Multi-Mode DVB-RCS Satellite Terminal with Software Defined Radio

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***Abstract*—A multi-mode radio communication terminal is a tunable terminal for passing and/or receiving bands in at least two radio communication systems. In the last few years many research resources have been invested in the study of this new type of terminal. In our study, we intend that a multi-mode terminal is a terminal capable of communicating both with a Bent-Pipe satellite and with an On-Board Processor satellite.**
In the literature different technologies are presented and they can be used to realize the multi-mode capability of a terminal, but, the most suitable technology is the Software Defined Radio (SDR). The SDR is a set of Hardware and Software technologies that allow one to obtain reconfigurable architectures for network and wireless terminals. The goal of our work is to plan a satellite system based on Digital Video Broadcast with the Return Channel Satellite (DVB-RCS) standard in which the Return Channel Satellite Terminals (RCSTs) are able to adapt to the channel state, configuring the transmission chain via software, respecting a certain Quality of Service (QoS) constraint on the Packet Error Rate (PER).

Keywords*:* SDR, Multi-mode Satellite Terminals, DVB-RCS.

I. INTRODUCTION

In the last few years, researchers have been trying to realize a terminal capable of interfacing with different networks.

The wide variety of wireless communication systems, each with a different operating frequency, modulation and coding technique, protocols and so on, requires its own terminal and infrastructure; while the enormous spread of wireless communication systems and the successive development of various standards and protocols (GSM, IS-95, CDMA, IEEE 802.11x, Bluetooth…) has led to the needing of creating terminals that permit interoperability between different systems.

Software defined radio (SDR) should be the solution to the described problems. The software is introduced as a module working on a generic platform hardware, capable of implementing different standards of a radio system. The flexibility offered from an SDR system helps to resolve problems between various standards. The SDR is a set of Hardware and Software technologies that allow one to obtain reconfigurable architectures for network and wireless terminals.

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 *Digital Video Broadcast with Return Channel Satellite* (DVB-RCS) standard [1] in which the *Return Channel Satellite Terminals* (RCSTs) are able to adapt to the channel state, configuring the transmission chain via software, respecting a certain *Quality of Service* (QoS) constraint on the *Packet Error Rate* (PER).

The paper is organized as follows: a brief overview on DVB-RCS satellite architecture is given in section II; section III introduces the SDR module; performance evaluation are presented in section IV; conclusions are summarized in section V.

II. DVB-RCS SATELLITE SYSTEM

For the purpose of our study we have considered a DVB-RCS architecture composed of two types of satellite: On-Board Processor Satellite, which improves the platform performances, and the simple Bent-Pipe Satellite.

In Figure 1 the most relevant elements of the DVB-RCS Network are shown[1-3]:

- RCST (Return Channel Satellite Terminal), denotes each terminal that accesses the network. It can be of four different types on the basis of different bandwidth capacity: RCST A (144 Kbps), B (384 Kbps), C (1024 Kbps), D (2048 Kbps).
- NCC (Network Central Control), it has to manage the access and allocate the band for all RCSTs.
- Gateway and Feeders are the elements for receiving and transmitting information outside the network.

The satellite medium access scheme is based on a Multi-Frequency Time Division Multiple Access (MF-TDMA) approach.

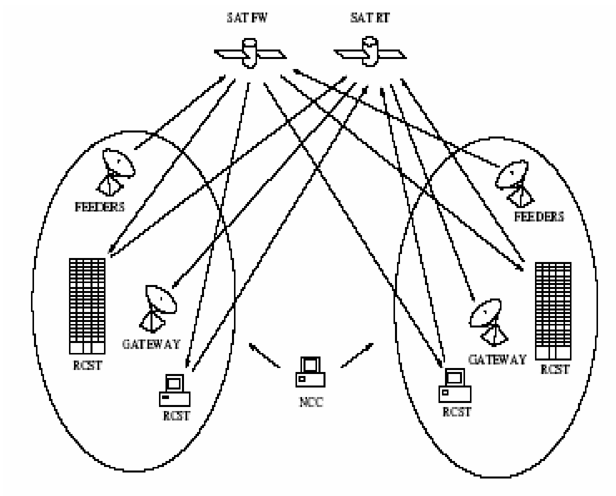

Figure 1 - Satellite system architecture.

The DVB-RCS standard provides five allocation request types [1]. They can be mixed in order to meet the RCST/NCC capabilities and the QoS requirements:

- *Continuous Rate Assignment* (CRA): is a fixed capacity negotiated between the RCST and the NCC. It is maintained across frames until a new negotiation takes place.
- *Rate Based Dynamic Capacity* (RBDC): it is a rate request, i.e. bytes/frame. The request has an absolute meaning and therefore the last one will overwrite all previous RBDC requests from the same RCST. The value of the RBDC request is subject to a maximum rate limit that will be negotiated between the RCST and the NCC.
- *Volume Based Dynamic Capacity* (VBDC): is a volume capacity request, i.e., bytes. The request has a cumulative meaning.
- *Absolute Volume Based Dynamic Capacity* (AVBDC): is similar to the VBDC request. It has an absolute meaning, i.e., it will overwrite any previous request of the same type.
- *Free Capacity Assignment* (FCA): it is not a true request.

Its purpose is to try to allocate the otherwise unused capacity. This capacity assignment is automatic and it does not involve signaling from the RCST to the NCC.

III. SDR MODULE

Software Defined Radio is a technology in fast evolution and which is receiving enormous acknowledgments and interests in the world of the telecommunications industry. SDR technology enhances the implementation of some modules of a radio system, like modulation and demodulation, signals generation and protocols. This helps to develop a reconfigurable radio system, where the parameters are selected in a dynamic mode. We can see it as a software capable of generating various types of transmission signals. Its implementation can be used in military, civil and commercial fields. Radio applications, like Bluetooth, WLAN, GPS, Radar, WCDMA etc., can be implemented using technology SDR.

SDR is a collection of hardware and software technologies that allows reconfigurable system architectures for wireless networks and user terminals. SDR provides an efficient and comparatively inexpensive solution to the problem of building multi-mode, multi-band multifunctional wireless devices that can be adapted, updated or enhanced by using software upgrades [4-6]. Therefore, SDR can be considered a technology that is applicable across a wide range of areas within the wireless industry.

Radios built using SDR concepts can allow [4-6]:

- Standard, open, and flexible architectures for a wide range of communications products.
- Enhanced wireless roaming for consumers extending the capabilities of current and emerging commercial air-interface standards.
- On-air downloads of new features and services as well as software patches.
- Advanced networking capabilities to allow truly portable networks.
- Unified communication across commercial, civil, federal, and military organizations.
- Significant life cycle cost reductions.

In our work the re-configurability is obtained programming the logic circuit of SDR platform. Therefore the terminal can adapt to the channel state setting via software the transmission chain. These considerations bring us to introduce the *Supervisor* (SPV) element [7]: 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 by the MAC level, while the information on the channel state is originated by the *Physical* (PHY) level.

The SPV algorithm calculates and provides to the MAC level the bit-rate/PER pair, moreover other information are returned (maximum bit rate available or least measured PER), that the MAC 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 interfaced satellite type is returned to the PHY level.

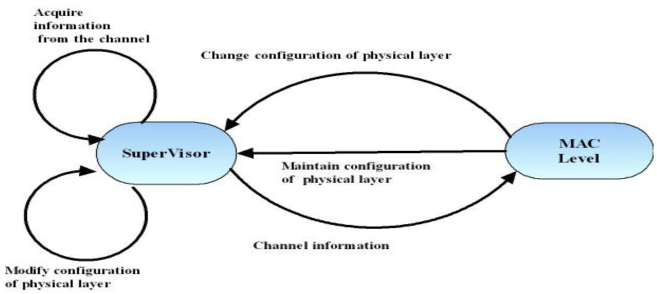

Figure 2 – Operation scheme of SPV

In Figure 2 the exchange messages are schematized: the SPV acquires information on the channel from an estimator and sends them to the MAC level; the MAC, therefore, sends a return message to the SPV in which it is communicated if the hardware must be reconfigured or not. If it is not necessary to change the transmission parameters, the SPV continues its phase of monitoring, acquiring information on the satellite channel; otherwise it will make a change via software on the transmission chain, trying to improve the performances.

```
void RCST::spvAlgorithm (.......)
{
 if (hardware_configuration_change)
 {
      if ( this.current_rate = = 3/4 )
      {
           this.current_rate = 3/2;
           this.update_state();
      }
      else if (this.current_rate = = 3/2 )
      {
          this.current_rate = 1/2;
          this.update_state();
      }
      else if ( this.current_rate = = 1/2 )
      {
           if ( this.current_power = = 2 )
           {
               this.current_power = 3;
               this.update_state();
           }
          else  if ( this.current_power = = 3 )
           {
               this.current_power= 4;
               this.update_state();
           }
          else  if ( this.current_power = = 4 )
          {
                 if( this.connected_satellite = = 'BentPipe' )
                 {
                      if ( this.change_satellite_is_possible() )
                      {
                           this.connect_to_new_satellite();
                           thi.set_to_initial_configuration();
                           this.update_state();
                      }
                      else this.close_session();
                 }
                 else this.close_session();
          }
      }
 }
 else
 {
    continue_monitoring();
 }
} //end spvAlgorithm
```

Figure 3 - Operative scheme of SPV

The SPV makes the reconfiguration of the SDR module following these priorities: 1) change of the transmission power; 2) change of the coding rate; 3) switch to a different satellite. In Figure 3 the pseudo-code of SPV algorithm is illustrated: if a hardware configuration change is necessary (e.g. when the constraint on the PER is not respected), the SPV chooses the new configuration following the priorities indicated in Figure 2.

IV. PERFORMANCE EVALUATION

In this work simulation was conducted through two different environments, in order to carry out tests on the physical layer and upper layer of the satellite network with multi-mode intelligent terminals.

In order to simulate the physical layer of the DVB-RCS satellite system we used the Simulink tool of Matlab. We analyzed the *Packet Error Rate* (PER) vs. *noise variance* for the various possible transmission configurations. For this purpose, we modeled a set of noise figures, like thermal noise and quantization noise as *Additive White Gaussian Noise* (AWGN) with zero mean and parametric variance. Moreover, we considered an attenuation due to free space propagation, path loss, based on Friis's model [3]:

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

where f_c is the carrier frequency, c is the light speed and d is the covered distance.

Moreover, in order to consider the atmosphere attenuation we introduced a corrective term both on the uplink and downlink channel as suggested in [3].

TABLE I
OPERATIVE RANGES (MAXIMUM NOISE VARIANCE TOLERABLE)

BP SATELLITE			
Transmission power (w) → / Code rate ↓	2	3	4
1/2	0.7	1.1	1.5
2/3	0.45	0.7	1
3/4	0.2	0.3	0.45
OBP SATELLITE			
Transmission power (w) → / Code rate ↓	2	3	4
1/2	1.6	2.4	3.5
2/3	1.2	1.85	2.65
3/4	0.75	1.2	1.65

The network simulator, that realizes the OBP and BP satellite network, was implemented in C++ development language. We suppose that the two satellites cover the same area and then it is not necessary to implement the antenna positioning mechanism. The simulator permits one to set QoS parameters that must be respected, so the SDR can adjust the transmitting power or the *Forward Error*

Correction (FEC) rate in order to obtain a better S/N ratio. We considered many simulation indexes such as delays, satellite load, admitted and refused connections and delivered and dropped packets. Moreover, in order to realize an accurate analysis of the system, we also considered measures of the transmitting power, number of switches, info on the transmitting rate or other information on the utilized number of time slots. The simulator utilizes integrated services, so the end user terminal performs the resource allocation with a reservation response to a path message, sent by the source terminal [9]. Moreover, the bandwidth needed to observe the constrained delay bound is calculated at the receiver side and for this reason the channel request to the satellite from the RCST source is made when the reservation message reaches the RCST, which has connected the source.

A. *PHYSICAL SIMULATION CAMPAIGN RESULTS*

The goal of the first simulation campaign was the analysis of average PER in order to obtain a set of operative range in terms of power transmission, code rate and satellite type for distinct noise power level, as expressed by different variance values. We carried out our simulation in critical noise condition to better underline the satellite performances. In Table I we summarize the operative ranges of the implemented system. We can see how the code rate has an important impact on the system performance, in fact the maximum tolerable noise level, up to which we have a PER of the order of 10^{-6} (*Quasi Error Free*, QES, transmission according to DVB-RCS standard specifics), rises considerably if the code rate increases. In particular, if we transmit with a power of 2 W on BP satellite, the system can reject a total noise of variance 0.7 with a code rate of ½, but only a noise of variance 0.2 if we lower the code rate at ¾ (we can see this trend in Figure 4).

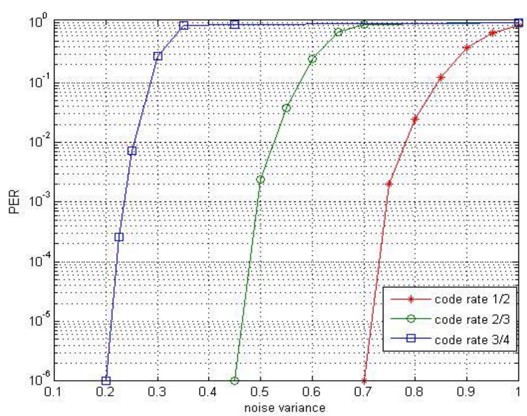

Figure 4 – PER vs. noise variance for BP satellite with a power of 2 W.

Besides, we can see in Figure 5 also as an increase of power transmission means also an increment of the maximum noise level tolerable.

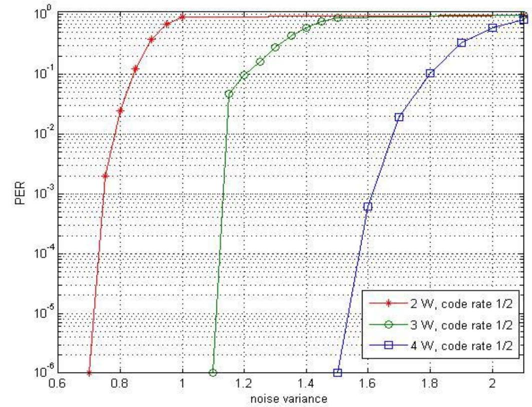

Figure 5 – PER vs. noise variance for BP satellite with a rate code of ½.

Instead, comparing two types of satellite (see Figure 6), we can see how the performance of the OBP satellite are better than BP one because the employment of regenerative satellite introduce a first phase of error correction already on board of satellite: therefore, for the same other conditions, a system utilizing a OBP satellite tolerates a higher noise level (e.g. if the radiated power is 4 W and the code rate is ½, a OBP satellite can tolerate a noise of variance 3.5, while a BP satellite can tolerate only a noise of variance 1.5).

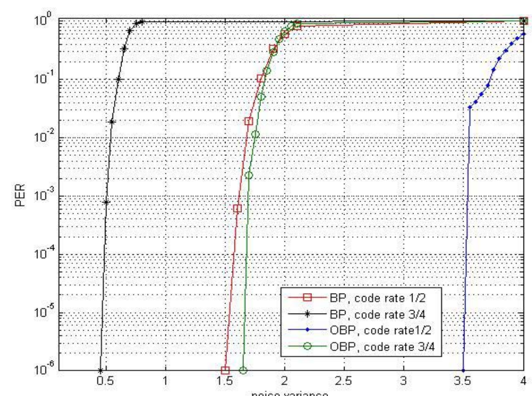

Figure 6 – PER vs. noise variance for BP and OBP satellite with a power transmission of 4 W.

B. *SIMULATION RESULTS*

In the following, we analyze simulation results for the network simulation campaign. In Table II we present the parameters that are utilized in the different simulation scenarios. We utilized an SDR system in which the RCST terminals have the properties of the SDR, and also we utilized a non-SDR system that is equipped with simple RCST terminals, which do not have the capacity to switch between different configurations.

TABLE II
SIMULATION PARAMETERS

Topology Parameters	Value
Total RCSTs nodes	5, 10, 25, 20
Total Source Terminals nodes	80, 160, 240, 320
Simulator Parameters	Value
Noise Variance paramters	1.5-3.3.5-4.6-3.7-3.8-3.9-4
Avarage calls	4/minute
Average duration of a single calls	5 minutes
Packets Control	200
Satellite System	OBP, BP
Network Parameters	Value
Medium Access Protocol	MF-TDMA
Target Burst Loss Probability (ε)	0.01
Atomic Channel (Slot)	32 kbit/s
Return/Forward Channel's Trama	47 ms
RCST Typology	D (2048 kbit/s)
Number of Source for RCST	16
Satellite Values	
Round Trip Time	540 ms
Return Channel's Slots	1400
Forward Channel's Slots	4000

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We have considered the following output values so to have a series of data to elaborate the performances of the system. These data regards the utilization of the Forward and Return links of the two satellites; these parameters give us information about the resources allocation over the links in terms of percentage. In this way it is possible to observe if the system is loaded and how much the system is loaded. Others parameters that are observed are for example the number of calls, generated from a source terminal during the simulation period; moreover, how many of these calls have been admitted, refused or completed .

In Figure 7 the comparison between two previous systems in terms of the average calls lost for the RCST terminal in the simulation time horizon is plotted. In the no-SDR system the calls, that have been closed due to their not respecting the QoS constraint, are much more than in the SDR system. In fact, in the no-SDR system, when the noise reaches the maximum supported level, the calls must be closed. Instead, when the SDR system is in the same conditions, an RCST can switch its configuration so as to support a greater noise threshold.

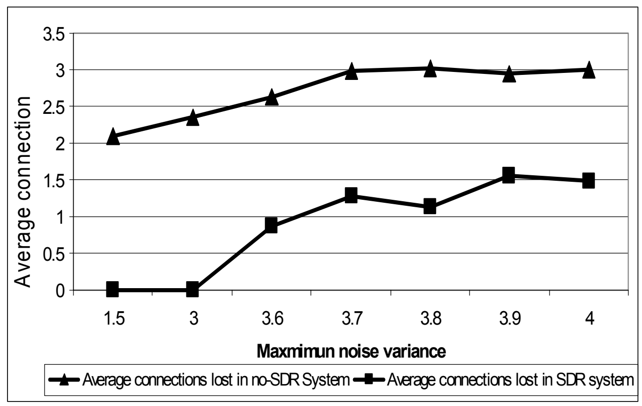

Figure 7 – Comparison between two system.

Figure 8 shows the allocation of the bandwidth at the RCST terminal: we can see the allocated bandwidths and the bandwidth that is available for a new connection. With the increasing of the source terminal per RCST we have obtained an increase of the average allocated bandwidth and, as consequence, a decrease of the average available bandwidth.

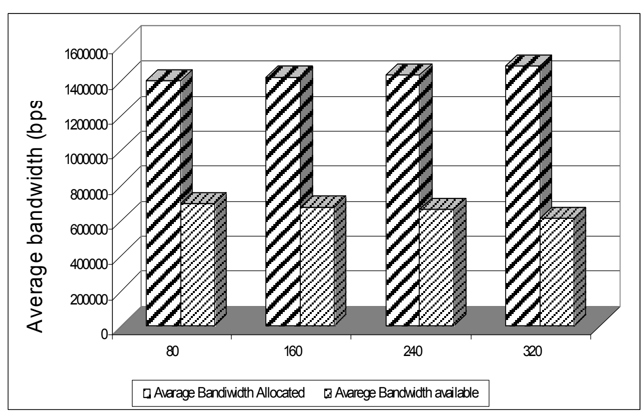

Figure 8 – Average Bandwidth over RCST Terminals

Figure 9 shows the utilization curves of the Return channel for both satellites (that are an OBP and a BP) in the SDR-system. The simulation starts with the logon of every

RCST on the BP satellite system. When the RCST terminal reaches the maximum possible configuration, its SDR module switches it on to the OBP satellite. When also in the OBP satellite system the maximum possible configuration is reached, the RCST terminal closes all active calls because the QoS constraint cannot be satisfied.

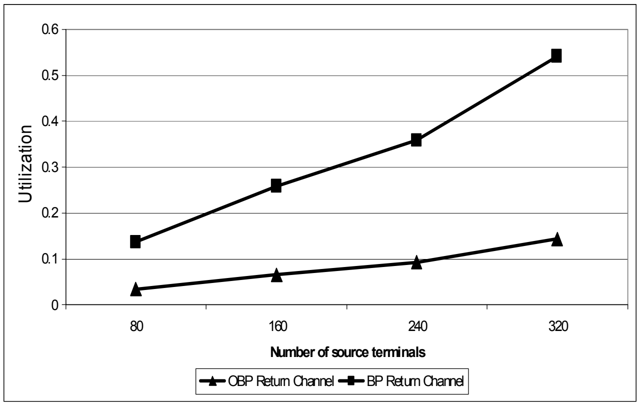

Figure 9 – Return Channels Utilization

Figure 10 shows the details of the calls in the SDR system. In particular, the average admitted calls for RCST terminal, the average refused calls and the average closed calls for unsatisfied QoS parameters are showed. The closed calls curve is referred to the calls closed when the RCST terminal is already on the maximum possible configuration of OBP satellite (that is, in our system, a power transmitting of 4 Watts and an FEC of ½) and the QoS constraint is not satisfied.

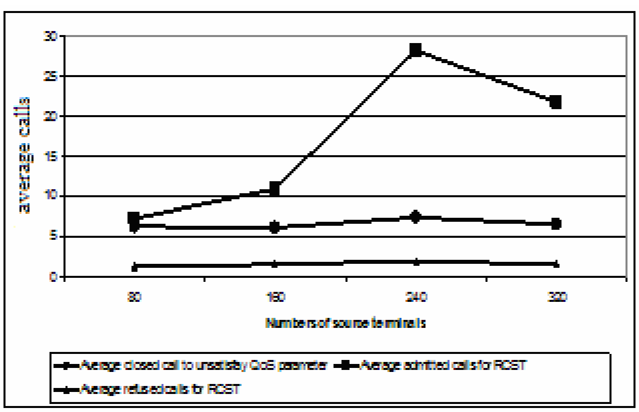

Figure 10 – Closed, admitted and refused calls vs. RCST number in the SDR-system

V. CONCLUSIONS

In this paper we have studied a new type of satellite terminal: a multi-mode terminal that is currently much requested on the market thanks to its flexibility and suitability. We have introduced this new terminal in a DVB-RCS satellite scenario and, in particular, we have introduced RCST terminals that are able to adapt it to the channel state, configuring the transmission chain via software respecting a certain QoS constraint on the PER. This system can be applied, for example, when two heterogeneous satellites (one BP and one OBP) are present in a nearby region of space. So we can utilize the BP satellite that has worse performances than an OBP satellite, to respect some QoS requirements. When the QoS requirements are not respected the connection now is not terminated, but it can be continued on the other satellite. This is possible only when the introduced delays, due to the switching time, do not exceed a tolerance threshold. The simulation campaigns have shown that a system with SDR terminals permits calls not to be closed, due to the PER threshold being exceeded. The simulation scenario shows that when the maximum noise variance is chosen, then the system with no-SDR terminals closes a number of average calls approximately double those of a system equipped with SDR terminals

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