Software Defined Radio-based Multi-Mode DVB-RCS Terminals

Floriano De Rango[1], Amilcare-Francesco Santamaria[2], Fiore Veltri[1], Mauro Tropea[1], Salvatore Marano[1]
D.E.I.S. Department, University of Calabria, Italy, 87036
[1]e-mail: {derango, fveltri, mtropea, marano}@deis.unical.it
[2]e-mail : santamaria@si.deis.unical.it

ABASTRACT

The recent increase of multimedia applications lead to the design of new terminals capable of working with different technologies. Software defined radio (SDR), a collection of hardware and software technologies that allows reconfigurable system architectures, should be the solution to the described problems. The new types of terminals that use the SDR technique are called multi-mode terminals. In our study, we intend that a multi-mode terminal is a terminal capable of communicating both with a Bent Pipe (BP) satellite and with an On Board Processor (OBP) satellite. The goal of our work is to plan a satellite system based on the DVB-RCS standard in which the RCSTs are able to adapt itself to the channel state, configuring the transmission chain via software, respecting a QoS constraint on the PER. These considerations bring us to introduce the Supervisor (SPV) element: on the basis of inputs coming from upper layer and from the information on the channel noise power level provided by an estimator, the SPV can adapt it to channel condition producing optimized directives and parametric values to the opportune reconfigurable adaptive blocks. For this purpose, a simplified analysis on satellite channel under Additive White Gaussian Noise (AWGN) has been led out in order to obtain Markov chain model useful to test the SDR platform. In order to model the error characteristic of satellite channel (both uplink and downlink), we employed the "Gilbert-Elliot model" based on two states Discrete Time Markov Chain (DTMC). Finally, a c++ simulation tool has been realized to validate the efficiency of proposed system.

INTRODUCTION

Today, with the increasing of the networks resources and application requests, a new frontier is to optimize resources allocation and offer better service in terms of QoS. In particular new applications, in order to have better performances, require much resources than the past. Hence better methods that permit to have smart resources allocation are involved. Moreover, maintenance of QoS level requires reliable algorithms capable to dynamically respond at every types of perturbations. In particular in this work is considered a multimedia broadband and broadcast. Our reference architecture considers two satellite that can cooperate between them in order to offer best performances at the end users. Both satellites use a Digital Video Broadcast with Return Channel via Satellite (DVB-RCS) platform that permits to have an interactive communication inside the network between terminals node also called Return Channel Satellite Terminals (RCSTs) that are covered by both satellites [1]. For this purpose, we introduce in the RCST architecture a module based on Software Defined Radio (SDR) technology ([2],[3],[4],[8],[9]). SDR is a set of Hardware and Software technologies providing reconfigurable architectures for network and wireless terminals. The purpose is therefore to use the same Hardware for different functions, through a dynamic configuration according to the operational context. SDR technology allows us to introduce the SPV element ([10],[11]): on the basis of inputs coming from upper layer and from the information on the channel noise power level provided by an estimator, the SPV can adapt it to channel condition producing optimized directives and parametric values to the opportune reconfigurable adaptive blocks. For this purpose, a simplified analysis on satellite channel under AWGN, [5], has been led out in order to obtain Markov chain model useful to test the SDR platform ([12],[13]).
Our paper is organized as following. In the next section we will describe the SDR architecture (what is it and how it can work), then we describe the reference system (in particular the DVB-RCS architecture) and finally we analyze the simulation results proofing the improving that our new terminal provides.

SOFTWARE DEFINED RADIO

On Software Defined Radio Technology

SDR is a set of Hardware and Software technologies providing reconfigurable architectures for network and wireless terminals. The purpose is therefore to use the same Hardware for different functions, through a dynamic configuration according to the operational context. This is possible thanks to "flexible" Hardware and a certain level of Software interface.
Currently, an univocal definition for Software Defined Radio does not exist ([3],[4],[8],[9]).
Historically, the term "Software Radio" was coined by Joe Mitola in 1991 in order to underline the transition from 80's digital radio to the new generation innovative

radio: a multi-mode an multi-standard radio definable via software [2].
The Federal Communications Commission (FCC) defines the SDR as a generation of device radio that can quickly be reprogrammed in order to transmit and to receive on every frequency of a specific range; whereas the International Telecommunication Union (ITU) has defined the SDR as a radio system in which the operative parameters (e.g. the frequency, the modulation and the power) can be set or altered by software. However, the research reference point on this area is SDR Forum [3]. It is an international non-profit organization founded in 1996 in order to accelerate the development of radio communication systems based on the concept of SDR.
The SDR Forum provides another definition: the SDR is a collection of hardware and software technologies able to reconfigure the system architecture of wireless networks and user terminals. In particular, SDR can be classified into 5 level [3].
In this work, in order to define a possible architecture for our multi-mode terminals, we refer to 2nd level defined by SDR Forum: our terminals is a radio platform realized through digital processor in which the physical functionality are implemented via software. Therefore we will define a SDR device allowing a satellite switching or a physical layer modification without hardware substitution. In fact our architecture considers two satellites one BP and another one with OBP. The reasons to utilize both satellites is principally economic. Today a lot of satellites that are in geostationary orbit are BP, moreover the OBP satellites have a greater economic cost owing to their technology but they have better performances than the BP. It is reasonable to distribute only the traffic with high priority and only those connections that have bad performances over the BP satellite to OBP satellites. Moreover in this way the BP satellites may be yet utilized for a lot of time. The proposed SDR architecture can utilize both satellites and in particular it can switch those transmissions that require better performances due to a QoS degradations or priority service class to be served. The considered user terminals called RCSTs are equipped with a SDR technology that allows to rearrange the transmission chain in order to satisfy the QoS requirements. These operations may be deterministic or may be also formulated as an optimization problem where the variables to set are some physical parameters.
However, we must underline that Adaptive Coding & Modulation (ACM) techniques are already implemented in satellite receivers such as S2 receiver [14]. ACM technology allows to vary modulation scheme and error correction in reply to feedback on channel state received by an user satellite terminal, however all decisions are made on a specific gateway called ACM gateway. In particular, ACM is implemented by the DVB-S2 modulator by transmitting a TDM sequence of frames, where coding and modulation format may change frame-by-frame. Therefore service continuity is achieved, during rain fades, by reducing user bits while increasing at the same time the FEC redundancy and/or modulation ruggedness.
Also our terminal can vary error correction rate and transmission power adapting it to the satellite channel condition on the basis of feedback sent it by destination terminal as it occurs for ACM device. However, contrary to ACM architecture, in our system decisions are made directly by SDR module installed on RCST: so every RCST can provide a different reply to an external stimuli and can carry out the most appropriate strategy following specific and various strategies. In fact, in ACM architecture the adaptive modality is relegated to rigid and pre-determinate schemes (adding new functionalities can require DVB-S2 standard modifications), instead the main advantage of proposed architecture is its flexibility: the reconfigurable mode obtained via software allows to adapt it to designer needs. In this work, we designed SDR terminals in order to vary transmission power, FEC rate and the satellite on which are log on (in particular this feature cannot be realized by ACM receivers) for the purpose of respecting a QoS constraint on the Packet Error Rate (PER): however new physical parameters (e.g. power consumption, modulation schemes, etc.) to take into account and more QoS constraints to respect could be easily added without distorting system architecture (no hardware change are needed, in fact it comports only the reprogramming of Super Visor element, see in the next section for further details).

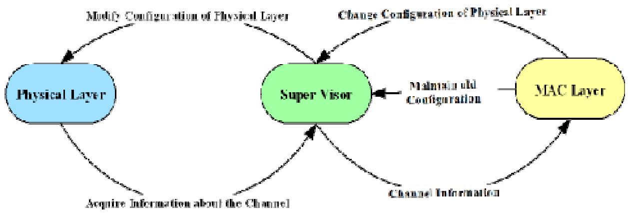

Figure 1: Operation scheme of SPV

Super Visor Module

In our work the re-configurability is obtained programming the logic circuit of SDR platform. Therefore the terminal can adapt itself to the channel state setting via software the transmission chain. These considerations lead us to introduce the Super Visor (SPV) element ([9],[10],[11]): on the basis of inputs coming from upper layer and from the information on the channel state provided by an estimator, the SPV is able to produce optimized directives and parametric values to the opportune reconfigurable adaptive blocks. In accordance with an inference algorithm, this is planned in an appropriate way. A scheme of principle of the SPV block is the following: the level of required QoS, represented by PER and bit rate, is provided to the MAC level, while the information on the channel state is originated by the Physical (PHY) level.

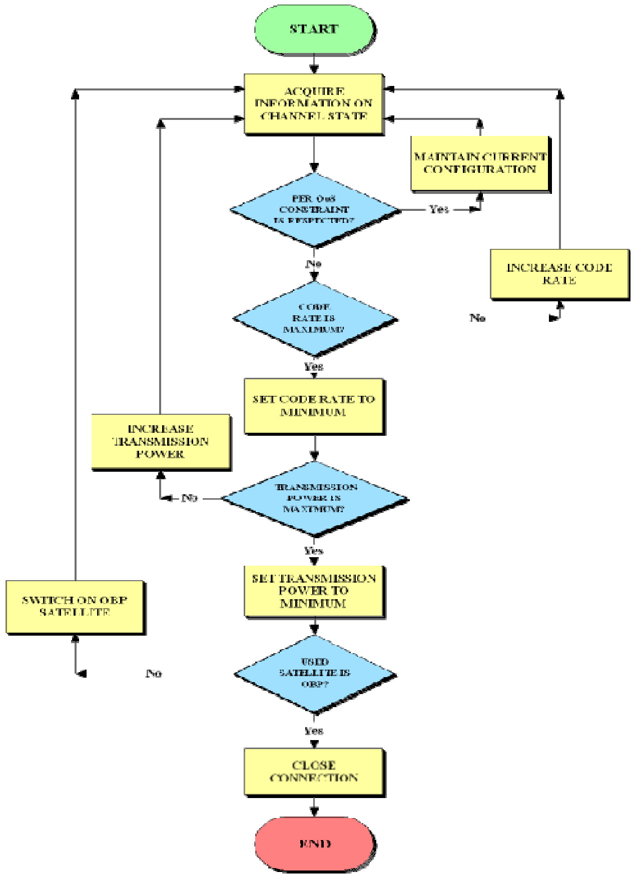

Figure 2: SPV Algorithm flowchart

The SPV algorithm calculates and provides to the MAC level the pair bit-rate/PER, moreover other information are returned (maximum bit rate available or least available PER), that the MAC layer could eventually use for performing some optimizations. Instead, the optimal combination of coding parameters (coding rate and length of the coding block), transmission power and used satellite type are returned to the PHY level.
In Figure 1 the exchange messages are schematized: the SPV acquires information on the channel condition from an estimator and sends them to the MAC level; the MAC, therefore, sends a return message to the SPV: this message contains information about the reconfiguration, that is if the hardware must be reconfigured or not. If it is not necessary to change the transmission parameters, the SPV continues its monitoring phase, acquiring information on the satellite channel; otherwise it will make a change via software on the transmission chain, trying to improve the performances. The SPV makes the reconfiguration of the SDR module following these priorities: 1) change of the coding rate; 2) change of the transmission power; 3) switch on a different satellite.
These actions are better explained in Figure 2 where the flowchart of SDR algorithm is shown. For example: if the constraint PER is violated then a hardware configuration change is necessary, so SPV verifies if the code rate is already at the maximum value. If it is false, the SPV increases code rate otherwise it sets the code rate to the minimum value and it tries to increase transmission power. If either this operation cannot be performed because the power is already to the maximum, then SPV tries to switch on OBP satellite. If the RCST is already logged on OBP satellite, no further operation can be performed because the system is already set on the better possible configuration and so the RCST must disconnected it from satellite system (QoS constraint cannot be respected and therefore it is useless to continue the transmission).

REFERENCE SYSTEM

In this work we propose an architecture based on two satellites: one BP and another one with the OBP. In this proposed system, some RCSTs could be covered by one satellite and others by both satellites. RCSTs can change its transmission chain in order to satisfy the QoS requirement, moreover RCSTs covered by both satellites have the possibility to change their transmission chain and they could switch from a satellite to other one, in particular from BP satellite to OBP satellite.

Satellite communications

DVB-RCS is a technology that permits to have return channel and forward channel over the same medium. In this way users can take advantages of the satellite communications [1]. Moreover it is obtained an interactive communications between the end-user and the source service. DVB-RCS system is composed by RCSTs, a *Network Control Center* (NCC), the satellite and a *Feeder/Gateway* (F/G) as is shown in Figure 3. The core of the system is the NCC that has the task to manage the entire system, in particular it manages the connection, the system synchronization and informs all the RCSTs about the system condition. Moreover the NCC can disconnect RCST from the network if a terminal is not active or for other administrative reasons. RCSTs give the access at the user terminals and it can be used to attach a LAN. The F/G are used in order to supply access from the DVB-RCS network towards the WWW and vice versa. Satellite communications permit to have greater bandwidth and reliable communication. Moreover, in these last few years, the improving of technology has permitted to reduce dish and terminal size. In fact, for satellite communications new application scenarios can be considered. In the recent past satellite communications was utilized to serve those zones that are hardly to be covered, or to reach those zones that had a greater distance between them. Nowadays satellite communications are utilized to distribute wireless broadband access and multimedia communications. Moreover satellite communications could be used for the civil protection and in particular in order to manage different centers which are organized in a hierarchical manner. A typical organization contains a national center and different local centers that have the task to inform the national center and applying decisions that come from it. Moreover satellite that permits to have a return channel via satellite gives broadband access that are not limited by congestion problem. However propagation delay is a greater limit for these types of communications. With BP satellites that permits only to retransmit the received signals the propagation delay is around $540\cdot10^{-3}$ sec. Instead if OBP satellite is used the propagation delay is around $270\cdot10^{-3}$ sec. Moreover the OBP satellite permits to have secure transmissions with a signal to noise ratio greater than the BP satellite. OBP satellite can analyze the signal and it can applies a gain only on the useful part of the received signal. This satellite permits to have a direct connection between a source and a receiver without pass through a Feeder/Gateway that are present in the Bent Pipe configuration. In order to consider the actual global satellite configuration we include in our SPV module the possibility to switch from a BP satellite to an OBP satellite. This switch permits to enhance the overall performances of the communication system taken advantages of the better performances of the OBP satellite.

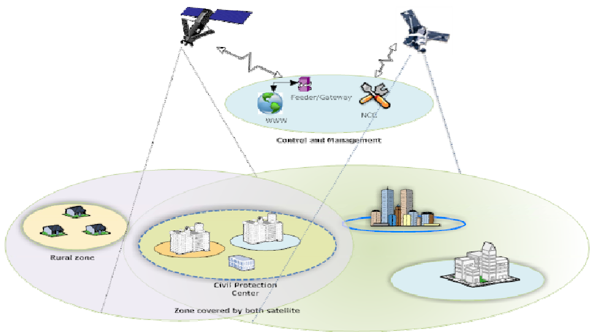

Figure 3: Reference Architecture

Satellite Channel Model

We remark that our first contribution is carried out an analysis on the SDR system, so for the paper purpose a simply satellite channel model can be considered. In order to provide a valid channel model, we implemented a Matlab model, allowing us to test the physical layer of DVB-RCS satellite system and to collect data to compute the transition state probabilities. We considered the thermal noise due to temperature, the quantization noise and the background noise due to other communication system as a single input, modelled as zero mean and parametric variance AWGN. Moreover, we considered an attenuation due to free space propagation, path loss, based on Friis's model ([5],[7]):

$$PL(d) = 20\log_{10}\left(\frac{4\cdot\pi\cdot d\cdot f_c}{c}\right) \quad (1)$$

where f_c is the carrier frequency, c is the light speed and d is the covered distance. The distance d between a geostationary satellite and a earth terminal placed on equator line is 35.778 Km. However for terminal located on other latitude is necessary add to d a further corrective term given a distance for the northern hemisphere by ([5],[7]):

$$d_{correction} = 42643.7\cdot\sqrt{1-0.295577\cdot(\cos\phi\cos\delta)} \quad (2)$$

where ϕ is the earth station latitude while δ is the difference between earth terminal longitude and satellite longitude. Furthermore, in order to take into account average climatic condition, also a rainfall attenuation term is considered in accordance with ([5],[7]). This term depends on earth station position (and so by elevation angle), therefore it depends on rain intensity in that particular zone (this information can be obtained from the rain climatic zone maps contained in [5]). Another important dependence is by central frequency: in fact attenuation due to rainfall is more significant for the high frequency (>10 GHz). Further details can be found in [5].

In order to model the error characteristic of satellite channel (both uplink and downlink), we employed a widely used and simple model: the "Gilbert-Elliot model" ([12],[13]). According with ([12],[13]), our model is based on two states Markov channel with the state named *Good* and *Bad*: we are in the *Good* state if the received packet is correct while we are in the other state if the packet is wrong. In particular, we model a *Discrete Time Markov Chain* (DTMC) for each possible transmission configuration. A DTMC is defined as a discrete-time stochastic process assuming discrete values such as the process evolution, starting from observation time, depends only on the current state [6]. This concept can be expressed by the following formula:

$$\begin{aligned}&P(X_n = x_n | X_{n-1} = x_{n-1}, X_{n-2} = x_{n-2}, \ldots X_0 = x_0) = \\ &= P(X_n = x_n | X_{n-1} = x_{n-1})\end{aligned} \quad (3)$$

Starting from (3), we can write:

$$p_{i,j} = P(X_n = j \mid X_{n-1} = i) \quad (4)$$

where $p_{i,j}$ is the probability that the process is in the state j at the time t_n if at the time t_{n-1} it is in the state i. These probabilities can be rewritten in a matrix form as follows:

$$\mathbf{P} = \begin{bmatrix} p_{0,0} & p_{0,1} \\ p_{1,0} & p_{1,1} \end{bmatrix} \quad (5)$$

P is called transitions probability matrix (further details on its proprieties can be found in [12] and [13]). Satellite channel characterization can be captured by a packet error trace in accordance to [13]. The trace contains information about whether a particular packet was transmitted correctly (i.e., a "1" represents a wrong packet and so a *Bad* state, while a "0" represents a correctly transmitted packet, that is a *Good* state). The simulations to collect trace have been carried out in critical noise condition to better underline satellite performance. In the following, due to lack of space, only an example, for a specific transmission configuration, of the procedure to compute transition state probabilities will be shown (for the others configurations the procedure is similar).

In this example, we fix the transmission power to 40 dBW, the code rate to ¾ while the employed satellite is OBP. Furthermore we suppose that sender RCST and receiver RCST are located at geographic coordinates of Rome and the both geostationary satellites (BP and OBP) are located at 7° East longitude (such choice is made because at this coordinates are located real satellites). Besides, we consider a total power noise contribution of 30 dB. Matlab simulations provided us the file trace to analyze. The first step is to evaluate the stationary propriety of the obtained trace: we define a trace to be *stationary* whenever the error statistics remain relatively constant over time. Using a specific Matlab tool, we verified that obtained trace is a stationary process, so we can proceed to compute transition state probabilities. The probability $p_{0,1}$, that is the probability that the next state is *Bad*, given that the current state is *Good*, is obtained as:

$$p_{0,1} = \frac{TGB}{NG} \tag{6}$$

where *TGB* is the number of transition from *Good* state to *Bad* state, while *NG* is the number of *Good* state. At the same way, we can compute the probability $p_{1,0}$.

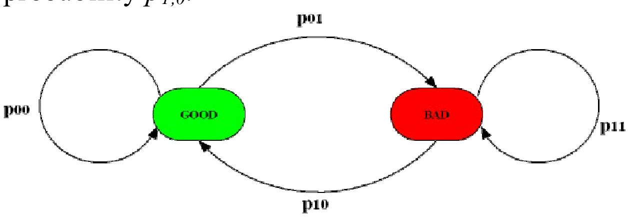

Figure 4: Two states Markov model

In our example, we obtain the following values for the **P** matrix:

$$\mathbf{P} = \begin{bmatrix} 0.8781 & 0.1219 \\ 0.8747 & 0.1253 \end{bmatrix} \tag{7}$$

In Figure 4 is schematized the two states based Markov model (we associate the symbol “0” to the Good state). Finally, the last step is to verify that the mean state sojourn time is exponentially distributed (in fact, in order to affirm that analysed model is a Markov chain it is necessary that mean state sojourn time is exponentially distributed). We test the mean state sojourn time using the Kolmogorov-Smirnov test: the result of this test is true if you can reject the hypothesis that the data set is exponentially distributed, or false if you cannot reject that hypothesis. In our case, the test return false for both state sojourn time. In particular, for the Good state sojourn time, we obtained the *Cumulative Distribution Function* (CDF) plotted in Figure 5 : we can see that the data set can be approximated by a exponential distribution with μ=8.17702 as the Kolmogorov-Smirnov test confirms.

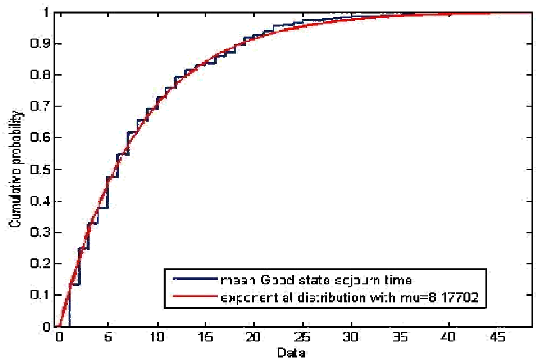

Figure 5: Mean Good state sojourn time compares with the CDF of an exponential distribution of mu=8.17702

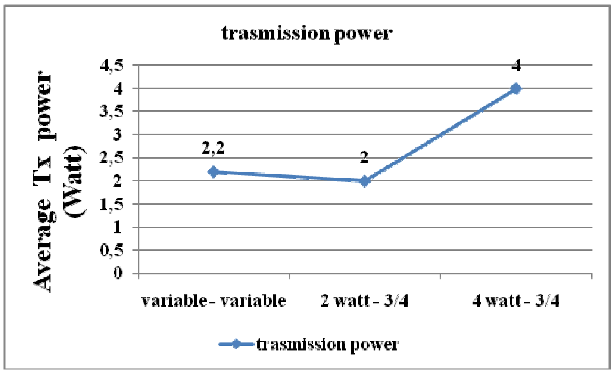

Figure 6: Average transmission power vs. SDR terminals capabilities

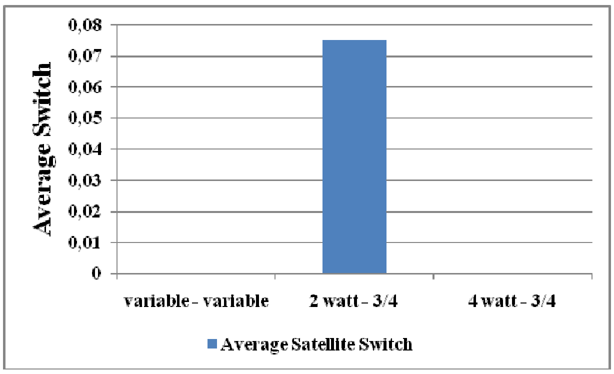

Figure 7: Average Satellite switch per terminal RSCT

SIMULATION RESULTS

In this section will be shown the results obtained by the simulation campaigns that has been carried out. These campaigns have the focus to demonstrate the effective efficiency of the SDR technology applied to the RCST terminals. With the use of the SDR the overall performances of the system are enhanced. In particular it is possible to have improvements in terms of refused calls or in terms of measured delay such as end-to-end or jitter delay. In the below figures we have focused our attention over the behavior of the system when the SDR capabilities of the terminals are limited. In particular we have used the parameters show in table 1. Firstly, RCSTs have all the capabilities, they can increase its power transmission, change its FEC and at last if the PER is not yet satisfied the RCSTs can switch to other satellite. Other points in the curves are obtained limiting the possibility to change transmission power and FEC in the transmission chain. In particular if PER requirements is not satisfied then the RCSTs can only switch from one satellite to another one. Figure 6 shows the different level of the transmission power utilized by the terminal during the transmission in the various simulated scenario. In particular, the first point of the curve represents a system with a transmission power and FEC variable. As it is possible to note the average transmission power utilized by the RCSTs is around 2,2 Watt that means that a system with only 2 Watt cannot guarantee the respect of the PER requirement. Moreover a transmission power of 4 Watt could be excessive for this particular noise level.

Figure 7 shows the average number of satellite switches, when the system is configured with a power transmission of 2 Watt and a FEC of ¾. The system in order to satisfy the PER requirement, must switch from BP satellite towards the OBP one.

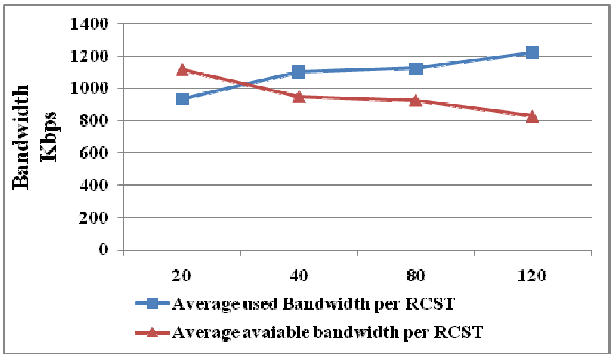

Figure 8: Average available bandwidth per RCST vs. end user terminals increasing

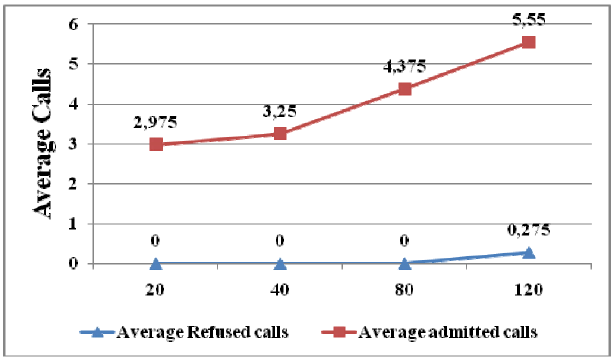

Figure 9: Average admitted and refused calls vs. the end-user terminals increasing

We want illustrate the behavior of the system with the increase of the end-user terminals. In particular all the RCST are covered by both satellite and they can change from the BP to the OBP satellite if necessary. Figure 8 shows the trend of the average available and used bandwidth per RCST. With the increase of the end-user terminals connected at the RCST it is obtained an increasing of the used bandwidth and a decreasing of the available bandwidth. Moreover the increasing of the end-user terminals also causes the refusing of some calls as shown in Figure 9.

Figure 10 and Figure 11 show the trend of the throughput for the return and forward channel of both satellites. As it is possible to note the return channel has a higher throughput owing to its available bandwidth. In fact the channels are asymmetric between them and for this reason the return channel throughput is more higher than the forward channel. Moreover, in this campaigns, where the RCST can switch between the two satellites, the OBP satellite is also utilized. Its utilization is lower than the BP satellite because in this scenario low noise level has been considered. With this configuration the RCSTs did not need to switch in order to satisfy the QoS requirement, in particular the power transmission and FEC rearrangement has been sufficiently to respect the requirement.

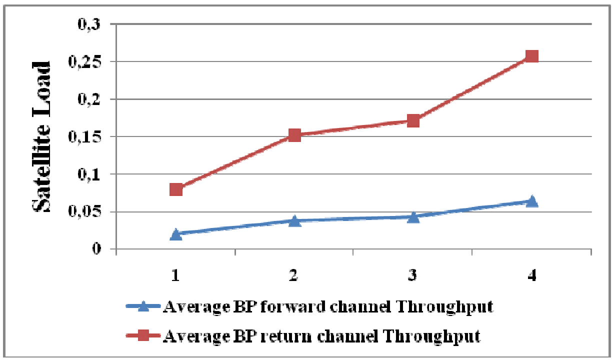

Figure 10: Throughput of the channels for BP satellite

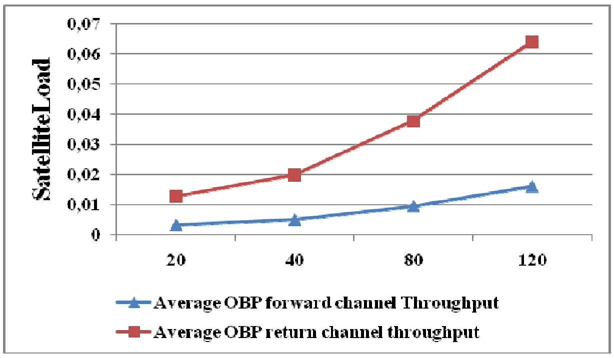

Figure 11: Throughput of the channels for OBP satellite

In Figure 12 is shown the trend of the system behavior, when the noise level augment. In particular it is shown the average closed calls owing to the maximum configuration reaching, this happen because the system cannot guarantee the PER level and not more configurations are possible in order to satisfy the requirement. The figure also shows the average number of satellite switch per RCST. The average number of satellite switch increase whit the augment of the noise level because the BP satellite cannot guarantee the PER requirement, instead the OBP satellite offers best performances, in fact it give a better C0/N0 ratio than the BP satellite. Moreover the Average transmission power switching are more explicative than the other two curves, in particular it is possible to note that the system converge to the same configuration when the noise level is greater than the 3.6 value. In other word the system has not more choice in order to satisfy the PER requirement.

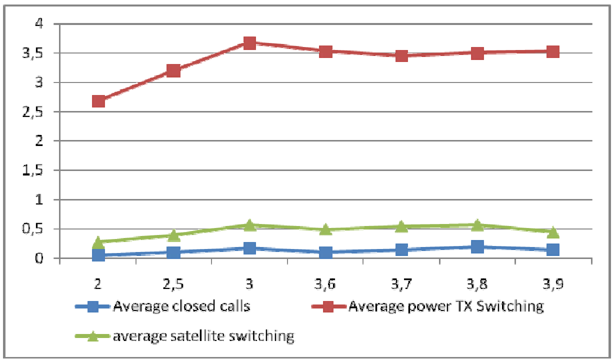

Figure 12 system behavior vs. noise level increasing

CONCLUSION

In this works we have proposed a new Terminal equipped with the SDR technology. This technology permits to rearrange the transmission chain in a dynamic way in order to satisfy the PER requirement. The SDR module is managed by a particular inference algorithm called SPV. This algorithm estimates the channel state through an estimator provided by physical layer; furthermore, in order to model the satellite channel, Markov chain analysis has been carried out starting from exhaustive campaigns on the physical layer in critical noise conditions.. Simulation campaigns that have been carried out have demonstrate that the dynamic change of the configuration can guarantee a better exploitation of the available resources. In particular, with the use of the SDR technology, the number of the calls correctly ending is greater than before. These calls are all the calls that are terminated with the respecting of the QoS requirements. Moreover using of this technology permits to use in a cooperation manner the BP and the OBP satellite. Finally, the time needed at RCST terminal to reconfigure the transmission chain does not degrade the performances of the system.

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Table -I-

Description	Used Value	
BP satellite number	1	
OBP satellite number	1	
RCST Number	10	
Number of user terminal	I – III campaigns	II campaign
	160	20-40-60-80-120
Reference platform	DVB-RCS	
SDR capabilities	I campaign	II - III campaigns
	Satellite switch/power tx changing/fec changing	Terminals equipped with full SDR capabilities
	Satellite switch/Fixed power tx/Fixed fec	Satellite switch/power tx changing/fec changing
Simulation Time	100	
Average calls per minutes	4	
RCSTs covered by satellite	BP/OBP	At beginning all RCSTs start its connection under BP satellite
Propagation Delay	BP satellite	OBP satellite
	540 10^{-3} sec	270 10^{-3} sec
Noise level	Constant in the I and II campaigns	Variable in the III campaign