# Q/V BAND SATELLITE CHANNEL PREDICTION TECHNIQUES: PERFORMANCE EVALUATION BASED ON ALPHASAT ALDO PARABONI P/L EXPERIMENTAL DATA

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## Abstract

Currently the use of Ka-band is the benchmark for high throughput satellite communications commercial application, while Q/V band is under scientific investigation through a European experimental campaign. The use of EHF, in particular Q/V-band and W-band, is one of the main methods to increase the system throughput, exploiting the large bandwidth availability. In a short-term scenario, these frequencies will be used in the feeder link, while Ka-band will be used in the user link to maintain user terminal backward compatibility. In a long-term scenario, "beyond Ka-band" frequencies could be used both in the user and feeder links. It is well known that the drawbacks of radio-waves propagation at these frequencies are the high impairments caused by the lower part of the atmosphere (troposphere), hence, research activities on troposphere propagation impairments mitigation techniques (PIMT) are needed. PIMT are able to dynamically adapt the system resources to the channel conditions and their control loop is based on the use of channel status estimators. In this paper, different channel short-term prediction techniques will be presented and optimized on the basis of real Q/V band experimental data collected during the current Q/V-band satellite communication experimental campaign of Italian Space Agency (performed through the Aldo Paraboni P/L, embarked on Alphasat).

## 1. Introduction

In light of the rapidly expanding demand for higher throughputs to more user terminals at ever lower cost, next generation high throughput satellites supporting 100s of Gbps are expected to become mainstream. At these kind of capacity levels, the use of Ka-band feeder links requires a linear expansion in the number of ground earth stations, which becomes restrictive from a cost perspective as the ground segment starts to become a significant contributor to overall system cost.

In the short to medium term, higher frequency bands will be exploited, where the additional bandwidth available will help to mitigate the number of ground earth stations required, with the trade-off between increased ground segment cost in the shorter term due to the new technology necessary to be deployed to operate at higher frequency being balanced against the reduced (by factor of 2 or 3) number of ground earth stations required to support the satellite capacity. One of the first bands to be exploited will be Q/V band, where technology advances are making ground hardware become available that will make operation at these higher frequencies possible.

Smart gateway techniques will also be employed to optimise the efficiency and number of ground earth stations required to handle the higher capacity, with statistical models and analysis utilised to size the network appropriately for a given availability and traffic level. An important benefit that this technique provides is also the ability for an operator to state the rollout of ground equipment and spread build out costs in line with increases in capacity demand.

In the short term, user links are expected to continue operating in Ka band to preserve interoperability with existing deployed satellites. Working in higher frequency bands for the feeder link brings some new challenges for the operator to manage techniques such as uplink power control and fade prediction in order to make intelligent decisions to switch gateway sites and maximise availability of the system. It is therefore vitally important to learn from experimental data the characteristics of these types of links in order to accurately design and optimally configure future ground networks.

As the overall system throughput increases, terrestrial link cost will also become significant, so techniques will need to be adopted to optimise traffic flow between sites, likely by centralising some network functions, and likely moving processing functions to cloud based platforms.

While Q/V band is expected to serve short and medium term future HTS systems, longer term even higher throughput satellites are expected to come into service, and a similar trade off analysis will need to be conducted for Q/V band sites/cost against other rapidly emerging technologies. Further expansion into even higher frequencies, such as W band will be analysed against alternative solutions such as optical feeder links, which require a different ground architecture.

Adaptive techniques, such as Adaptive Coding and Modulation (ACM) or Uplink Power Control (ULPC), are based on a link quality estimation tool which drives the algorithm to follow the current channel conditions using the most suited transmission parameters. Therefore, the transmission parameters are selected on the basis of channel estimation performed at the transmitter side (open-loop approach) or at the receiver side sending a command through a return link to drive the algorithm (closed-loop approach).

Physical layer adaptation using channel estimation should take into account channel estimation errors (limited resolution, interference, non-Gaussian noise, HPA non-linearity) and the long propagation delay of the satellite channel. Channel variations are a consequence of a slow component (rain fading) and a faster component (scintillations) [1]. As a consequence of the long propagation delay, PIMTs are not able to follow fast channel variations, but this type of variations must be taken into account during the design of PIMTs.

The objective of the experimental activities reported in this paper is to optimize short-term channel prediction techniques over Q/V-band satellite channel that could be used at the terminal side of a High Throughput Satellite (HTS) system. The paper is organized as follows: Section 2 reports the main SNR estimation techniques and the experimental set up that has been used to collect Q/V band satellite data, in Section 3 the short-term predictive channel estimation techniques are introduced and their performance over a real Q/V-band satellite channel is reported in Section 4; conclusions are drawn in Section 5.

## 2. SNR Estimation techniques and experimental scenario

Channel estimation is an important topic of research, being the control loop of every PIMT based on such estimate. The Signal to Noise Ratio (SNR) is estimated at the receiver side during the demodulation process or just after that and it is computed as the ratio between an estimation of the useful signal and an estimation of the noise power (and or interference power) [2].

Non Data Aided (NDA) estimation methods compute the SNR using only the values of the received discrete-time signal $y(n)$, while Data Aided (DA) estimation methods may also use the information concerning the transmitted discrete-time signal $c(n)$.

A Maximum Likelihood (ML) estimator is the one that maximizes the likelihood of making the observations given the parameters. The SNORE algorithm is a ML estimation method developed by the Jet Propulsion Laboratory (JPL) and further elaborated in [3] and [4]. The DA-SNORE algorithm represents the best SNR estimator in AWGN channels and is the estimator which is practically used in current satellite systems exploiting ACM techniques.

SNR data, estimated through DA-SNORE algorithm over and end-to-end Q/V-band communication channel, has been collected in the framework of the current Italian Space Agency experimental campaign based on Aldo Paraboni P/L embarked on Alphasat [5], [6]. The experimental setup foresees the collection of SNR data from the Tito Scalo (south Italy) Rx station.

During the experimental campaign different estimated SNR time-series have been collected under different rain conditions. The time-series have been grouped on the basis of the fading event peak attenuation: light fading, for peak attenuation up to 4 dB, moderate fading, for peak attenuation up to 8 dB, strong (deep) fading, for peak attenuation up to 16 dB. The update period of SNR values, i.e. the time from an SNR estimation and the next new SNR estimation, is about 0.05 s. The overall duration of time series is variable from 5 to 10 hours.

The main parameters of the system setup are here reported (the whole set can be found in [5]):, carrier frequency of 38.1 GHz, baud rate equal to 1 Mbaud, antenna diameter of 4.2 m, linear polarization.

It has to be underlined that, due to the fact that SNR time-series have been collected in a single site, the results cannot be considered of wide applicability in locations with different climate trends.

## 3. Predictive Channel Estimation

The classical approaches for physical layer adaptation consider the instantaneous estimated channel quality to select the optimal physical layer configuration (e.g. MODCOD). 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 channel quality feedback is received at the transmitter. 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 signal with new parameters adapted to the predicted channel condition is received, i.e. the Round Trip Time (RTT). A classical method based on linear regression is to consider the previous $W$ instantaneous channel estimations to predict the channel parameter at time $i+T$.

Linear regression can be implemented using a FIR filter of order $W$-1 called Linear Prediction Filter (LPF). It is worth noting that, for a Gaussian time-varying signal, the optimal predictor in terms of Mean Square Error (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 this work, we consider a total of four channel prediction techniques based on LPF as an enhancement to the simple single point channel estimation based on a single SNORE estimation.

Therefore, the first method is here called single point, which is achieved using the single SNR estimation to predict the future SNR.

The second method is the moving average filter, which is a lowpass FIR filter where the weights of each delay tap are identical. It represents the arithmetic mean of the SNR over a set of $W$ samples.

The third method is a LPF with set of coefficients given by a linear ramp; it has the property to give more importance to the latter values of the sequence with respect to the earlier values.

The fourth method is the Least Squares (LS) LPF, which determines the coefficients of a forward linear predictor by minimizing the prediction error in the least squares sense.

## 4. Performance Evaluation

The performance of each channel prediction method have been evaluated in terms of MSE as a function of the window size. The MSE is computed applying the specific channel prediction method to the sequence of SNR values measured by a SNORE channel estimator in a real Q/V-band satellite link.

An example of the results in terms of MSE are shown in Figures 1, 2, and 3 for each fading event.

The achieved results in terms of MSE as a function of the window size can be summarized as follows:

- The simple single point estimator (method no. 1) achieves a MSE which is always larger than the MSE of channel prediction methods no. 2, 3 and 4. Therefore, channel prediction algorithms are useful to achieve better performance at the expenses of a very low increase of complexity.
- For each channel prediction method, except the single point estimator (method no. 1), the MSE is a convex function of the window size $W$, i.e. it has a minimum for a specific value of $W$ and this minimum is unique. This result is a consequence of the trade-off that exists between smoothing of the SNR sequence (better with large $W$) and correlation of the considered SNR values in a window and the future SNR value to be estimated (better with small $W$).

- The best channel prediction method is the linear prediction filter with linear ramp coefficients. On the other hand, it has to be outlined that the performance of method 2 are very close to the one of method 3).
- The optimal value of the window size is around *W*=35 (about 1,5 seconds).

The above conclusions are independently drawn from the specific rain event.

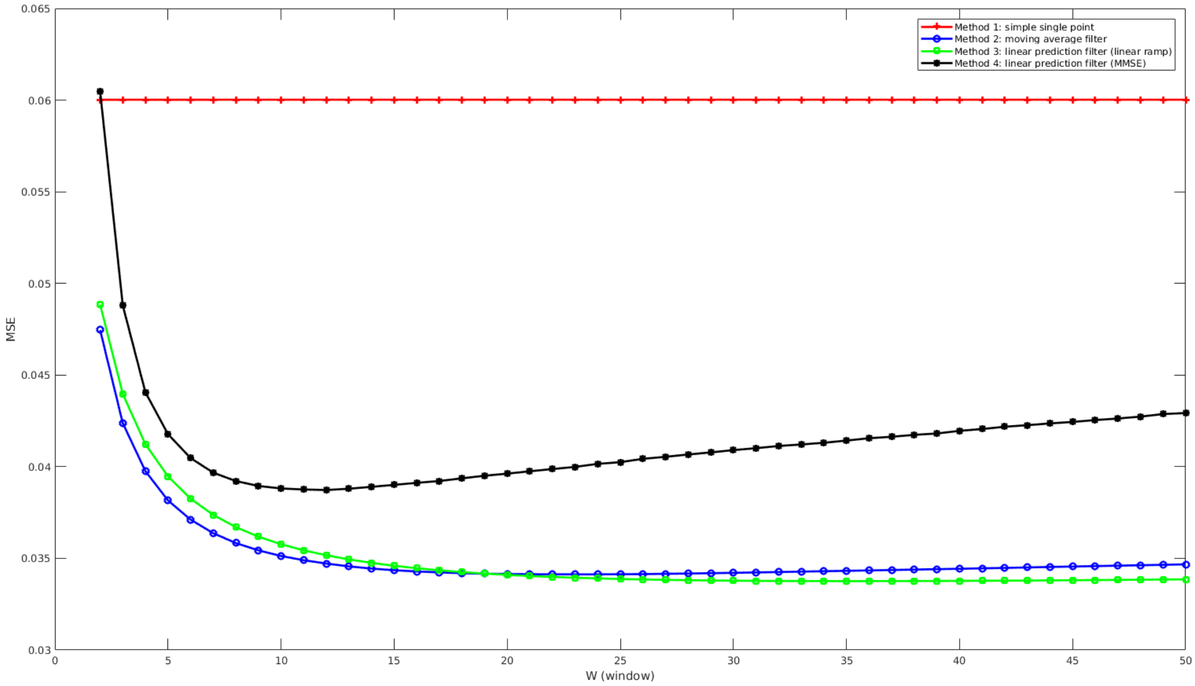

Figure 1: Plot of MSE as a function of the window size for different SNR prediction algorithms in Q/V-band (deep rain fading event).

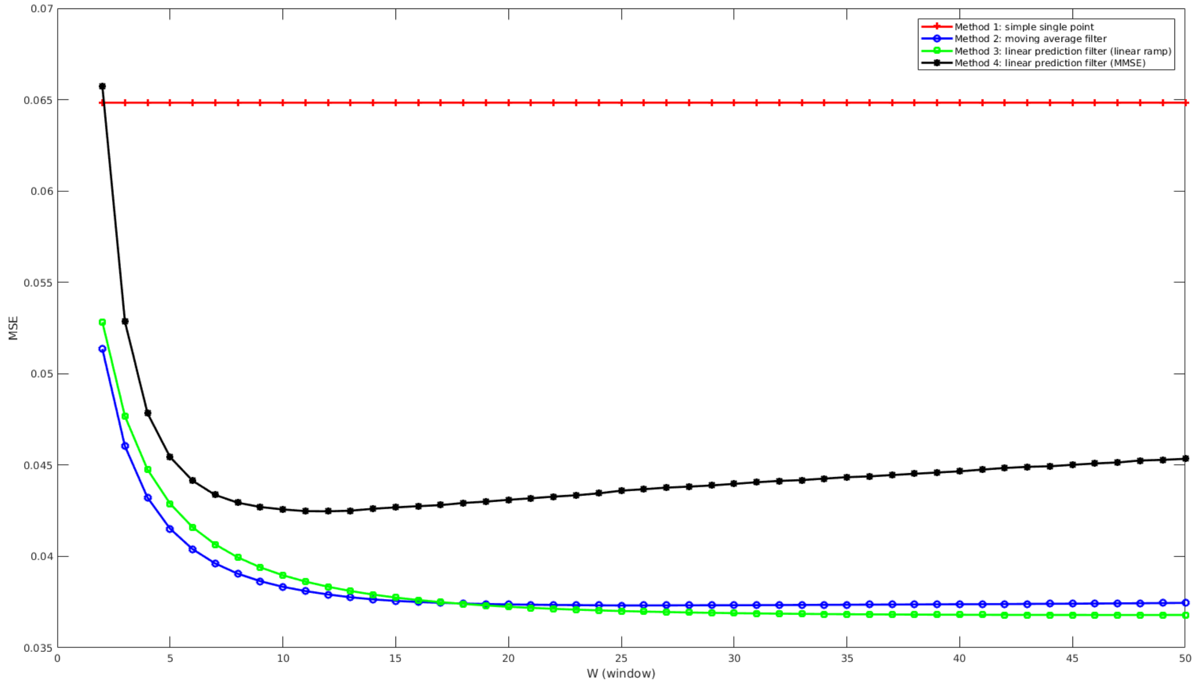

Figure 2: Plot of MSE as a function of the window size for different SNR prediction algorithms in Q/V-band (moderate rain fading event).

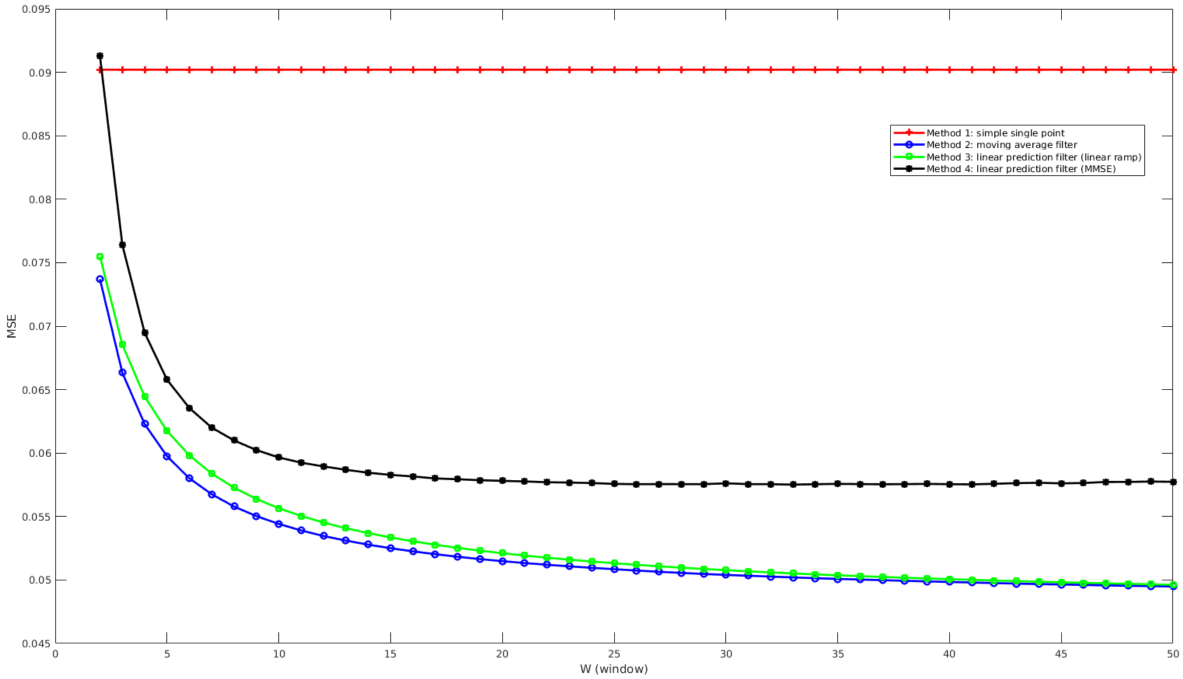

Figure 3: Plot of MSE as a function of the window size for different SNR prediction algorithms in Q/V-band (light rain fading event).

## 5. Conclusion

In this paper, short-term channel prediction techniques have been introduced and analyzed for a Q/V-band end-to-end satellite link. The data used for the analysis have been collected during the current Italian Space Agency Q/V-band satellite communication experimental campaign, based on Aldo Paraboni P/L embarked on Alphasat. Different SNR short-term prediction techniques have been introduced and compared. The best performance are achieved using a linear prediction filter with linear ramp coefficients, considering a FIR filter length of about 35 samples (corresponding to about 1,5 s of SNR measurements).

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## References

[1] E. Matricciani, M. Mauri, and C. Riva. Scintillation and simultaneous rain attenuation at 49.5 Ghz. In Antennas and Propagation, 1995, Ninth International Conference on (Conf. Publ. No. 407), volume 2, pages 165–168, Apr 1995.
[2] D. R. Pauluzzi and N. C. Beaulieu. A comparison of snr estimation techniques for the awgn channel. IEEE Transactions on Communications, 48(10):1681–1691, Oct 2000.
[3] C. E. Gilchriest. Signal-to-noise monitoring. Technical report, JPL Space Programs Summary, 1964.
[4] S. Cioni, G. E. Corazza, and M. Bousquet. An analytical characterization of maximum likelihood signal-to-noise ratio estimation. In 2005 2nd International Symposium on Wireless Communication Systems, pages 827–830, Sept 2005.
[5] T. Rossi, M. De Sanctis, F. Maggio, M. Ruggieri, G. Codispoti, and G. Parca. Q/V-band satellite communication experiments on channel estimation with Alphasat Aldo Paraboni P/L. In 2015 IEEE Aerospace Conference, pages 1–11, March 2015.
[6] T. Rossi, M. De Sanctis, M. Ruggieri, C. Riva, L. Luini, G. Codispoti, E. Russo, and G. Parca. Satellite communication and propagation experiments through the alphasat Q/V band aldo paraboni technology demonstration payload. IEEE Aerospace and Electronic Systems Magazine, 31(3):18–27, March 2016.