the different RAT's that are accessible in a specific area [10] – [13]. On the other hand, the management of computing resources refers to the hardware that implements the (software-defined) signal processing chains for radio communications; this means that some SDR modules can improve the resulting Quality of Service (QoS) by increasing their computing costs. However, the final goal of computing resource management is to minimize use of resources to perform the processing tasks of the radio processing chain and adapting them to the changing environment. Therefore, an efficient usage of computing resources is also key word for sustaining a requested service [17].

2. COMPUTING AND RADIO RESOURCE MANAGEMENT COOPERATION

2.1. Approach.

While the RRM strategies lead with the spectrum problem preserving a certain quality target for each user, the computing resource management expects to reduce the amount of effort to perform processing tasks that are involved when the environment changes. This idea aims for a joint interaction of Computing and Radio Resource Management. The idea is centered into a framework suitable for trading off communication against computation and vice versa, i.e. an intelligent wireless communication system seeking an efficient usage of both computing and radio resources [3].

It is known that the output performance of several algorithms in a processing chain, and consequently its computing requirements, depends of the quality of the service demanded [7] – [10]. Hence, the radio systems shall be analyzed in the form of tasks graphs showing their computing costs, expressed in million of operations per second (MOPS). Here we focus on a WCDMA receiver as it is shown in [3]

3. CASE STUDY: UMTS DOWNLINK

3.1. Radio and Computing Capacity

In a real scenario appear important dependences between radio and computing capacities of a system that lead to redefine physical and link parameters for matching the best solutions, and making trade-offs if it is necessary. Thus, the subsequent remarks must be taken into account.

First of all, in WCDMA each new connection increases the interference level of other connections, affecting the user quality in terms of a certain signal to noise ratio [11].

Second, the variations in the radio capacity due to the interference and noise variations are function of the environment since there will be different pattern for different scenarios, i.e. urban, suburban and rural areas [16].

Third, in a SDR Base Station where the dynamic reconfiguration is the base of its computing resources management a good estimation of the required computing resources (for instance, the number of iterations for the turbo decoder) is mandatory in order to adequately manage the overall resources.

Fourth, On the other hand, it will also be necessary to acquire good estimates of the radio resources in the form of capturing current E_b/N_0 because the radio capacity in terms of number of users is limited by the values of the Energy bit to Noise ratio. The radio scenario conditions and the algorithm assumed in the advanced RRM entity produced a distribution of target E_b/N_0 for assuring certain level of QoS to the considered user. Good estimation will allow the assignment of the adequate resources to each one of the users being served by Node B freeing all the resources not needed that will be available for the rest of the users.

Fifth in the SDR terminal side the information related with the current capabilities of such terminal, among them the available computing resources and the battery power, should be of relevant importance in the assignment of one E_b/N_0 target from the RRM side.

Sixth, RRM strategies should tend to limit the maximum transmitted power per user, because such required power will increase the saturation probability of the Base Station, and decrease the power availability for the other users.

3.2. Quality of Service (QoS) Parameters

It is well known that the QoS parameters try to identify the proper values of the relevant parameters of the transmission chain in order to provide a suitable experience to the user when using such service. Nevertheless, these values experiences important changes with the scenario variations that make necessary to perform a characterization of the different scenarios and identify the proper values of the relevant QoS parameters for each one of them. QoS parameters of the different traffic services characterize such service imposing certain requirements to the transmission process. A summary of these values for a urban scenario is included in next table.

Table 1 Typical traffic parameters for an urban scenario in an UMTS network [18].

Parameter	**Services**	
	Video Conference	**Video Streaming**
Bit Rate	64 kbps	128 kbps
Processing Gain	60,0	27,0
E_b/N_0 target (dB)	3,8	3,1
FER	< 1% FER	< 1% FER
BER	$< 10^{-3}$	$< 10^{-3}$; 10^{-6}

It is mandatory, when designing a new system, to adapt the settings in order to meet the QoS limitations for the worst case; however always trying to reduce the consumption of resources with special emphasis on the, non exceeding, computing and power resources of the mobile terminal.

3.3. The UMTS turbo decoder Module

One of the most relevant blocks in WCDMA reception is the Turbo Decoder. Turbo decoding principle is iterative, i.e. the frame error rate decreases while the Number of Iterations (NOI) arises. Turbo decoders algorithms have been well studied in the literature (consult for example [4] - [5]), its performance have been validated for WCDMA communication under different conditions, nevertheless the processing power claimed through it is a crucial constraint, due to the hardware limitations in the devices. For instance, considering a frame with service requirement of Bit Error Rate (BER) < 10^{-4}, the decoder will need to execute 20 iterations with poor channel conditions (E_b/N_0 = 1 dB), which imply an extreme demanding condition. This can be observed in Figure 1.

Regarding the problematic of computational load for turbo decoding, Valenti [5], introduced a method for avoiding useless iterations; the algorithm based on the calculation of the log-likelihood ratio (LLR) is called the dynamic halt condition. The decoder is able to stop once the absolute value of the LLR's is above a threshold denominated dynamic halt (? $_T$) as in (1). The authors on [4] incorporated the dynamic halt algorithm within their implementation of the UMTS turbo decoder on a digital signal processor (DSP).

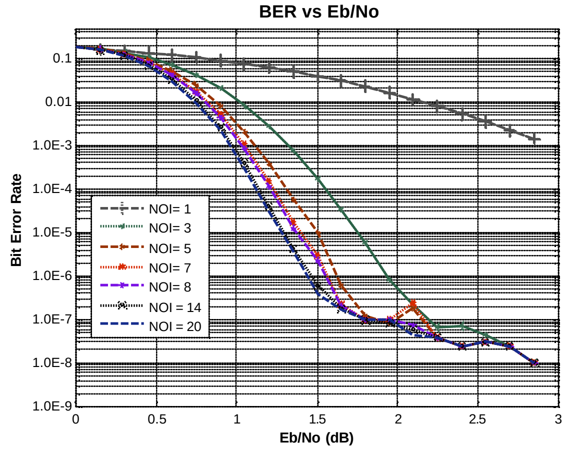

Figure 1: Performance Behavior of the Turbo decoder

$$\min_{1\le k\le C_L} = \{|\Lambda_2(X_k)|\} > \Lambda_T \tag{1}$$
$$C_L = \text{code length}$$
$$\Lambda_2(Xk) = LLR$$
$$\Lambda_T = \text{dynamic halt threshold}$$

Figure 2 and 3 illustrate the performance of such implementation and shows the dependence of choosing an appropriate value according to the signal to noise ratio target in order to achieve the required BER for the user service. Conversely, the Number of Iterations needed to decode the frames grows slightly as ? $_T$ is increased; however the relationship between computational requirements and the NOI is not directly defined. The algorithm used is the Max-Log-MAP and that the code length is set to 1024 bits.

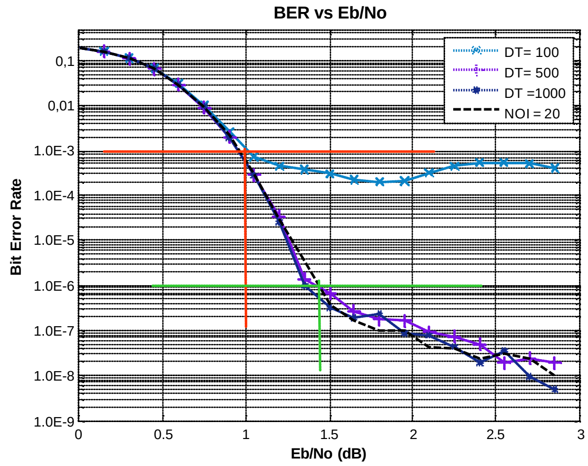

Figure 2: Performance Behavior of the Turbo decoder for different Λ_T values (DT on the graph).

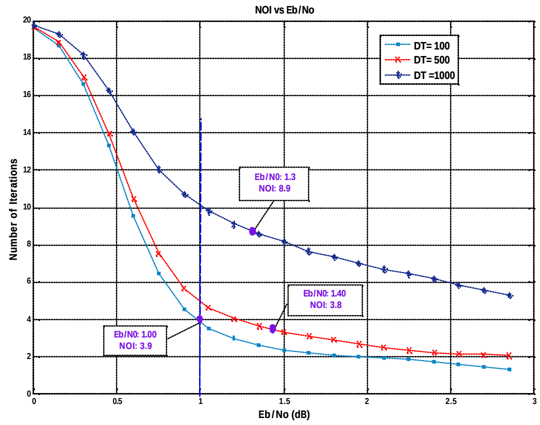

Figure 3: Average number of iterations required for different Λ_T values (DT on the graph).

3.4. UMTS Turbo decoder Computing Cost

The analysis here follows the methodology on [3] – [4] for obtaining the computing costs from the resulting averaged NOIs. The consequent results from the analysis lead to information results that are resumed in the following points:

a) The arithmetic costs per iteration of the turbo decoder result in a mean 114 cycles/bit.

b) The total amount of operations per second depend of the transmission rate R and the processor parallel capacity. For the DSP TMS320C6416 which can achieve up to 8 operations per cycle and the outcome are shown in Table 2.

c) Processing costs savings can be achieved for example, by reducing the arithmetic complexity during the computationally most intensive operations implicated or by changing the current algorithm for another, with different cost and performance, more adapted to the scenario [3], [17].

d) If the purpose is to control the NOI, it can be assured a certain value of ? $_T$ which will be more suitable in terms of both, computation and radio quality constraints.. The results are resumed in Table 3.

Table 2: Resulting MOPS for different service rates.

Rate (kbps)	MOPS per iteration
128	116.6
64	59.7

Table 3: Relationships between QoS and Computing Resource parameters.

BER	Suitable ? $_T$	E_b/N_0 (dB)	NOI
10^{-3}	100	1	4.0
10^{-6}	500	1,4	3.84
10^{-6}	1000	1,3	8.9

From the information provided in the tables above can be stated that the use of an adequate ? $_T$ values in the turbo decoder of the downlink receiver can minimize the computing cost while providing the desired performance (BER in that case).

3.5. RRM in UMTS Downlink

In the UMTS downlink case the capacity of the system is limited by the fact that all the users share the same bandwidth and each new connection increases the level of interference of the rest of connections. In addition the total transmitted power P_T of the node B is shared among all the users and should be enough to overcome the path loss of each user providing the adequate E_b/N_0 for the service considered. Therefore the instantaneous location of a given user impacts on the performance of the rest of users in the cell. Because of this, the capacity of the system becomes limited by the maximum available transmitter power $P_{T\ max}$ [11] and it can be evaluated throughout (2).

$$P_T = \frac{P_p + \sum_{i=1}^{n} \frac{\frac{L_p(di)(P_N + c_i)}{W}}{\frac{W}{\left(\frac{E_b}{N_0}\right)_i R_{b,i}} + r}}{1 - \sum_{i=1}^{n} \frac{r}{r + \frac{W}{\left(\frac{E_b}{N_0}\right)_i R_{b,i}}}}$$

P_T = Base station transnsmitted power

L_p = the path loss of the i-th user

d_i = location of i-th user

$R_{b,i}$ = the i-th user transmission rate

W = Bandwidth

P_N = the background noise

P_p = the power devoted to CCCHs

r = orthogonality factor (2)

c = Intercell Interference

Where:

$$\bar{L}_P(d) = 15.3 + 37.6\log_{10}(d) \qquad (3)$$

<u>Scenario Definition:</u>

The following consideration has been done in order to evaluate the radio capacity:

- It is assumed a downlink scenario where all users are randomly distributed within a cell area of radio r which is covered by one single Base Station. Therefore no intercell interference is considered.
- The downlink orthogonality factor which appears due to multipath, and shall be compensated by the RAKE receiver diversity is set to 0.4 (as specified for macro-cellular environments) [11].
- Downlink pilot control channel and synchronization channel power at 2 W (33 dBm).
- Chip rate of 3.84Mcps.
- The service taken into account is a video Streaming at Rate 128 kbps, and its corresponding Spreading Factor is 32. This is assumed for all users to which the BS gives service.
- The Maximum power that the BS can transmit to is set to 43 dBm.
- The path loss influences the system capacity, so that users with large path loss increase the possibility of node B saturation. Outage occurs in the downlink when the maximum available power P_{Tmax} is not enough to reach all the users with a suitable level.
- Path losses for the users are defined by (3) as in [14] for scenarios in urban and suburban areas.

An evaluation of the radio performance, under previous assumptions, can be seen in Figure 4.

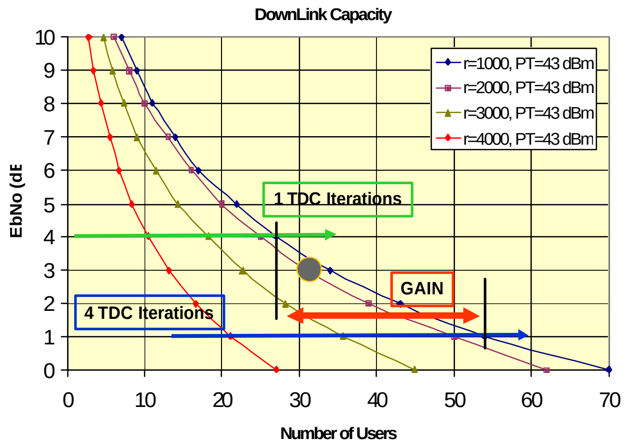

Figure 4: Average System Capacity for different scenarios considering the same Maximum Transmitted Power.

The graph shows the dependence of the downlink radio capacity from the cell radio (r) and the Energy bit to Noise ratio. Moreover is observed that, for the turbo decoder implementation used, in order to achieve the capacity indicated by the green line, the turbo decoder may accomplish one iteration, while for the blue line it must execute four iterations in average for the complete set of users in the scenario. Therefore a tradeoff can be found between the required radio capacity and the averaged NOI required in the turbo decoder.

3.6. Computing Costs Saving Strategy.

It can be granted that for an accurate management of resources available, interactions can be set between radio and computing in order that the most suitable algorithm(s) to execute the requested service(s) and the optimal parameters for execution of the algorithms are chosen. For this case, the parameter which handles the computational load is the Dynamic Halt directing to control the NOI that the turbo decoder need to achieve the quality of service constraint.

Generally the systems are designed so that the terminals achieve a mean of four iterations, independently of the scenario and the E_b/N_0. With these assumptions most of the cases are covered for a typical value of E_b/N_0 target of 3 dB.

The availability in the RRM side of information related with the behaviour of each one of the implementations of the different turbo decoder modules available in the user terminals can help for a better selection of a proper E_b/N_0 target for each one of such terminals. In order to evaluate the importance of knowing the performance and computing cost of the turbo decoder (can be extended to the rest of modules in the processing chain) when RRM decisions are taken two basic approaches can be compared:

a) No module performance availability. This implies that the RRM assumes that all the terminals in the scenario are capable to manage the radio link in the worst conditions. This means that, from the turbo decoder perspective, the available computing power should allow running no less than one iteration. Furthermore at the input of the turbo decoder must be received a signal with an E_b/N_0 of 3.1 dB for video streaming and 3.8 dB for video conference (RRM defines the proper E_b/N_0 target) and BER equal to 10^{-3}. According to Figure 4 the resulting capacity for the radio link is 31 and 25 users respectively. Here come to reason that the dynamic halt condition is fixed on 100, which from Figure 3, will result in the minimum averaged number of iterations required, NOI = 4, and an associated computing costs of 466.6 MOPS. On the other hand, when the BER is 10^{-6}, assuming the same E_b/N_0 (for instance, suitable for streaming service) the dynamic halt condition selected will be fixed on 500, resulting in NOI = 2, with computing costs of 233.3 MOPS.

b) Module performance availability. The availability of such information facilitates the introduction of the processing requirements in the overall scenario capacity equation. It is clear that as much processing power is needed in the terminal side less battery time will be available. In addition the link conditions observed by each terminal suffers important changes during the session and therefore the availability of processing power could also change, specially if a full SDR and cognitive radio terminal is considered.

3.7. Relationship between the scenario and the management strategy.

Scenario: Rb=128kbps, Cell Radio=3000 m, P_{Tmax}=43 dBm

In order to determine the influence of the selection of proper E_b/N_0 target taking trying to minimise the impact in the processing power of the terminals in the scenario (*Rb=128kbps, Cell Radio=3000 m, P_{Tmax}=43 dBm*) two different approaches for selecting the E_b/N_0 target has been tested has been defined. They have been identified as 1r4R and 4r1R.

1. **1r4R**. The E_b/N_0 target selected for terminals at a distance of the BTS lower than r (variable) is 1 dB for BER 10^{-3} and 1.4 dB for BER 10^{-6} and for those terminals at a distance higher than r the selected E_b/N_0 target is 4 dB.
2. **4r1R**. The E_b/N_0 target selected for terminals at a distance of the BTS lower than r (variable) is 4 dB (the minimum) and for those terminals at a distance higher than r the selected E_b/N_0 target is 1 dB for BER 10^{-3} and 1.4 dB for BER 10^{-6}.

Depending of the values of r both strategies defines a set of averaged E_b/N_0, NOI and Capacity of the radio link that will facilitate the discussion. Those results can be summarised in the Figures 5 and 6.

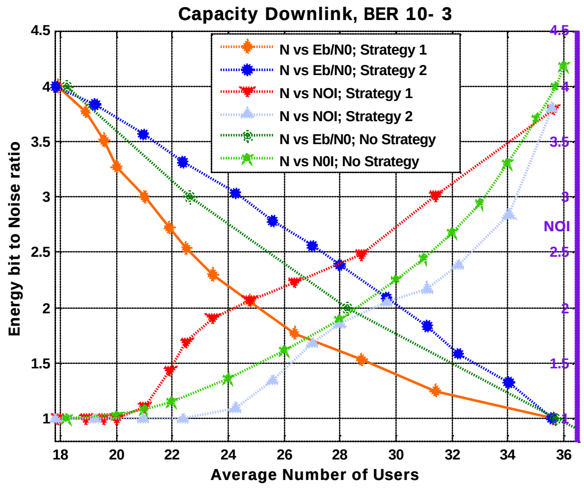

Figure 5: Downlink system capacity versus E_b/N_0, NOI for the strategies 1r4R and 4r1R considering BER 10^{-3}.

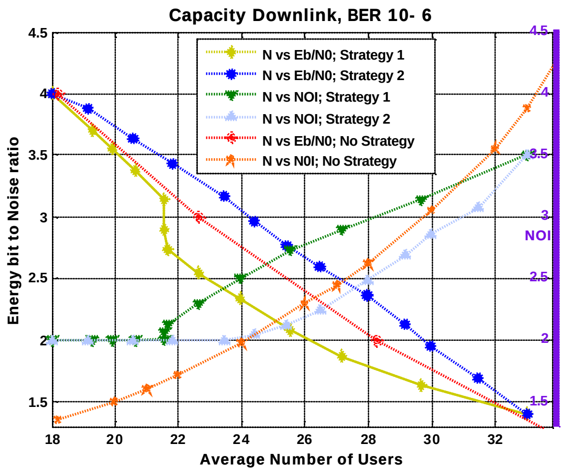

Figure 6: Downlink system capacity versus E_b/N_0, NOI for the strategies 1r4R and 4r1R considering BER 10^{-6}.

First of all, it is clearly stated that for low computing capabilities of the terminals, higher E_b/N_0 target are required and thus with a higher capability for executing turbo decoder Number of Iterations, the E_b/N_0 target is decreased.

In addition can be noticed that the 1r4R strategy, which assumes a higher E_b/N_0 target (4 dB) for the users more far from the BTS, presents a lower performance in terms of radio link capacity for a defined averaged E_b/N_0 than the theoretical one (assuming the same E_b/N_0 for all the users). On the other side the 4r1R strategy shows a slight improvement. Both results reflect only the behaviour of the capacity of the system under the identified approaches. Nevertheless what is relevant here are that the decisions taken by both approaches requires information about the current processing capabilities of each one of the terminals as input to the decision process. In addition, looking at the results related with the averaged NOIs we can observe that the 1r4R strategy shows a higher value of the required number of iterations in the turbo decoder module than the 4r1R one to provide similar performance in terms of capacity for the radio link. This means that the 4rIR strategy presents a significant better performance in terms of averaged computing requirements of the set of active terminals than the 1r4R for a number of users up to 35 for BER 10^{-3} and 33 for BER 10^{-6}. Therefore such strategy can be suitable for reducing the computing requirements to the set of terminals. On the other side allow a lower E_b/N_0 target to those users that can be found far from Node B which is also relevant to increase the overall radio capacity of the system.

7. CONCLUSIONS

Within this work has been observed how the decisions of cooperation between radio and computing resource management are strongly influenced by the environment, the current status of the system and the given constraints such as minimum required performance, real-time deadlines and quality of service (QoS) parameters. The approach shall be based on a dynamic reconfiguration of the software defined radio platform.

It has been stated that the application of some resource management strategy which take into account the availability of the computing resources of the terminals grants a better performance in terms of both, the system capacity and the computational load, because the most suitable algorithm(s) to execute the requested service(s) and the optimal parameters for its execution is chosen.

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