Optimization of Q/V-band Smart Gateway Switching in the framework of Q/V-Lift Project

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Abstract—**High-Throughput Satellite (HTS) systems are expected to reach the milestone of terabit/s capacity in few years through the exploitation of Extremely High Frequencies (EHF), in particular Q/V-bands and W-band, in the feeder link. In this respect, the H2020 QV-LIFT project, kicked-off in November 2016, aims at filling crucial gaps in the ground segment technology required by future Q/V-band HTS systems. One of the most challenging objectives of QV-LIFT team is develop and test a smart gateway management system (SGMS) operating in the Q/V- band. The SGMS will implement fade mitigation techniques able to counteract the detrimental propagation impairments across the feeder link. This paper reports the optimization and simulation activities that have been performed to design SMGS control logic, with a focus on the atmospheric channel predictor and switching decision algorithm. The channel is fully characterized by synthetic time series of rain attenuation generated by a Multi-site Time-series Synthesizer (MTS).**

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1. INTRODUCTION

Smart Gateway Diversity (SGD) is a strategy for managing Earth segment resources in HTS systems, based on the principle of site diversity. The gateways are connected together into a network and their resources are shared among the user beams by a network operation center to maximize system throughput as well as robustness to propagation impairments. Specifically, a number of SGD configurations have been proposed as an effective fade mitigation technique in future HTS that are predicted to operate in the Q/V-band [1][2]. In fact, even though Q/V-band links are much more vulnerable to rain fading than the currently used Ku/Ka-bands, nonetheless they would provide a significant increase in system capacity as 1) a larger bandwidth would be available at higher frequencies for the feeder link and 2) the entire Ku/Ka-band would be free for the user link. In this framework, beyond Ka-band frequencies, together with new "softwarization" paradigms, as Software Defined Netowrking (SDN), Network Functions Virtualization (NFV) and Software Defined Radio (SDR), will be strategic both for satellite and terrestrial communication services [3], [4], [5].

Several studies have investigated the feasibility and performance of different SGD schemes. Most of the research work so far has been done through simulations at different layers of the system [6][7]. The QV-LIFT project (QV-band earth segment link for future high-throughput space systems), funded in the frame of the H2020 programme, aims at filling some of the technological gaps involved with Q/V-band exploitation. In particular, QV-LIFT will provide a test bed for demonstrating gateway switching operation, including Q/V-band hardware and an ad-hoc network architecture, namely the Smart Gateway Management System (SGMS).

An important part of the SMGS is the gateway switching strategy. In particular, two aspects are crucial. First, the gateway switching has a latency, hence, for minimizing the probability of link outage, it is necessary to predict rain fading in advance. Second, the process should be started when a suitable switching threshold is exceeded over a certain observation window.

In this paper, a switching decision algorithm is proposed and optimized by a long-term time-domain simulation of the propagation channel, which is modeled through a time-series generator. The paper is organized as follows. In Section 2 the smart gateway experimental setup used in the Q/V-LIFT Project is presented, Section 3 is devoted to the description of channel predictors and smart gateway switching algorithm. Section 4 reports the results of simulation activity. Conclusions are drawn in Section 5.

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2. Smart Gateway Diversity Implementation in the Q/V-LIFT H2020 Project

Among other objectives, the QV-LIFT project aims at testing the concept of Smart Gateway Diversity (SGD) using redundant spare gateways shared among the user beams. All the gateways are assumed to be interconnected and the shared resources to be allocated by a network management system. The effect of rain fading is mitigated by spacing the gateways far apart enough to reduce the probability that deep fades occur at the same time across different feeder links (space diversity) [1].

Figure 1 shows the deployment of the QV-LIFT system, which is built around the Aldo Paraboni QV band payload on board of Alphasat [8], developed by the Italian Space Agency (ASI) and currently in operation. The QV-LIFT ground segment includes two ASI already operational Ground Stations in Italy: one in Tito Scalo, named Earth Station 1, and one in Spino d'Adda, named Earth Station 3. One more ground station, named Earth Station 2, to be installed in Matera (Italy) and an aeronautical terminal are also included in the system and are both currently under development. The payload can transmit and receive two 10 MHz Q/V-band channels (in linear polarization) in loop-mode or cross-mode, as depicted in Figure 2 [9].

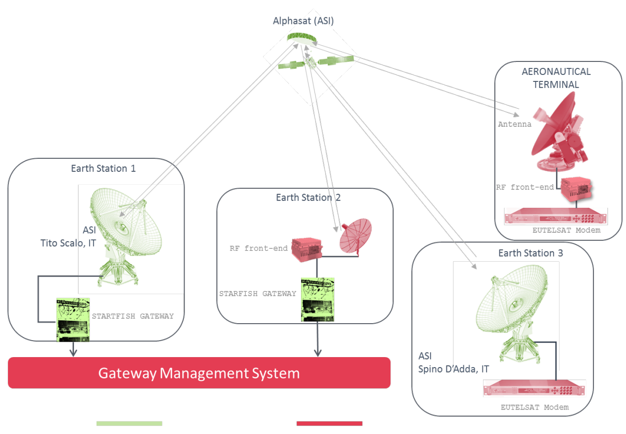

Figure 1: Layout of the QV-LIFT system.

The QV-LIFT test scenario is depicted in Figure 3 and makes use of the Earth Station 1 in Tito Scalo, acting as the operative gateway, and of the Earth Station 2 in Matera, acting as the spare gateway. The Earth Station 3 in Spino d'Adda simulates the user station.

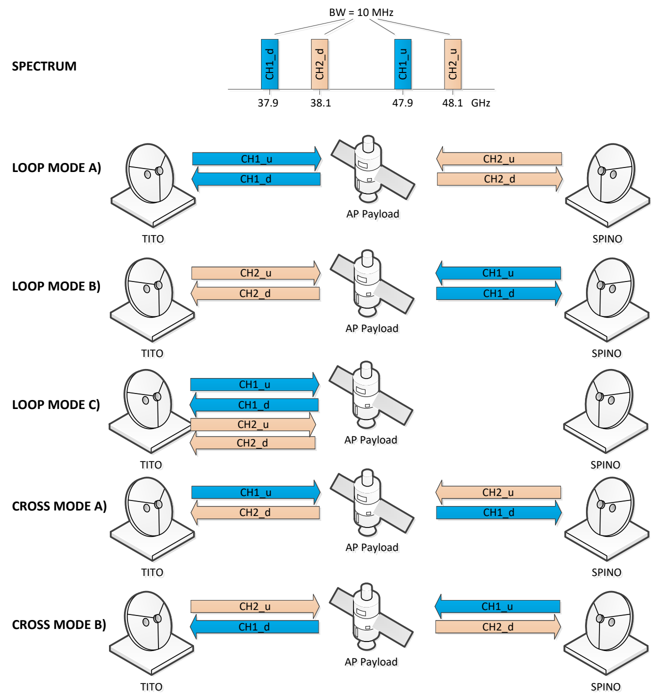

Figure 2: Aldo Paraboni payload operational modes.

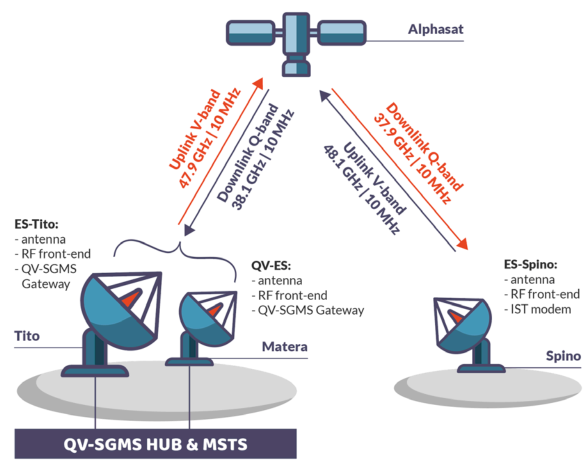

Figure 3: Q/V-Lift test scenario.

The smart gateway performance tests aim at demonstrating the orchestration of the services provided and involving all system components and the AP system. Their goal is to demonstrate that:

- the traffic is rerouted according to the smart gateway diversity concept,
- the automatic triggers for rerouting the traffic perform reliable,
- traffic loss and times necessary to reroute traffic.

Figure 4 shows the High level block diagram of the Q/V-Lift SGMS. The gateway switching process relies on the propagation channel predictor. The switching decision is taken based on the comparison between the predicted value of rain attenuation and the link margin to counteract rain fading, considering a certain observation period to avoid false alarms. During the QV-LIFT experimental campaign, the predictions will be based on the time-series of attenuation generated by a Multi-site Time-series Synthesize (MTS) [10] or on actual measurements of the propagation channel.

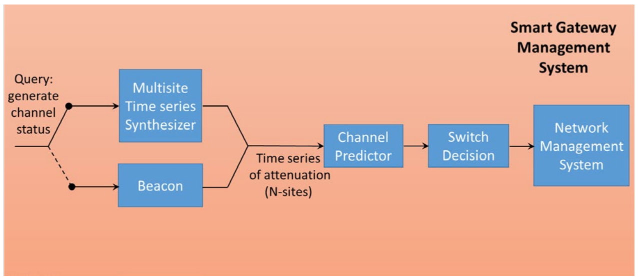

Figure 4: High level block diagram of the Q/V-Lift SGMS.

3. Smart Gateway Prediction and Switching Algorithm

In this work it is assumed that link outages are due to rain attenuation; this is reasonable at Q/V-band considering that the fading produced by oxygen, water-vapor and clouds can be fully mitigated through static margin.

The smart gateway switching algorithm is based on some system parameters that are peculiar of the operative scenario. In particular:

- Attenuation level (dB), M_R, that can be counteracted by the power margin available on each up-link feeder-link. When the link is subject to a higher fading the gateway is in outage.
- Switching operation latency (s), Δt_1. This is the time required by the system to perform all the operations necessary to achieve the traffic handover between two gateways.
- Prediction duration (s), Δt_2, this is the prediction duration time window, hence at time t_0 the predictor is able to estimate channel up to $t_0 + \Delta t_2$. The prediction duration has to be larger than the switching operation latency so that the switching decision can be taken on the basis of attenuation predicted from $t_0 + \Delta t_1$ up to $t_0 + \Delta t_2$. In particular, if the number of predicted link outages (i.e. attenuation level larger than M_R) is larger than a certain value, Out_{min}, the station switching is activated.

The simplest approach for site diversity switching schemes consider the instantaneous estimated channel quality (e.g. additional rain attenuation in our case) to select the optimal physical layer configuration or ground station. However, this approach is not very effective in satellite networks with long delays between the time when the channel quality is estimated at the receiver and the time when the new configuration is reached. To overcome this limitation, predictive channel estimation methods are useful.

Consider the prediction of a channel parameter $y(i+T)$ at time index $i+T$, computed using the information available up to time index i. Assume that T is the delay between the time when the channel prediction is performed and the time when the new configuration adapted to the predicted channel condition is received.

A classical method based on linear regression is to consider the previous W instantaneous channel measurements to predict the channel quality at time $i+T$, as follows:

$$y(i+T) = c_1 y(i) + c_2 y(i-1) + \cdots c_W y(i-W+1) = \mathbf{c}^T \mathbf{y}$$

where $\mathbf{y}$ is the column vector of W instantaneous channel measurements and $\mathbf{c}$ is a weight column vector of dimension W which can be computed using several different approaches. This Equation represents a FIR filter of order W-1 called Linear Prediction Filter (LPF). It is worth noting that, for a Gaussian time-varying channel, the optimal predictor in terms of MSE is a linear predictor. The focus on linear predictors allows to restrict the category of predictors.

The coefficients of a linear prediction filter indicate how much importance is given to the historical values of the channel parameters to predict the future value.

In the following, we describe the channel prediction methods considered in this study.

Method no.1: Simple Single Point

The most basic channel prediction algorithm, here called single point, is achieved using the single channel quality measurement to predict the future channel quality. The Equation defining this simple method is the following:

$$y(i+T) = y(i)$$

This estimator will be used as a reference estimator to measure the advantages of using channel predictors based on the historical sequences of channel quality measurements.

Method no. 2: Moving Average Filter

The moving average filter is a lowpass FIR filter where the weights of each delay tap are identical. The Equation for the predictor is the following:

$$y(i+T) = \frac{1}{W} y(i) + \frac{1}{W} y(i-1) + \cdots + \frac{1}{W} y(i-W+1)$$

The above equation represents the arithmetic mean of rain attenuation measurements over a set of W samples.

Method no. 3: Linear Prediction Filter (Linear Ramp Coefficients)

The linear prediction filter with coefficients given by a linear ramp has the property to give more importance to the later values of the sequence with respect to earlier ones. In particular, the predicted value of channel quality at time $i+T$

is as follows:

$$y(i+T) = \frac{1}{W}y(i) + \frac{2}{W}y(i-1) + \cdots + y(i-W+1)$$

Method no. 4: Linear Regression (Extreme Values)
This method is based on a linear regression model that considers only the first and the last samples of the sequence over a window of W samples. In particular, the prediction is obtianed through the following equation:

$$y(i+T) = a + bT$$

where:

$$a = y(i); \qquad b = \frac{1}{W-1}\left(y(W+i-1) - y(i)\right)$$

Method no. 5: Linear Regression (Averaged)
This method is based on a linear regression model that considers all the samples of the sequence over a window of W samples. This method can be defined through the following equation:

$$y(i+T) = c + dT$$

where:

$$c = \frac{1}{W}\left(y(i) + \cdots + y(W+i-1)\right); \quad d = \frac{1}{W-1}\left[\left(y(i+1) - y(i)\right) + \cdots + \left(y(i+W-1) - y(i+W-2)\right)\right]$$

4. Simulation Results

In order to test the above channel predictors and the switching decision algorithm defined in Section 3, simulation activities have been carried out. The simulations make use of one-year synthetic attenuation time series generated by the MTS for the two QV-LIFT gateways located at Tito Scalo and Matera (Southern Italy). The channel predictors have been tested and optimized for the above two locations.

The performance of the channel prediction methods are provided in terms of False Positive (FP) and False Negative (FN) occurrences assuming a binary prediction of rain attenuation below or above a threshold of 8 dB. FP and FN curves for each prediction method and for a set of window sizes W are shown in Figures 5-8.

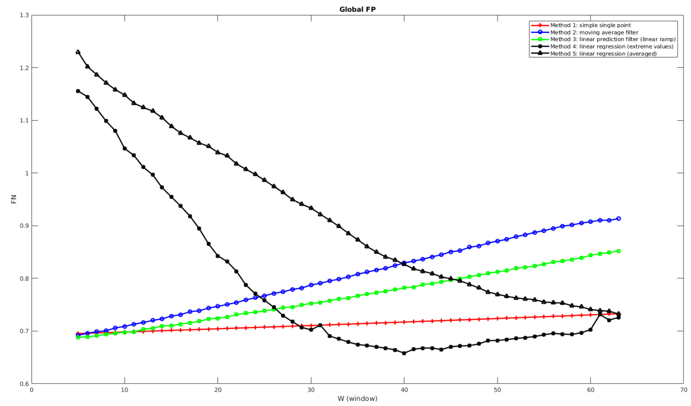

Figure 5: Performance in terms of False Positives (FP) of each prediction method for the Tito station.

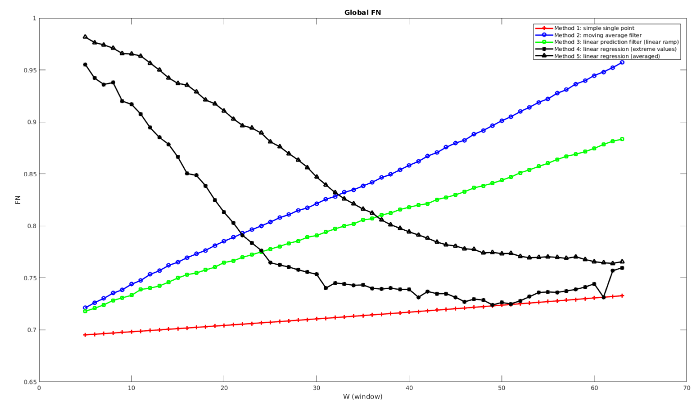

Figure 6: Performance in terms of False Negatives (FN) of each prediction method for the Tito station.

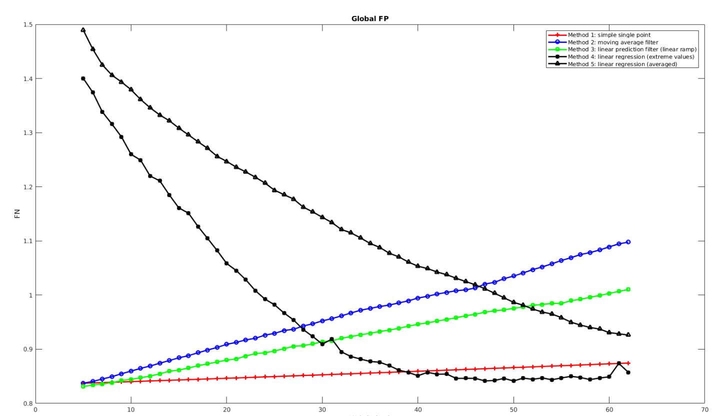

Figure 7: Performance in terms of False Positives (FP) of each prediction method for the Matera station.

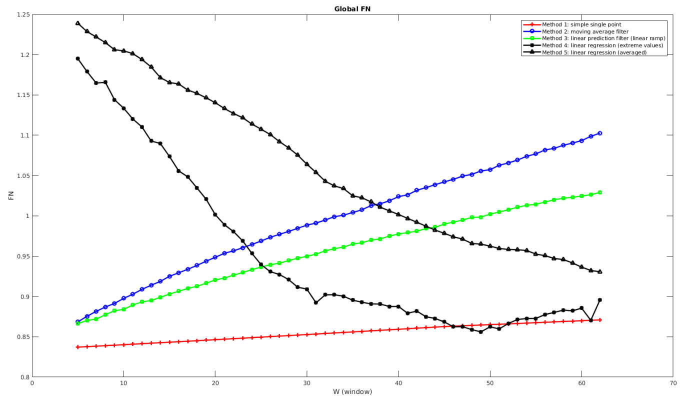

Figure 8: Performance in terms of False Negatives (FN) of each prediction method for the Matera station.

From the results reported in Figures 5-8, the best predictor in terms of FN and FP, is method no. 4 with W=40. This method has been subsequently used to evaluate the performance of the switching algorithm.

The main simulation parameters of the scenario are reported in Table 1.

Table I. Smart Gateway switching main parameters

Parameter	Description	Value
GW1_loc	Tito Scalo GW location	[40.6° 15.7°] Lat/Lon
GW2_loc	Matera GW location	[40.6° 16.7°] Lat/Lon
M_R	Link power margin against rain attenuation	8 dB
Δt_1	Switching operation latency	30 s
Δt_2	Channel prediction duration	60 s
W	Prediction widow length	40 s
Out_{min}	Minimum number of link outages in $\Delta t_2 - \Delta t_1$	1

Two metrics have been selected to identify the overall system performance: number of switchovers and outage percentage. The perfect knowledge of channel attenuation (deterministic channel) has been used as a benchmark to evaluate the simulation results.

An 17% increase of the number if switchovers has been estimated w.r.t. the deterministic channel (68 and 58 respectively). An outage percentage of about 1×10^{-4} has been calculated over one year, against a value of 9×10^{-5} in the case of deterministic channel. These results are quite encouraging and reflect the good performance of the channel estimator.

5. CONCLUSION

This paper reports the plan for the experimental activities on smart gateway optimization over Q/V-band satellite links that will be performed in the framework of Q/V-LIFT Project. In particular, simulations of the operative scenario have been used to optimize both channel predictor and switching control logic. The preliminary results show that the system performance is quite satisfactory and close to deterministic channel benchmark. As a matter of fact, the degradations produced by channel estimators are: a switching number increase of about 17% and an increase of service unavailability (system outage) of about 10^{-5}.

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BIOGRAPHY

Roberto Nebuloni *(male), received the Laurea Degree in Electronic Engineering and the PhD degree in Electronic and Communication Engineering, from Politecnico di Milano, Italy, in 1997 and 2004, espectively. In 2005, he joined the National Research Council of Italy (CNR), where he is currently a researcher at the Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni (IEIIT), in Milan.*

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Since 1992, he participated in the Olympus, Italsat and Alphasat 'Aldo Paraboni' propagation measurement campaigns, in the COST255, COST280 and COSTIC0802 international projects on propagation and telecommunications and in the Satellite Communications Network of Excellence (SatNEx). In 2010, he has been Director of the 49° Course "Radiowave Propagation" in the frame of the 'International School of Quantum Electronics' at Erice. In 2011 he has been nominated to the Steering Committee of ESA's Network of Experts as Italian Representative. In 2012 he has been appointed Principal Investigator by the Italian Space Agency for the Alphasat Aldo Paraboni propagation experiment. Since 2015 he is Chairman of Working Party 3J ('Propagation

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2004, CABIS (CDMA for Broadband mobile terrestrial-satellite Integrated Systems) from January 2001 to December 2002. In 2007he has been involved in the Internationalization Program funded by the Italian Ministry of University and Research (MIUR), concerning the academic research collaboration of the Texas A&M University (USA) and the University of Rome "Tor Vergata" (Italy). From 2011 to 2014 he has been the scientific responsible of the activities of the University of Roma Tor Vergata for the TETRis project (Innovative Open Source Services over TETRA), funded by the MIUR, grant "P.O.N. Ricerca e Competitivita' 2007-2013". He is involved in the coordination of the Alphasat "Aldo Paraboni" Payload (Technology Demonstration Payload - TDP 5) scientific experiments for broadband satellite communications in Q/V band, funded jointly by ASI and ESA. Presently, he has research collaboration with the Peoples' Friendship Universityof Russia (RUDN University), Moscow, Russian Federation. He is serving as Associate Editor for the Space Electronics and Communications area of the IEEE Aerospace and Electronic Systems Magazine. His main areas of interest are: wireless terrestrial and satellite communication networks, data mining and information theory. He co-authored more than 80 papers published on journals and conference proceedings. He was co-recipient of the best paper award from the 2009 International Conference on Advances in Satellite and Space Communications (SPACOMM 2009).

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