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# A study on Ka-band site switching using advanced prediction for rain-induced attenuation

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*Abstract* - **High frequency satellite communications suffers from rain-induced attenuations, which may cause service discontinuity during high-intensity rain events. To combat this, we propose a novel site switching technique that anticipates signal attenuations using a linear dynamical system response model and performs site switching in advance. Using only the rainfall data measured at a ground station for attenuation prediction, we demonstrate that our method is able to lessen signal attenuation while maintaining link availability.**

*Index Terms* — **Attenuation, expectation-maximization, Kalman filter, site switching.**

## I. INTRODUCTION

Satellite communications in high frequency bands, e.g. Ku-band or Ka-band, suffers from attenuations caused mainly by rain and other atmospheric disturbances. One of the widely used diversity techniques for discontinuity avoidance is site diversity [1], [2]. At least two ground stations with different geo-locations are required. In case of a high rain-induced attenuation event occurring at the main site, the transmitted signal will be sent instead from the secondary site. Normally, site switching is operated *after* severe degradation or signal discontinuity has been observed. This motivates us to develop a site switching technique that predicts attenuation *in advance*, in order to improve the signal quality and maintain link availability during high-intensity rain events.

## II. METHOD

### A. Data model

We have previously proposed modeling the statistical relationship between signal attenuation and rainfall rate using the linear dynamical system response (LDSR) model as [3],

$$x_{t+1} = ax_t + w_t \tag{1}$$

$$y_{t+\tau} = cx_t + v_t \tag{2}$$

where $t$ represents time sample with one minute increment; $x$ is the signal attenuation level (dB) and $y$ is the measured rainfall rate (mm/hr) shifted by the expected lag of $\tau$=14 minutes obtained from the study in [3]. Equation (1) describes the variation in attenuation and (2) relates the attenuation to the rainfall rate. The noises $w_t$ and $v_t$ are assumed zero-mean Gaussian with variance $q$ and $r$, respectively. The unknown parameters for the model are $\theta=\{a,c,q,r\}$. The parameter $c$ is estimated from the ratio between the highest rainfall rate and the signal attenuation within the time interval of interest. The remaining unknown parameters $\{a,q,r\}$ are estimated using the fixed-interval smoother and the expectation-maximization algorithm. Advanced signal attenuation prediction is subsequently calculated using Kalman filter. The detailed calculations can be found in [3] and references therein.

### B. Site switching process

The block diagram of our proposed method is given in Fig. 1. Only the rainfall rate measured at the main satellite ground station is used for the attenuation prediction, not the signal itself. We collect rainfall rate data in $w$-minute intervals and use it to estimate the LDSR model parameter $\theta$. During precipitation time $\theta$ is repeatedly updated to minimize modeling error. The current value of $\theta$ is then use to predict the signal attenuation $x_t$ for the future $f$ minutes.

Site switching is triggered if the predicted attenuation at the main site is higher than a practical acceptable level of 6 dB. Subsequent transmission is held at the secondary site for $h$ minutes before switched back to the main site.

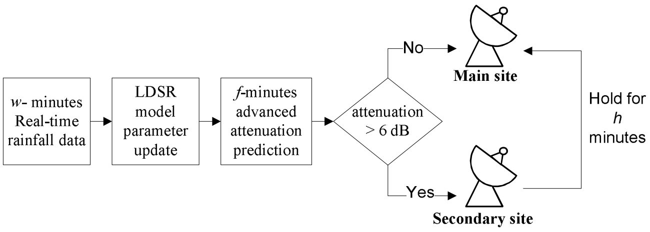

Fig. 1. Block diagram of the proposed site switching process.

## III. RESULTS

We demonstrate the capability of our site switching technique using 4-month data from Thailand's rainy season in 2011. The rainfall rate data is from a tipping bucket rain gauge (Casella Co. Ltd.) installed at Thaicom PLC. Kaerai satellite station in Nonthaburi, Thailand. The actual signal attenuations are obtained from Thaicom-4 (IPSTAR) satellite beacon signals in Ka-band (20.1998 GHz) received at Kaerai station and at Ladlumkaew satellite station in Pathumthani, Thailand. We assume Kaerai station is the main site and Ladlumkaew station is the secondary site.

We first investigate the optimal values of the window size $w$ used to update the LDSR parameters, the advancing time $f$ used for advanced attenuation prediction, and the holding time $h$ to stay in operation at the secondary site. Table I and II report the improvement in signal quality at different values of $w$ and $f$, respectively. The values that give the best signal quality improvement for most months are $w = 30$ minutes and $f = 5$ minutes.

We also vary the holding time $h$ between 5-30 minutes, but discover that this variable has negligible effect on the percent improvement. Therefore, we use the average duration of attenuation measured at both ground stations as our guide. The averaged attenuations at Kaerai and Ladlumkaew stations are 24.83 minutes and 24.63 minutes, respectively. Hence, we set the value of $h = 24$ minutes in our process.

TABLE I
OPTIMAL WINDOW SIZE ($w$)

| Window size (minute) | Signal quality improvement (%) | | | |
|---|---|---|---|---|
| | May | June | July | August |
| 10 | 42.23 | 53.27 | 57.32 | N/A |
| 20 | 26.21 | 57.79 | 53.17 | **21.43** |
| 30 | **50.43** | **63.38** | **73.78** | 10.86 |
| 40 | 25.46 | 61.50 | 65.05 | 11.35 |

TABLE II
OPTIMAL ADVANCING TIME ($f$)

| Advancing time (minute) | Signal quality improvement (%) | | | |
|---|---|---|---|---|
| | May | June | July | August |
| 5 | **44.57%** | 61.02% | **83.51%** | **14.28%** |
| 10 | 34.54% | 62.61% | 77.47% | 10.85% |
| 15 | 34.31% | 62.97% | 78.13% | 7.07% |
| 20 | 28.77% | **63.53%** | 70.95% | 11.07% |
| 25 | 29.60% | 59.54% | 73.36% | 6.70% |
| 30 | 26.77% | 61.34% | 70.69% | 9.10% |

Examples of signal attenuation levels after utilizing site switching are depicted in Fig. 2 and 3 for May 17-20, 2011 and July 11-14, 2011, respectively. It is evident that the attenuation levels are decreased after incorporating site switching. Fig. 2 illustrates the limitation of our technique when both ground stations suffer from rain-induced attenuation at the same times. However, drastic signal quality improvement is possible if the attenuations at the two stations do not coincide, as can be seen in Fig. 3.

Overall, we test the technique using consecutive rainfall data within each month. The improvements in signal quality after site switching are summarized in Table III. The percent improvement is largest in July because the attenuations at Ladlumkaew station are low. On the other hand, large attenuations at Ladlumkaew limit the improvement in August.

## IV. CONCLUSION

This paper presents a novel yet simple technique for advanced site switching using only rainfall rate data at the main satellite ground station. Our technique can significantly improve signal quality with the added benefit of being able to anticipate and prevent signal attenuation before service discontinuity actually happens. If the rainfall data is also available at the secondary site, it is possible to predict attenuations at both sites in advance and use the information to adjust the holding time more appropriately. This is the topic of our further investigation.

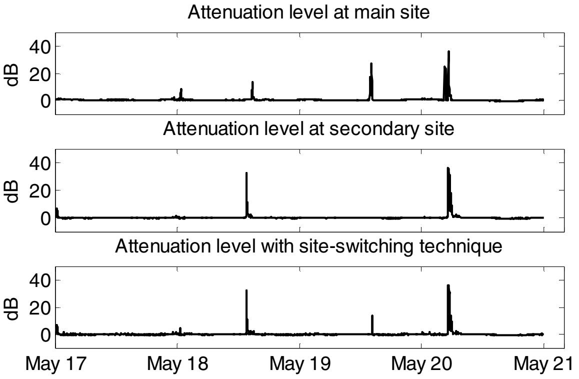

Fig. 2. Attenuation levels during May 17-20, 2011.

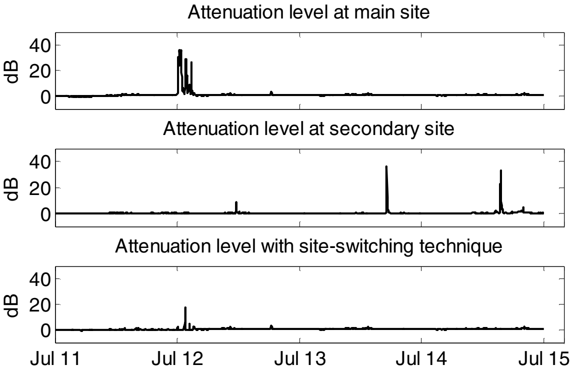

Fig. 3. Attenuation levels during July 11-14, 2011.

TABLE III
SIGNAL QUALITY IMPROVEMENT AFTER SITE SWITCHING

| Month | May | June | July | August |
|---|---|---|---|---|
| Signal quality improvement (%) | 44.57 | 61.02 | 83.51 | 14.28 |

## ACKNOWLEDGMENT

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