Gateway Site Diversity Statistics for EHF Band Satellite Systems

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***Abstract*—This paper evaluates the site diversity statistics between two satellite gateways which are ~500 km apart. Using satellite beacon data from the Aldo-Paraboni experimental onboard Inmarsat's Alphasat, propagation measurements were taken at Chilbolton, southern England and Edinburgh, Scotland at 40 GHz. Rain fade measurements for the year 2017 were analysed and the diversity gain statistics were computed for the whole year. Results demonstrate the benefits of site diversity during rain events at Q/V bands where significant spectral efficiency gains can be achieved depending on the switching thresholds. A lower switching threshold will produce the greatest throughput gain. However, this comes at the cost of shorter switch durations and higher number of switches. The operating point should be determined by the practical switching rate that can be afforded by the specific satellite system. The site at Edinburgh is seen to benefit more from diversity than the site at Chilbolton.**

Rain fading is a major impairment for High Throughput Satellite (HTS) links using the Ka, Q/V and W bands on gateway earth-space paths. In preparation for the practical deployment of these frequencies in HTS systems and to provide higher data rates and better quality of service (QoS), there is a need to study the availability statistics as a means of providing smart switching for these gateways. This may involve, among other things, the determination of the best time to switch the link based on the link conditions.

As the signal fade depth increases with rain rate, system designers consider the size of rain cells (~10 to 25 km) [1] with the assumption of a low probability of correlated rain at the same time instants between sites.

Site diversity is one of several techniques deployed in satellite transmissions to ensure an improved QoS [2]. In site diversity, the downlink beam of a satellite has a footprint covering a wide geographical region. The several gateways employed in the satellite footprint are spread widely over the coverage region. One or more of these gateways may be active, while a reduced number can be redundant, ready to be brought into service when the active stations' link conditions deteriorate and are in danger of losing connection. This is sometimes referred to as the N+P smart gateway scheme [3].

General diversity techniques for the provision of high availability include selective combining, equal gain combining, switched combining and maximal ratio combining [4]. However, due to the switching delay involved in HTS satellite systems, these techniques cannot be used on the fly. The compromise is to use a modified selection technique, where a site with little or no fade is used as a backup for a site experiencing severe fade for the whole duration of the rain event as determined by a switching threshold [2,5].

This work investigates site diversity based on rain fade data captured in the Q/V band (40 GHz) over two sites in the United Kingdom for the year 2017 as described in the next section. Statistics for diversity gain, spectral efficiency gain and switch duration are computed and analysed accordingly. The CCDF of rain attenuation of the two sites and the joint scenario is computed as part of the diversity analysis.

The link-level simulator implements modulation and coding (ModCod) schemes from the DVB-S2X standard [7,8], ranging from QPSK 2/9 with a spectral efficiency of 0.43 bits/symbol and a SNR threshold of -2.35 dB up to 256APSK 3/4 with a spectral efficiency of 5.9 bits/symbol and a threshold SNR of 19.57 dB. We assume normal DVB-S2X frames of 64,800 bits transmitted over the duration of a rain event at 45 Mbaud symbol rate in a linear AWGN channel with satellite link round trip delay of 0.5 s. We also assume the use of perfect Adaptive Coding and Modulation (ACM) (where the link state is perfectly adapted to without any link estimation errors). In this case, the spectral efficiency at each time instant is determined by the ModCod selected based on the link SNR corresponding to the applied rain fade level [9].

Computer simulations were used to determine the spectral efficiency and switch durations (Fig. 1) of the rain events based on switching thresholds. Whenever the fade threshold is reached, the current site is switched to the alternate site until the rain fade level at the alternate site reaches the switching threshold.

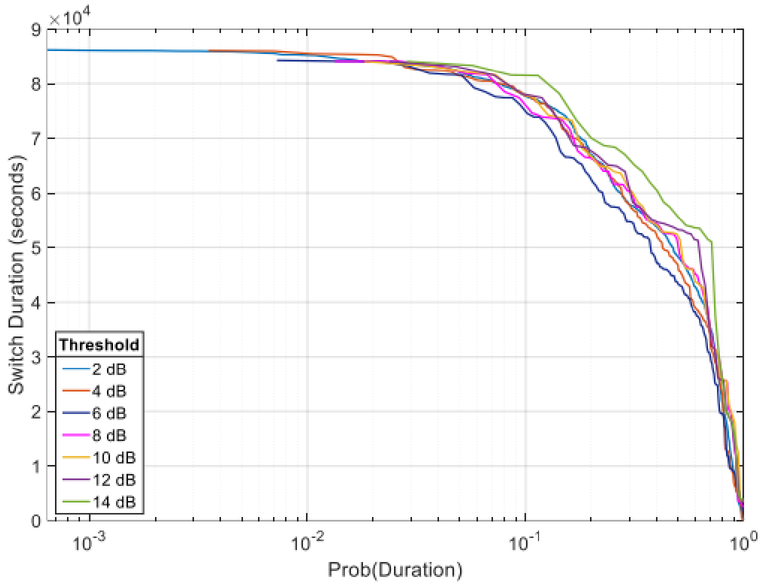

Fig. 1: CCDF of switching duration for different thresholds.

Threshold (dB)	No. of Switches
2	3084
4	628
6	266
8	148
10	109
12	80
14	68

Table 1: Switches per thresholds

Results show that the two sites are sufficiently uncorrelated to achieve a high diversity gain. In an N+P diversity configuration, significant improvements in average spectral efficiency can be achieved during rain events. A lower switching threshold achieves higher throughput gains but requires a higher number of switches while a higher threshold achieves lower throughput gains but requires less switching (Table 1). The chosen threshold can be determined by the switching rate affordable by the specific satellite system and the equilibrium point of switching requirements from all sites in the N+P configuration. It can also be observed that the diversity scheme investigated in this paper achieves an overall throughput which benefits the single site scenario at Edinburgh more than Chilbolton.

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