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# **Ka-band return link for UAVs using adaptive spreading factor for DSSS in a DVB-RCS2 context**

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## **Abstract**

This paper evaluates the potential performances of a Direct Sequence Spread Spectrum (DSSS) satellite communication for Unmanned Aerial Vehicles (UAVs) in Ka-band using low directional antenna. The need to comply with the interference templates established by ITU enforces a bound to the signal power emitted toward adjacent satellites and greatly limits the accessible data rate. That prevents the UAVs communications to use a dedicated repeater for the return link. Instead, simultaneous transmission with return link communications in accordance to DVB-RCS2 standard is investigated. The proposed system is thus based on simultaneous transmission of narrow-band carriers (DVB-RCS2 primary system) and spread spectrum carriers (secondary system dedicated to UAVs). Mutual interferences are evaluated, it is shown that secondary transmissions do not affect primary systems availability, but conversely DVB-RCS2 carriers forces the secondary systems to use a high spreading factor, typically between  $2^8$  and  $2^{14}$  which can be updated as the number of primary active carriers changes within the beam. A compromise between secondary burst length and speed of adaptation for spreading factor is also discussed. Typically, if the targeted Packet Error Rate (PER) of the secondary link is  $10^{-5}$  and modulation is QPSK with a code rate 1/3, SNIR has to be held over 0 dB. This objective is reached with a spreading factor switching from  $2^{10}$  to  $2^{14}$  as the number of active primary carriers changes with a maximum bandwidth occupation of 90%, resulting in a data rate varying between 8 kbps and 34 kbps for the secondary system and a SNIR maintained between 1.5 dB and 4.5 dB.

## **I. Introduction**

The use of satellite communications for UAVs, particularly in the Ka-band, raises the problem of the use of directional antennas. The project presented in this paper and led by ISAE-Supaero on the contrary considers the use of low directional antennas, typically half-space. Such antennas with wide aperture have low gain especially in Ka-band (see [1] and [2]) and need to respect the radiation constraints to the adjacent satellites that greatly limits the available power level and imposes a relatively limited accessible data rate. It is then not acceptable to consider a dedicated system whose efficiency would be notoriously poor. The project envisages simultaneous transmission in the same repeater of return link com-

munications in accordance with DVB-RCS2 standard (primary system) and communications dedicated to drones (secondary system).

The design chosen for the secondary system waveform is a DSSS signal with similarities to 3G format. The spread signal occupies the entire bandwidth of the considered repeater. As a first effect of using DSSS, the interference introduced by the secondary system does not degrade significantly the link budget for the primary system signals, hence inducing a very limited effect on the total availability of the primary service. A simplified representation of the repeater bandwidth occupation is shown on Figure 1. After spreading operation, secondary system carrier power spectral density (PSD) is below noise level. DVB-RCS2 carriers bandwidth and number depend on primary RCST type as described in [3].

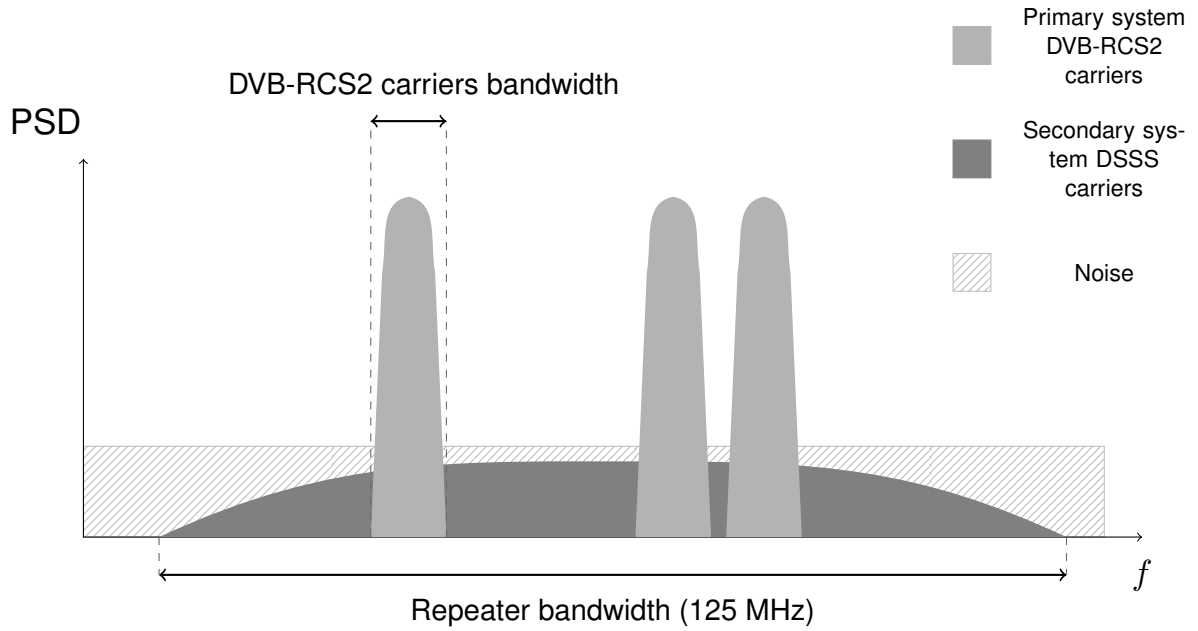


Figure 1: Example of repeater bandwidth occupation with  $N_s = 1$  spread spectrum carrier and  $N_p = 3$  DVB-RCS2 carriers.

The design of the spread spectrum link for drones, however, leads to many difficulties. The carriers of the primary system act from the point of view of the DSSS signal as so many narrow-band interferers. In the conventional 4-color scheme adopted by the primary system, up to 50 carriers can be present with high power levels. The resulting interference level strongly limits the link budget and imposes a spreading factor up to  $2^{14}$ . The idea developed in the project is to introduce a variable spreading factor associated with a frame length sized according to DVB-RCS2 Bandwidth Time Unit (BTU). The spreading factor actually applied to a frame is then determined on the basis of L2S signaling necessary for the operation of the DVB-RCS2 system, and mainly on the basis of the Terminal Burst Time Plan 2 (TBTP2).

To adapt the spreading factor closely to the primary carriers number in real time allows for the optimization of the secondary system bit rate. The traffic profile from a time-frequency point of view can be precisely known in real time through the reception of TBTP2 sent by the Network Control Center (NCC) to all the DVB-RCS2 terminals. From this table, the system can estimate the interference for each BTU and therefore, decrease or increase its bit rate to match the targeted spreading factor. This high reactivity is brought by the use of Orthogonal

Variable Spreading Factor (OVSF) codes. The effect of DVB-RCS2 systems traffic on the secondary link is evaluated. The spreading factor adjustment shows bit rate increase as the bandwidth before spreading grows when traffic is low while keeping the secondary and primary SNIRs above link budget requirements.

The burst format for secondary transmissions is finally discussed. Its symbols are widely spread which leads to long bursts compared to primary bursts duration. Secondary systems then will not be able to adapt their spreading factor to the number of active primary carriers as close as the optimum. A compromise has to be set between secondary burst length and speed of adaptation.

## II. Scenario description

### A. Primary and secondary systems

The system scenario in which the performance of the proposed signal and burst shapes will be evaluated consists of satellite terminals held on UAVs and several Return Channel over Satellite Terminals (RCSTs) transmitting in accordance to DVB-RCS2 standard. All of them are operating in Ka-band on the same geostationary satellite with a total user link bandwidth of 500 MHz. A 4-color reuse pattern is implemented, the considered bandwidth per beam is  $B_T = 125$  MHz. Although DVB-RCS2 standard offers the option to use random access, notably for control and logon procedures, primary RCSTs are considered to use dedicated access for user traffic (DAMA), hence establishing deterministic time-frequency occupation of the satellite beam. Three different types of primary RCSTs are considered depending on their geographical position and which satellite beam is covering them, each type having its own budget link performances as described in [3]. When the secondary system budget link is evaluated, only one type of primary RCST is considered. The radio link is modeled as an additive white gaussian noise (AWGN) channel.

### B. Mutual interferences

As secondary systems use half-space antenna they will interfere with adjacent satellites. The signal power level transmitted in these directions has to observe ITU recommendations [4]. For Ka-band transmissions, EIRP has to stay below  $7 - 10 \log_{10}(K_m)$  per 2 MHz band for 180 degrees off-axis emission,  $K_m$  being the maximum number of active secondary systems. This leads to (1).

$$K_m = \left\lfloor 10^{\frac{7 - \text{EIRP}_s}{10}} \right\rfloor \quad (1)$$

with  $\text{EIRP}_s$  the secondary EIRP per 2 MHz band and  $\lfloor \cdot \rfloor$  integer operator.

Considering the same propagation conditions for secondary and primary systems, link budget for drone communication predicts  $\text{EIRP} = 16.5$  dBW with an antenna gain of 7 dBi and no output back-off as strongly spread signal will not reach the saturation point of the high power amplifier. Given that secondary EIRP is spread over  $B_T$ , it gives  $\text{EIRP}_s = -1.46$  dBW per 2 MHz band, thus  $K_m = 7$  in these conditions.

Based on [3] primary systems have an EIRP about 35 dB greater than secondary systems. Integrating  $K_m$  of them into primary SNIR calculation shows less than 0.1 dB loss on

the budget link. Secondary carriers are noise-like for primary systems, the interference is negligible.

On the other hand, primary systems act as so many narrowband interferers on the secondary link. Without DSSS, secondary SNIR is evaluated from (2) as in [5].

$$(\text{SNIR}_s)^{-1} = \left(\frac{C_s}{N}\right)_U^{-1} + \left(\frac{C_s}{N}\right)_D^{-1} + \left(\frac{C_s}{N_p C_p}\right)^{-1} + \left(\frac{C_s}{(N_s - 1)C_s}\right)^{-1} \quad (2)$$

with  $C_s$  the secondary carrier power without spreading,  $N$  the noise power over the entire beam bandwidth  $B_T$ ,  $N_p$  and  $N_s$  the number of primary and secondary active carriers in  $B_T$  respectively and  $C_p$  primary carriers power.  $U$  and  $D$  indicate uplink and downlink propagation respectively.

At the receiver side, despreading operation isolates the desired secondary signal having the effect to spread other primary and secondary carriers [6]. Spreading factor  $W$  can thus be integrated in (2).  $W$  is then separated as in (3).

$$W = \text{SNIR}_s \cdot \left( \left(\frac{N}{C_s}\right)_U + \left(\frac{N}{C_s}\right)_D + \left(\frac{N_p C_p}{C_s}\right) + (N_s - 1) \right) \quad (3)$$

$\text{SNIR}_s$  is the targeted SNIR for the secondary transmission and depends on the desired QoS. Typically, if the targeted Packet Error Rate (PER) of the secondary link is  $10^{-5}$  and modulation is QPSK with a code rate 1/3, SNIR has to be held over 0 dB. Once  $\text{SNIR}_s$  is fixed,  $W$  will mainly depend on  $N_p$  which varies within the same frame, depending on the number of primary active carriers.

### III. Variable spreading factor

#### A. TBTP2 and OVSF sequences

Holding the secondary SNIR above link budget requirements needs to apply a sufficiently high spreading factor  $W$  depending on primary active carriers number  $N_p$  which has to be precisely known. Medium access for the considered primary systems is MF-TDMA with dedicated access. It is then not necessary to have a statistical estimation for primary traffic. The NCC is permanently communicating with DVB-RCS2 terminals through forward link using signaling tables such as TBTP2. This table informs on the time-frequency primary bursts distribution on the superframe scale, which is  $T_f = 45$  ms and  $B_f = B_T = 125$  MHz in our DVB-RCS2 scenario. The TBTP2 is divided into bandwidth-time units (BTU) of equal bandwidth and duration, whose size depends on RCST type. Finally, TBTP2 can be viewed as a BTU grid with empty and busy slots. Therefore,  $N_p$  can be precisely known for each timeslot of the next frame and  $W$  be calculated on this basis as the modulation and coding scheme for primary terminals remains the same within a frame.

A schematic example of the time-frequency occupation by primary carriers along the next superframe is shown Figure 2. By representing the TBTP2 by a grid of busy and empty BTUs, the number of active primary carriers  $N_p$  can be extracted for every BTU and used for  $W$  calculation in (3).

Switching from a spreading factor to another may lead to computational limitations, as a specific chip sequence must be elaborated for each  $W$ . Use of easily switching channelization codes is important, as the speed of adaptation leads to bit rate optimization. OVSF

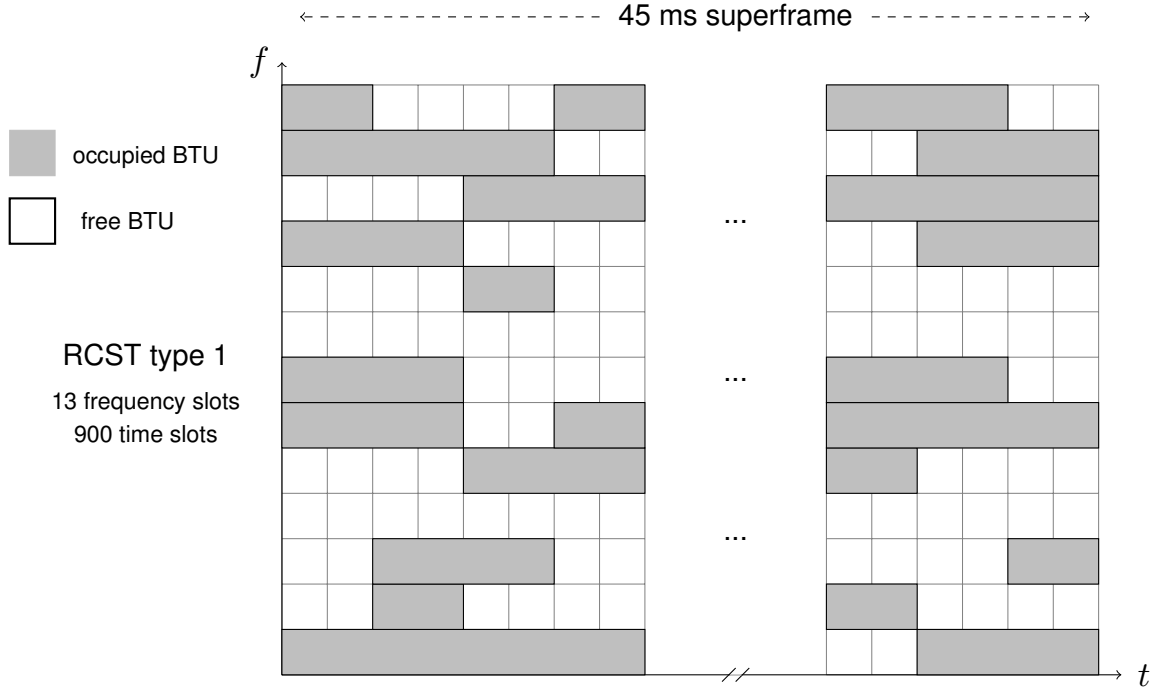


Figure 2: Schematic TBTP2 example with primary RCST type 1 (span 13 BTU bandwidth and 900 BTU duration) with  $N_p = 11$  primary active carriers.

codes offer orthogonality and simplicity for matching  $W$  to a specific chip sequence thanks to its tree structure. As a counterpart, sequences length has to be a power of 2 and can be selected as described in [7]. To maintain the secondary SNIR above the established threshold is essential, hence  $W$  is rounded to the upper power of 2 after being calculated from (3) at the expense of the bit rate.

Unlike massive multiusers systems, drone communications in this context may reach a maximum number of users  $K_m$  and has no need to use a scrambling code in addition to channelization code to separate different users on the receiver side. Thus, scrambling operation is not considered through this paper.

## B. Burst format

The frame structure considered in this study is inspired by 3G UMTS forward link format which is a QPSK modulated signal with I and Q channels both used for mixed data and signaling. Hence, bursts are made from data associated with a header including information on the burst format itself, coded with 2 bits, and the spreading factor  $W$  used on the burst coded with 3 bits allowing  $W_{min} = 2^8$  to  $W_{max} = 2^{14}$ . In order to maximize the decoding probability of the burst at the receiver side, the header is always spread with  $W_{max}$ , thus  $5 \times 2^{14} = 81920$  chips are necessary for signaling on each burst. With  $B_T = 125$  MHz and a roll-off factor  $\alpha = 0.22$ , chip rate is 102.4 Mcps per channel which leads to a header duration equal to 800  $\mu s$ .

To avoid suboptimal transmission, data duration within the burst has to be at least the same as for the header. This leads to bursts as long as 10, 19 or 32 BTU depending on

Format	RCST 1		RCST 2		RCST 3	
	Header	Data	Header	Data	Header	Data
1	800	800	800	800	800	800
2	800	1200	800	1600	800	1600
3	800	1600	800	2400	800	3200
4	800	6000	800	8000	800	10000

Table 1: Duration of header and data parts ( $\mu s$ ) according to primary system type.

primary RCST type. Assuming primary bursts are 2 or 6 BTU long [8], duration rate between secondary and primary bursts is about 2 to 16 for secondary bursts made of 50% header and 50% data. Duration rate is even higher if more data is appended to the header. In addition,  $W$  has to be the highest on the burst span.

$N_p$  changes every 2 or 6 BTU, so does the optimal  $W$  but secondary burst duration is about 10 BTU or more. Consequently, the choice has been made to smooth  $W$  granularity and round its value to the highest found on the burst duration. In this way  $W$  is constant over longer periods, and more data can be appended to the same header to increase the bit rate. Table 1 shows format definition according to primary RCST type. Bursts are defined longer for RCST 2 than for RCST 1, also longer for RCST 3 than for RCST 2. Indeed, RCST 3 bursts have smaller bandwidth than RCST 1 but compensates with a longer burst duration. This possibly leads to longer spans with the same spreading factor  $W$ , thus more data can be merged to the burst header.

## IV. Results

### A. Simulation of the DVB-RCS2 system

The performance analysis of the spread spectrum transmission planned for the secondary system requires a first step of modeling the primary system DVB-RCS2 in order to generate representative TBTP2 resource allocation tables. This modeling is carried out using the OMNET ++ software ([www.omnetpp.org](http://www.omnetpp.org)) and the INET model library ([inet.omnetpp.org](http://inet.omnetpp.org)). The models specific to the DVB-RCS2 satellite link are developed at ISAE-SUPAERO.

The structure of the model is presented in the following figure:

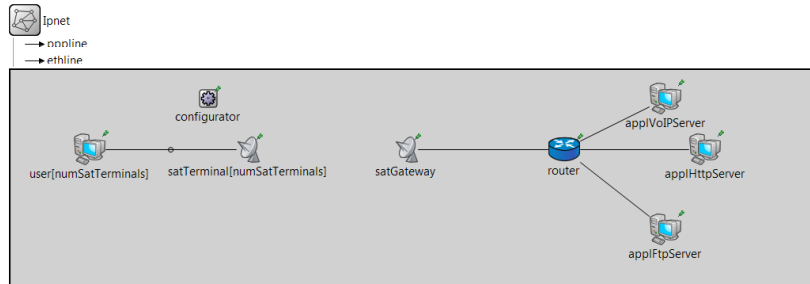


Figure 3: OMNET++ DVB-RCS2 model

The number of users is fixed at the start of simulation by numSatTerminals parameter, the simulator can then instantiate as many user/satellite terminals as requested. The simu-



lation result analysis can thus be conducted over a large traffic load range. The considered DVB-RCS2 system meets the following parameters:

Parameter	Value
Configuration	RCST3
Superframe duration	45 ms
BTU duration	150 $\mu s$
Symbol rate	1.9 Mbaud
Modulation and coding	16 QAM 5/6
Carriers	53

The traffic generated in the model by each user combines real-time streams, sporadic streams, and elastic data streams. For the first two types, the transport layer uses UDP. The elastic data streams use a TCP transport layer to take into account the influence of satellite delay and the on-demand resource allocation mechanism on the observed round-trip times and the bit rates obtained. On the user side, the satellite terminal implements a differentiated quality of service management as specified in the DVB-RCS2 standard (based on IP DiffServ paradigm). On the service provider side, the gateway implements a simple DAMA process with two priority level: Rate Based Dynamic Capacity (RBDC) and Volume Based Dynamic Capacity (VBDC).

The evolution of performances according to the load makes it possible to determine 3 scenarios: low, medium and loaded. The red curve on Figure 4 shows the evolution of observed delays and clearly shows that beyond 300 terminals, the system cannot correctly respond to the demand and convey the generated volume of traffic.

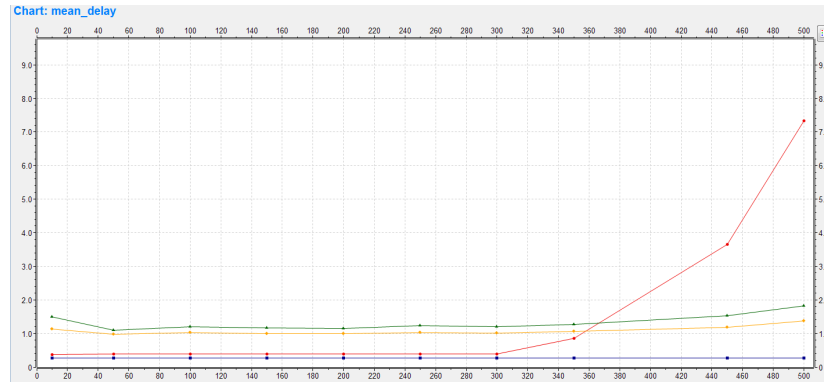


Figure 4: Mean delays versus number of active terminals

This limit to 300 terminals is corroborated by the evolution of the Volume Based Dynamic Capacity (VBDC) satisfaction rate. A report of 1 indicates that the system can, on average, serve all queries. A ratio of less than 1 indicates a capacity deficit with respect to demand. This can be seen Figure 5.

The three retained scenarios therefore correspond respectively to 100, 200 and 300 active terminals. In the case of a simulation with 300 terminals, the delays of insertion of the IP datagrams at a terminal can be broken down as in Figure 6.

The performances are already considerably degraded and confirm the loaded scenario configuration.

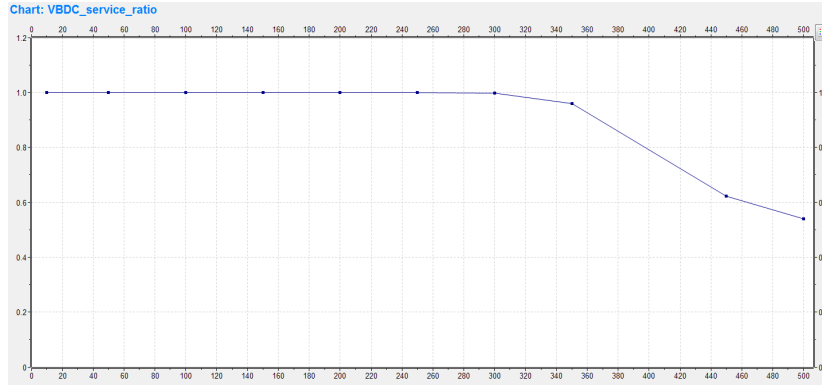


Figure 5: Volume Based Dynamic Capacity (VBDC) satisfaction rate versus number of active terminals

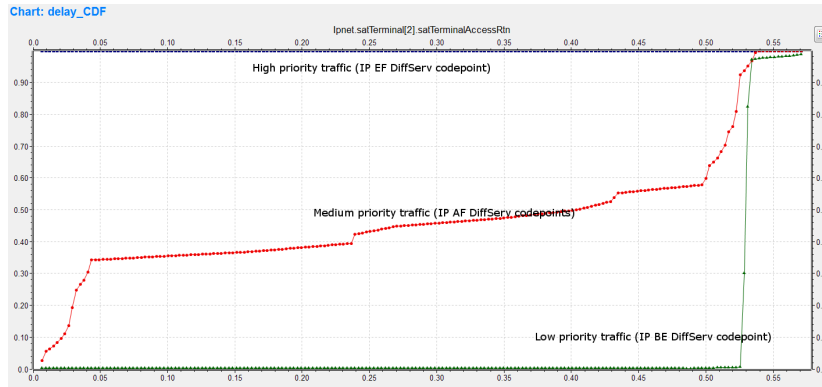


Figure 6: IP datagram insertion delays (Cumulative Density Functions)

## B. Application to the DSSS system

Each of three different DVB-RCS2 scenarios presented above leads to a series of TBTP2 tables which are used to evaluate the optimum spreading factor and burst format for the secondary DSSS system. Simulation time is 10 seconds long which in our scenario represents approximatively 220 TBTP2 tables.

The first scenario with 100 DVB-RCS2 active terminals illustrated on Figure 7 has a low load and therefore a secondary spreading factor  $W$  switching from  $2^{12}$  to  $2^{13}$ . The corresponding useful bit rate, which is calculated for a 1/3 code rate and a QPSK modulation, obviously follows the  $W$  variations but also burst format variations. When the spreading factor  $W$  is tuned down, the burst format is also lowered if  $W$  quickly increases again. This is clearly the case for the first two variations seen on Figure 7. However, if  $W$  is tuned down and do not quickly increases again, burst format is maintained high with a low  $W$ , which is the best combination for bit rate performances. Figure 8 shows the parameter variations over a smaller timescale.

On the second scenario Figure 9, the load is 200 active primary terminals which leads to higher optimum spreading factor, between  $2^{13}$  and  $2^{14}$ . Regularly, primary traffic load decreases and so does  $W$  where corresponding bit rate peaks can be seen.

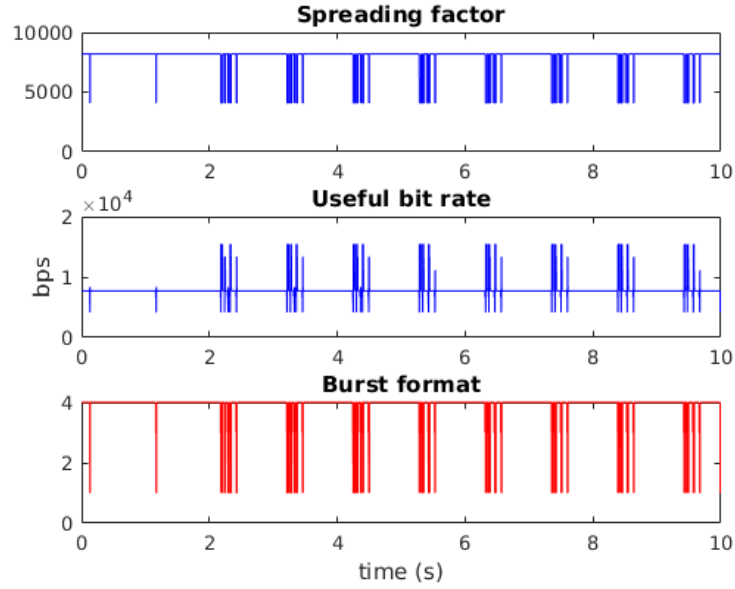


Figure 7: Spreading factor, useful bit rate and frame format applied to secondary system for 100 DVB-RCS2 terminals load

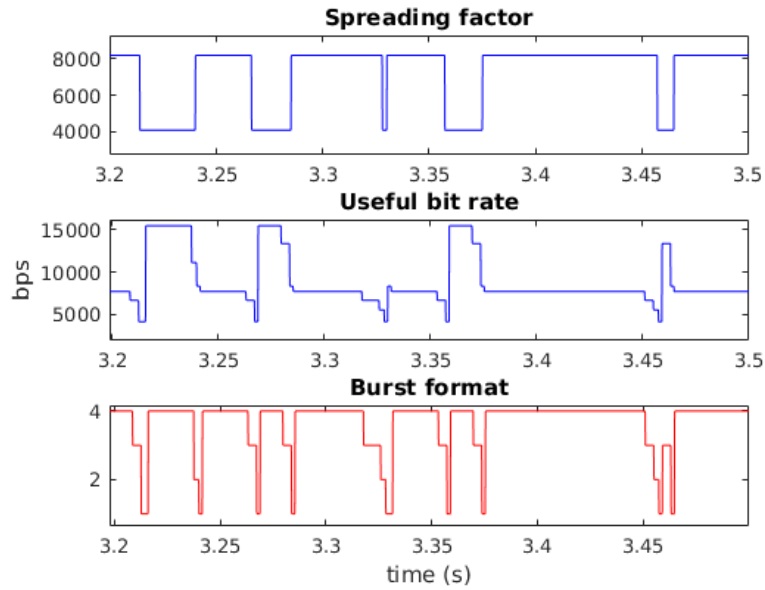


Figure 8: Spreading factor, useful bit rate and frame format applied to secondary system for 100 DVB-RCS2 terminals load - Zoom

Finally, the effects of the full loaded scenario with the most constraining RCST type on the secondary system is pictured Figure 10. Spreading factor is now switching from  $2^{14}$  to  $2^{15}$  and so does the bit rate which regularly decreases. Secondary communications can be ignored on these short time spans where the needed spreading factor is so high that bit rate merely reaches 1 kbps.

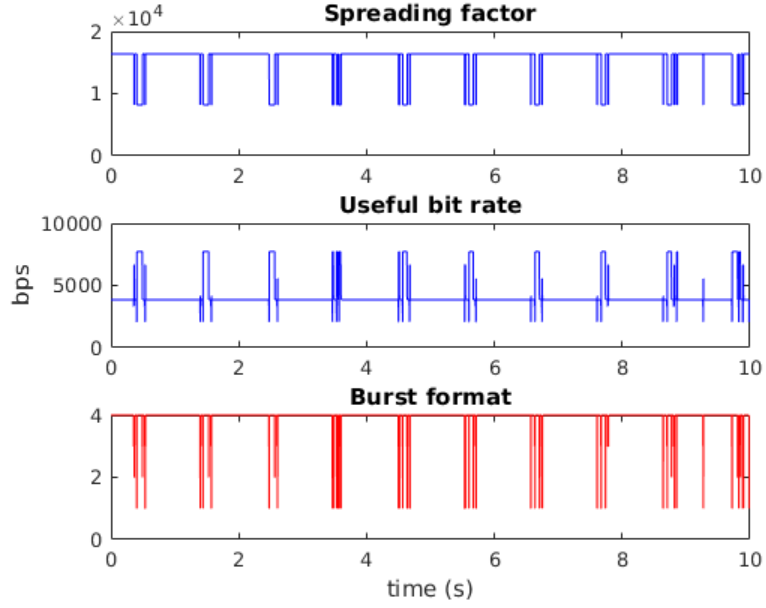


Figure 9: Spreading factor, useful bit rate and frame format applied to secondary system for 200 DVB-RCS2 terminals load

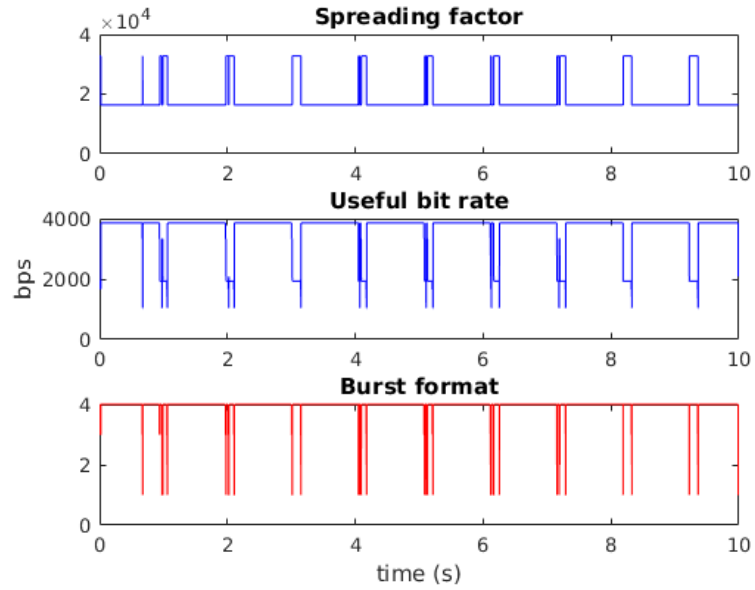


Figure 10: Spreading factor, useful bit rate and frame format applied to secondary system for 300 DVB-RCS2 terminals load

## V. Conclusion

Using quasi omnidirectional antennas at Ka-band enables the integration on-board UAVs, but induces a drastic limitation on the accessible data rate on the return link as established in

the first part of this paper. The very limited spectral efficiency prevents the use of dedicated radio-frequency capacity and justify the analysis of a combined system with narrow-band carriers compliant to the DVB-RCS2 standard and spread dedicated signals for the UAV communications. Narrow-band carriers then act as interferer to the direct sequence spread spectrum signal and a precise description of the interference pattern is needed. A realistic model of the DVB-RCS2 system is used to determine the activity on the narrow band carriers and to generate the corresponding signaling (TBTP2 tables). In the proposed system, the L2S signaling transmitted on the forward link is also received by the drone. TBTP2 tables thus provide information about the primary traffic in real time and interferences can be consequently predicted to adapt the drone's spreading factor in order to maintain both primary and secondary SNIRs above budget link requirements. Burst size selection allows UAV's bit rate increase, taking advantage of the variable spreading factor granularity. Further design options are under investigation in order to increase the secondary system capacity. First, spreading the DVB-RCS2 signals as defined in the standard can reduce the interference on the UAV communications at the cost of a reduced capacity for primary users. Second, the gateway has a complete knowledge of the interference pattern after demodulation and decoding of the DVB-RCS2 signals. Interference cancellation techniques could thus be implemented.

## Acknowledgment

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