A BCH ERROR RECOVERY SCHEME FOR ADAPTIVE ERROR CONTROL IN WIRELESS NETWORKS

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Abstract- In this paper, we evaluate the performance of an adaptive error correction scheme for Wireless ATM Networks (WATM). This scheme attempts to minimize the system throughput in order to satisfy the user defined Quality of Service (QoS) constraints. Indeed, error control for high speed wireless ATM networks is an important research topic even wireless communication channels are highly affected by unpredictable factors like co-channel interference, adjacent channel interference, propagation path loss and multipath fading. We propose an intelligent-agent architecture to implement our mechanism “A-BCH-FEC” (Adaptive BCH FEC Scheme) for Rayleigh fading environment. Intelligent agents are distributed over all system entities. In the latter, base station agents cooperate with other agents to choose the appropriate BCH coding scheme related to a specific level of Signal-to-Noise-Ratio (SNR). Finally, we illustrate our implementation by some simulation results from a cellular system. These results show that the adaptive scheme using BCH codes improves significantly the performance of WATM networks.

I. INTRODUCTION

Asynchronous transfer mode (ATM) is the internationally accepted transfer mode for broadband integrated services digital networks (B-ISDN). It is maturing rapidly for telecommunications. It is a high-bandwidth switching and a low-latency multiplexing technique that uses constant-length packets (cells) as the basic data units. An ATM cell, as defined by ITU recommendation I.361, contains 5 bytes header and 48 bytes payload which are transported via virtual paths and circuits in a connection oriented fashion. Thus, B-ISDN supports a wide range of traffic types with different QoS (delivery guarantees and timing restrictions). Five service categories have been identified as follows: CBR (Constant Bit rate), rt_VBR (Real-time Variable Bit Rate), nrt_VBR (Non Real-time Variable Bit rate), UBR (Unspecified Bit Rate) and ABR (Available Bit Rate).

Moreover, in recent years there have been a great explosion of activities in the area of wireless and mobile networks [1].

The growth of wireless communications coupled with rapid developments in ATM networking technology have led to a new era in telecommunications. WATM has became a significant topic over the last three years in worldwide research and developments [2,3,4,5,6,7] through a panoply of programs [1] such as Advanced Communications Technologies and Services (ACTS), Mobile Broadband System (MBS) and Universal Mobile Telecommunication System (UMTS).

Nevertheless, the integration of wireless networks into B_ISDN/ATM networks introduces a number of issues which arise from the inherent mismatch between wired and wireless links in terms of transmission speed and Bit Error Rates (BERs) [8]. For example, ATM supports audio and video services which are mainly sensitive to delay constraints; even when data traffics are sensitive to Cell Loss Ratio (CLR) performance. CLR should be less than 10^{-8}. However, it is difficult to achieve such low CLR in wireless mobile environments. In fact, wireless communication channels are notorious for their unreliability and poor BER in the range of 10^{-4} and 10^{-5}. Error sources entail an important unpredictable degradation of the received signal which varies considerably in time and space according to interference conditions. Contrarily ATM networks provides BER of around 10^{-9}. Rayleigh fading is considered as a major

impairment whereas in this paper we consider this type of error source.
To reduce the high BER of wireless links and to control their behavior, we should apply to classical error control schemes. There are two basic approaches for error control : 1) Forward Error Correction (FEC) and 2) Automatic Repeat reQuest (ARQ) [9]. FEC is frequently used but it is not sufficient to reach efficiently the required QoS. So, we propose to use an adaptive error coding scheme suitable for a self adaptive WATM system. This mechanism must be able to adapt itself to dynamic variation of the environment in terms of SNR and/or BER of the underlying channel. It therefore offers applications best requirements and mitigates the bad effects of fading.
Network entities and more particularly base stations must then perform many additional tasks and become more "intelligent". Coordination between network entities is also necessary to achieve efficient throughput at the global network level. Our solution consists in introducing intelligent agents to increase wireless reliability and perform link adaptation. The used agents can have adaptive behavior and many goals. In this work, we consider only the goal of reducing the high BER and realizing an acceptable throughput according to a specific user application QoS. Multi-Agent System (MAS) provides a powerful paradigm for modeling complex systems and seems so appropriate to use in third generation mobile networks. Recent applications show the growing interest of this paradigm in the network domain [10]. It allows to model a society of agents which co-operate and communicate with other agents. To implement these agents, we use an operational multi-agent simulation platform named DIMA [11]. DIMA realizes an integration of a generic agent architecture and a discrete event simulation framework. It provides us with a good tool to study a collection of interacting agents in a dynamic mobile environment.

This paper is organized as follows. Section II provides a brief description of DIMA platform used to implement our new agent model. In Section III, we investigate the feasibility of setting up the adaptive scheme A-BCH-FEC. Section IV presents the model and simulation results. Finally, in section V, we summarize our main results and we highlight some future work.

II. DIMA PLATFORM DESCRIPTION

Object-oriented concurrent programming (OOCP) is the most appropriate and promising technology to implement agents. Furthermore, the combination of the agent concept and the object paradigm leads to the notion of agent-oriented programming [10,11]. Several agent architectures have been defined. We have opted to use a generic, modular and open architecture called DIMA. The platform DIMA mainly integrates a generic agent architecture and a discrete event simulation framework which can be used to simulate the dynamic environment of the agent by using stochastic variables. In the following section, we describe these two components [11].

II.1 The discrete event simulation (DES)

A DES model (see Figure 1) assumes that the states of the simulated system are only modified at discrete points in simulated time. This model progresses from one state to another on the occurrence of a timestamped event. The event timestamp indicates when these changes occur. Given the dynamic nature of the simulation model, we need a *simulation clock* that indicates how far the simulation has progressed. This clock advances in regular time intervals (*synchronous*) or in irregular time intervals (*asynchronous*). This paper deals only with asynchronous system simulation.

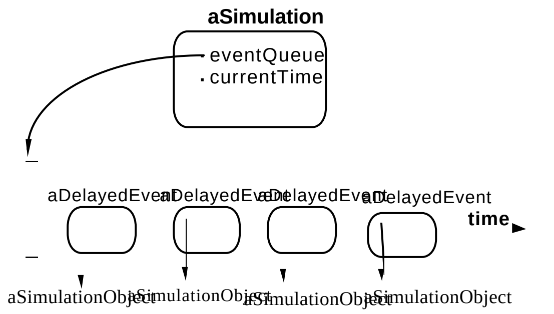

Figure 1: Overview of the used DES simulator

The discrete event simulation framework used in DIMA is presented in [12]. Its basic mechanisms are defined in three classes : Simulation, SimulationObject and DelayedEvent. A Simulation instance implements the simulation engine. It has two instance variables: a time variable (currentTime) and a sequencing set (eventQueue). Their purpose is to control the global aspects of a simulation application and to schedule the actions according to the progression of a global virtual clock. This framework includes various distributions to simulate the variation of the simulation objects states. This allows to have data very closed to the real ones. For example, in our application, the arrival of mobile stations and the call duration are easily defined.

II.2 Intelligent-Agent architecture model

DIMA is founded on a modular and open agent architecture. This architecture (see Figure 2) relies on two abstract layers:

- The **lower** layer is composed of several interactive and concurrent modules describing procedural behaviors and/or knowledge-based behaviors. Each agent may have one or more behaviors. In our application, base station (BS) agent owns two behaviors : communication and deliberation.
- The **higher** layer is made up on a supervision module. It represents the agent meta-behavior.

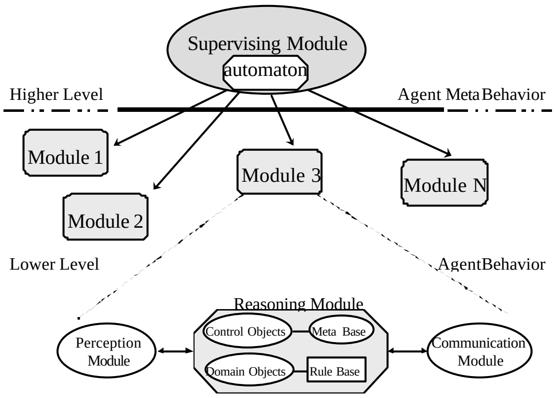

Figure 2: DIMA agent model

In the following paragraphs, we define the agent behaviors and the agent meta-behavior

1. The Agent Behaviors

An agent may have two kinds of behaviors: reactive (stimulus-response) and deliberative behaviors. We define a reactive behavior to be one that owns only simple procedural competencies, it does not use symbolic reasoning. Moreover, we define a deliberative behavior to be one that contains both kinds of competencies (knowledge-based and/or procedural) [13]. Each behavior can be viewed as a combination of three modules:

- **The deliberation module:** It represents beliefs, intentions and knowledge of the agent. It is responsible 1) for generating adequate responses to the messages transmitted by the communication module or to the changes detected by the perception module, and 2) for achieving the agent goal(s). For example, after learning process, BS agent decides which code mobile station (MS) should use in the next time period to correct information.
- **The communication module**: It manages the interactions between the agent and the other agents of its group. In our application, each BS agent knows its neighbors and communicates new information to them when its state changes.
- **The perception module :** It scans all events produced in the agent environment and reacts in real-time to unpredictable changes.

2. The Agent Meta-Behavior

This meta-behavior gives each agent the ability to reason about its own behaviors, e.g. in order to make appropriate decisions about control or to adapt its behaviors over time to new circumstances. It provides the agent with a self-control mechanism to dynamically schedule behaviors in accordance to its internal state and to its neighboring environment states. The proposed meta-behavior relies on three fundamental notions: states, transitions and actions which build up an Augmented Transition Network (ATN). Each module is represented by a set of states. Each transition links an input state with an output state. transition conditions are the various signals received by different modules (data receipt message, confirmation message, ..). Many actions occur like reading mailbox, activating, suspending and resuming modules.
We have proposed a Multi-Agent WATM (MA-WATM) architecture which is described in [14]. It classifies agents in four categories : ATMSwitch-Agent, BS-Agent, MS-Agent and Jammer-Agent. The BS-Agent is composed of an expert sub-agent dedicated to BER optimization.

III. PROPOSED MULTI-AGENT BCH FEC SCHEME

III.1 Basic concepts

As described earlier, a variety of factors contribute to the unreliability of wireless channel. Carrier-to-Interference (CIR) is the quantity that is widely used to determine the error characteristics. It is defined as the ratio of the received signal power to the noise and the interference power. In our work, we assume that the thermal noise and the inter-channel interference are sufficiently small to be neglected. Then , SNR is equal to CIR and in the following we speak only about SNR. The relationship between SNR and BER, with Binary Phase Shift Key (BPSK) modulation, is as follows [15].

$$BER = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1+SNR}}\right) \quad (3.1)$$

Coding schemes

In our system, MSs and BSs negotiate the code to use for a certain time period to protect data information. BCH codes are employed in the adaptive scheme. A $BCH(n,k,t)$ code is capable of correcting a maximum of t symbols in an n symbol codeword. k is the code dimension (number of information bits by codeword). d is the minimum distance of the codeword which determines the error correcting capability. *R=k/n* is called code rate, it determines the effective utilization of the channel total throughput capacity. In our system, information block length *k* is fixed to 424 bits. Berlekamp iterative algorithm is used to find errors location. No interleaving is used. The adaptive scheme is obtained by changing the code size.

III.2 Adaptive-BCH-ERS description

Each MS and BS contains their intelligent agents. Their aim is to find the appropriate BCH code for a given level of SNR without degrading QoS in terms of throughput and residual error rate (RER). BS agents carry out two specific features: learning and communication. The communication between agents is assumed to occur through Operation And Maintenance (OAM) cells in the ATM infrastructure as mentioned in [14]. The network will go through three phases:

1) An initialization phase where BS agents construct their knowledge base after performing correction using a specific code. We assume one BCH code per BS which determines a certain expertise on the use of a specific code. Specially, a table with three main information is constructed. It regroups SNR, throughput and code parameters used.

2) A learning phase where BS agents derives a set of rules on information collected. It gives a view on both the current environment and the agent behavior. The rules are presented as follows:

$$if \;\; val1 \le throughput \le val2 \;\; and \;\; threshold1 \le SNR \le threshold2 \Rightarrow use \;\; Code1$$

3) A communication phase where agents should have to communicate their experience knowledge to improve the overall throughput of the system. We can say that the agent performs a learning task combined from three sub-tasks : learning with events produced in the past, communicating its relevant information to the neighboring agents only when a change event occurs and finally finding the adequate BCH code for a time period.

The pseudo-algorithm executed by BS is presented below (see Figure 3). The time is divided into periods. We suppose that period should be at least as large as it is required to obtain reasonable performance measurements. The communication and learning processes are repeated at the end of each time period to adjust dynamically thresholds. The algorithm is iterative. At each iteration a couple of MS and BS collaborate to evaluate the channel performance. We denote $(T_i, SNR_i, Code_i(n,k,t))$ information used during the i^th iteration. T_i is throughput, SNR_i the level of noise and $Code_i(n,k,t)$ the code used within a period. At the end of a period, the BS checks the average SNR to see if this case has been already encountered. It also uses a similarity function based on Euclidean distance to find a closed case stored already in knowledge base using SNR and calculated T. This function is called S which is compared to a defined threshold (see formula 3.2).

$$S((SNR_i,T_i),(SNR_j,T_j)) = \sqrt{|SNR_i - SNR_j|^2 w_1 + |T_i - T_j|^2 w_2} \quad (3.2)$$

$$w_i : weight\, related\, to\, SNR\, and\, T \qquad i = \overline{1,2}$$

If the current information collected is so far, the BS stores the new information and the associated agent communicates to the neighboring agents the new case.

Algorithm

```
BS for iteration i
Begin
Calcultate SNR_i, BER_i and T_i
Set min-T = T_i, best-code = ""
Foreach Code Code(n,k,t) ∈ (Knowledge Base)
do
   lookup (SNR_i, Code_l(n,k,t))
   calculate S
   if (S < treshold) && (T_l accepatble) && (T_l < min-T) then
   min-t = T_l
   best-code = Code_l(n,k,t)
   endif
endForeach
if min-T = T_i then store (SNR_i, T_i, Code_i(n,k,t))
send (new data) to other agents (neighbors)
endif
store (Teffective, Tbest, Code-effective, Code-best) related to SM
choose best-code for next period, send parameters to SM
end
```

Figure 3: BS pseudo-algorithm

IV. SIMULATION MODEL & RESULTS

In order to study the performance of A-BCH-FEC, we use a system consisting of a group of SMs and SBs in a cellular system.

IV.1 Simulation model

The simulation model consists of a classical cellular system with two dimensional grid of 30 hexagonal shaped cells as shown in figure 4. Among the assumptions made in the study:

- the call duration is exponentially distributed with a mean value of 120 seconds,
- the arrivals follows a Poisson distribution with a non uniform spatial distribution.

  Non uniform traffic patterns are obtained by setting the arrival rates in each cell as follows: $l_i = a_i * l$

with $\sum a_i = 1$. l_i is the arrival rate for cell i and l the cell cluster aggregate arrival rate.

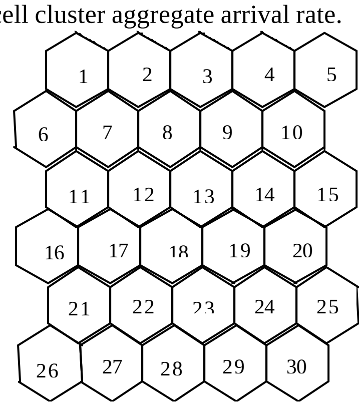

Figure 4: Layout for a 30 cell cellular system

The choice of channel model is of prime importance. To take into account Rayleigh fading, we use a log-normal model. The propagation model used to simulate the SNR measure uses a signal power P :

$$P = Kd^{-a_p} 10^{x/10} \qquad (4.1)$$

x is a log-normal random variable, its standard deviation is taken as $s = 6\,dB$.

d is the distance between MS and BS.

The path loss exponent is chosen as $a_p = 4$.

The SNR can be written as :

$$SNR = \frac{C}{I} = \frac{C}{\sum_i I_i} = \frac{Kd^{a_p} 10^{x/10}}{\sum_{i=1}^{30} Kd_i^{a_p} 10^{x/10}} \qquad (4.2)$$

The throughput is defined as the ratio of the number of decoded information digits to the total number of transmission digits. Four BCH codes are used : BCH(7,4,1), BCH(15,7,2), BCH(15,5,3) and BCH(31,16,3).

IV.2 Results

Figure 5 shows the system throughput as a function of the mean SNR, while Figure 6 depicts the decoded RER performance versus the average SNR. In these figures, results for the adaptive scheme are compared with those of non-adaptive schemes using BCH(7,4,1), BCH(15,7,2) and BCH(31,16,3). System throughput obtained in the case of A-BCH FEC is better than that gained in other mechanisms using fixed codes. For example, A-BCH-FEC achieves a 34% improvement in system throughput relative to the non-adaptive scheme using BCH(7,4,1) code. Also, an improvement of about 24% compared to BCH(31,16,3) is clearly shown. In Figure 6, we notice that RER performance results for A-BCH-FEC are close to those of BCH(31,16,3). However, throughput is improved of about 12% relative to the non-adaptive scheme. Thanks to the agent learning and communication strengths, the BS is capable of choosing the appropriate codes and adapting itself to changes occurring in the mobile environment.

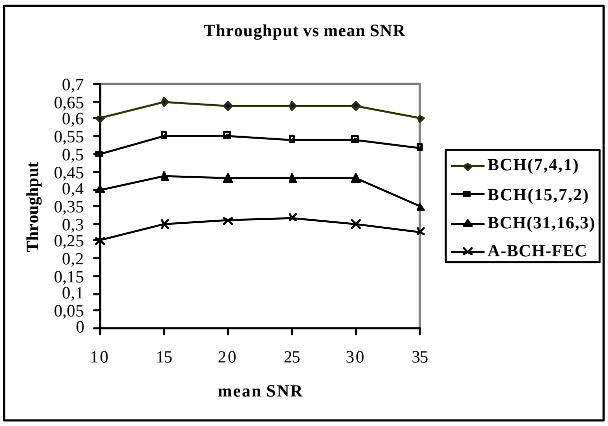

Figure 5: Throughput comparison between adaptive A-BCH-FEC and BCH
fixed schemes with code rate R=50%

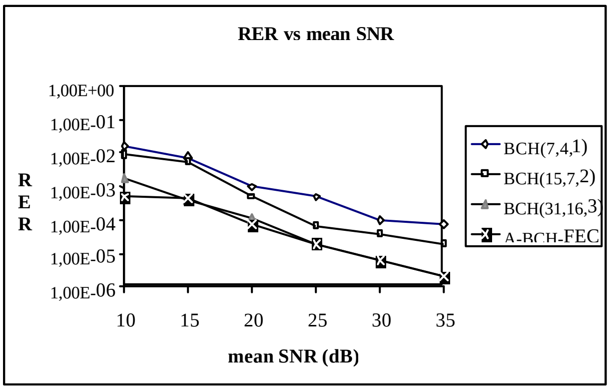

Figure 6: RER comparison between adaptive A-BCH-FEC and BCH
fixed schemes with code rate R=50%

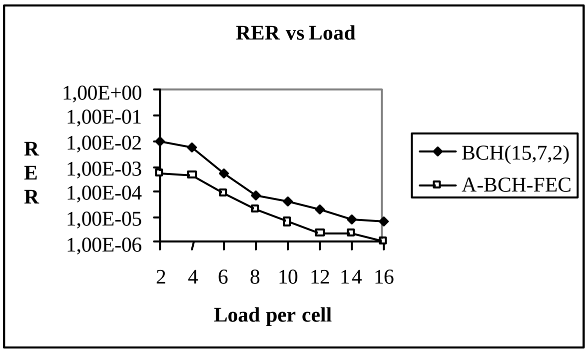

Figure 7: RER versus traffic load

We have also compared RER performance between BCH(15,7,2) and A-BCH-FEC for various traffic load values (see Figure 7). Results confirm the expected behavior with the increased interference effects arising from higher loads.

In Figure 8 and 9, results with variation of correction capability lead to make identical conclusions as in the case of variation of the code size. Results are again much in favor of A-BCH-FEC.

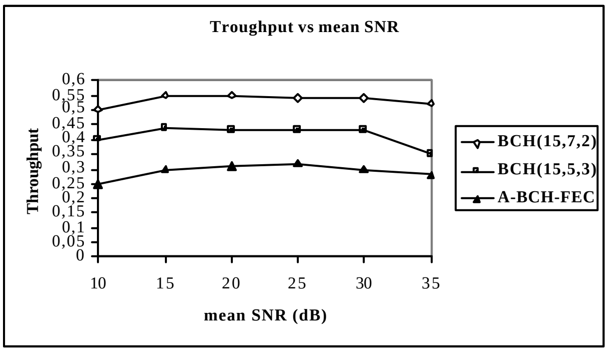

Figure 8: System Throughput versus SNR with correction capability variation

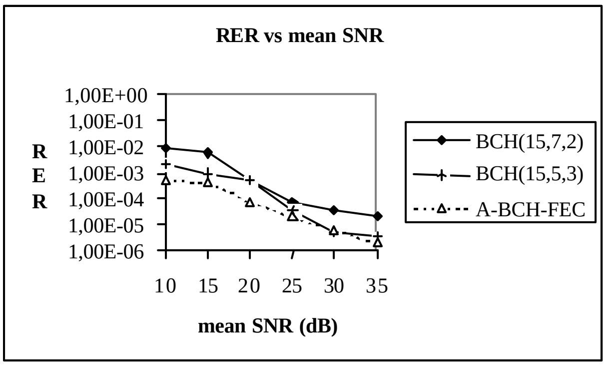

Figure 9: RER versus SNR with correction capability variation

V. Conclusion

In this work, we investigated the feasibility of the integration of multi-agent approach in wireless ATM networks. A multi-agent platform related to specifications described in this paper has been developed using DIMA architecture. For BER optimization in Rayleigh fading environment, we proposed an adaptive error control scheme using intelligent agents that adapts to the fluctuations in the wireless channel by changing the coding parameters. A performance study has been evaluated by making comparison between the adaptive scheme and some fixed coding mechanisms. Results show that the scheme A-BCH-FEC can support better quality channels as compared to schemes that use fixed codes. For future work, we intend to analyze the performance of other kinds of codes as well as Reed-Solomon and convolutional codes.

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