THE PREDICTION OF RARE PROPAGATION EVENTS: THE CHANGING FACE OF OUTAGE RISK ASSESSMENT IN SATELLITE SERVICES

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INTRODUCTION

Telecommunications systems have evolved from the analog world to the digital world in two decades. This is particularly true for all categories of commercial satellite service: fixed, mobile, or broadcast. In the field of radiowave propagation modeling, however, the transition from the analog era to the digital era has been somewhat slower. Forcing the pace of propagation modeling has been the evolution, and then rapid expansion, of digital services for the end user. These might be packet or circuit switched; connection-oriented or connectionless; IP based or MPLS; and so on. How to define performance and availability when it is the throughput of un-errored bits that (literally) count? This paper looks at the origins of propagation modeling for satellite services and then recasts the approach in terms of the needs of the service providers and users in the digital age of the twenty-first century. It is seen that there are two very different propagation modeling requirements: one for high capacity terminals and one for low capacity terminals.

BACKGROUND

Telecommunications link budgets provide a margin for propagation effects. A typical, short-form, link budget equation is shown below, using decibel notation.

$$P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra} \qquad \text{dbW} \qquad (1)$$

In (1), P_r = received power, G_r = receive antenna gain, L_p = Free Space Path Loss, L_a = Propagation Loss, L_{ta} = Transmit Antenna Loss, and L_{ra} = Receive Antenna Loss. The only parameter in (1) that is not under the control of the operator, and which can vary significantly, is the propagation loss. Propagation loss is caused by the constituents in the atmosphere, which change their characteristics with weather patterns. Weather is a cyclostationary process; that is the major features repeat (spring, summer, autumn, and winter) in a regular fashion, even though individual events occur randomly. The first attempts to quantify attenuation margin therefore adopted a statistical approach [1]. Path attenuation measurements were taking over periods of at least a year, and annual average loss margins were developed. This worked well for traditional trunk systems, which at that time carried significant voice message traffic along point-to-point routes that were designed in much the same way terrestrial systems had been three decades earlier. The introduction of satellite video distribution and broadcast traffic saw the adoption of worst month criteria, which led to the need for a conversion process to change annual average data to worst month values. The adoption of worst month criteria pointed out the need to evaluate the risk of rare propagation events occurring at particular times.

RARE EVENT PREDICTION

The prediction of rare propagation events followed similar approaches to those used for the prediction of rare meteorological events. Terms such as “ten year” storms and “return periods” started to appear in the prediction of severe propagation events for specific locations where major earth station complexes were to be found. Such complexes, however, started to change their major roles in the 1990s from nodes in an analog point-to-point telephony network to that of hub stations in the distribution of broadcast video and back bone Internet services. As such, the need to have very low outage for the link was still of paramount importance, and propagation models that allowed an accurate prediction of the likely loss were developed that concentrated on 0.01% of an average year [2]. But component and network technology have advanced rapidly since 1990 with extensive digital signal processing capabilities and video compression technology enabling telecommunications networks to move the decision-making functions closer to the end user and to provide streaming voice, data, and video. The term, *distributed intelligence*, was coined for advanced terrestrial and satellite networks. A new class of Direct To Home (DTH), Small Office, Home Office (SOHO) service offerings were formulated for advanced satellite systems, providing two-way multi-media services.

For DTH/SOHO satellite services, the key element to initial customer acceptance is the cost of the terminal. The smaller the antenna, the lower the cost – and the lower the available propagation margin. About twenty million low-margin direct broadcast video terminals were operating worldwide by 2002. Such direct broadcast services have grown to include two-way Internet offerings in Ku and Ka-band. The propagation margin for these terminals is typically less than 10 dB, with annual outages of around 0.3 to 0.5%. Extreme propagation predictions for such terminals are irrelevant; even a moderate shower will cause an outage [3]. Two new approaches to propagation modeling are required for such low margin terminals: *Combined Effects* models [4] and accurate *Second-Order Propagation Predictions* [5].

PROPAGATION MODELING

Combined Effects Modeling

Low margin terminals will be adversely affected by even small path losses, since their operating margins are limited. Cloud, scintillation, and drizzle can combine to cause an outage whereas for large terminals only heavy convective rain causes an outage. Two problems face combined effects models. The first is a suitable choice of a prediction procedure for each of the single loss mechanisms (e.g. rain attenuation). The second, and perhaps the more difficult, is a suitable procedure for combining the single effects models into a comprehensive whole. In the first combined effects model [4], the rain model has stood up well to testing, but there are still questions surrounding both the other individual effects models selected and the method of combining all of the effects. No doubt, future developments of combined effects models will increase the overall accuracy of the total loss prediction at all time percentages. Given an ability to predict accurately the average occurrence of propagation effects at all levels, the next concern is to be able to predict ***when*** they are likely to occur, for ***how long*** they will occur, and when will they ***occur again*** at the same level. These are second-order propagation event predictions.

Second-Order Propagation Event Prediction

Second-order propagation event prediction looks beyond the annual average attenuation statistics to investigate the detail of the individual rain events. Of particular importance in these analyses is the identification of when the events occurred (time of year, time of day), how long the events remained at the given attenuation level, and when did a similar event occur again, both in duration and in level. These can be characterized as *seasonal effects*, *diurnal effects*, *event duration*, *intra-event duration*, and *inter-event duration*. Some specific and schematic examples of these are shown in Fig. 1. Additional specific examples can be found in the literature (e.g. 6, 7).

Seasonal effects may follow typical temperate climate seasons (spring, summer, autumn, and winter) or they may follow climate trends more prevalent in tropical regions (wet and dry seasons, monsoon season, etc.)[6]. In temperate regions, diurnal attenuation trends tend to show more attenuation events in the afternoon and evening, while in wet, tropical regions there is no clear diurnal pattern [6]. Event duration, on the other hand, tends to follow much the same trend in tropical or temperate regions, although on low elevation angle paths, it is difficult to separate tropospheric scintillation events from rain events. The distribution of tropospheric scintillation durations tends to approximate a power law while rain attenuation durations tend to follow a log normal distribution [8]. The prediction of long events due to rain are more relevant to satellite broadcast services, while the prediction of short events will effect the Internet like services to be provided by satellite. For the latter, the type of data stream – voice, video, or data – and the type of error recovery and Quality Of Service (QOS) flags used, will determine the relative importance of specific fade duration lengths and intervals. In some instances, it is useful to generate time series of tropospheric propagation to simulate outage event durations.

Generation of time series of tropospheric attenuation

Many propagation impairment mitigation techniques use a shared resource (e.g. power, frequency, time, code level) that can be assigned to the affected channel. To succeed, such techniques must act in real-time, and so the dynamic behaviour of the propagation channel needs to be known. Time series of attenuation under various weather conditions and climates would provide the dynamic data required, but measured time series are not generally available for all climates, and so simulators are being developed to create these time series. Some simulators use a statistical approach (e.g. Markov chains or spectral analyses), some are physically based, while others use actual measured data that may be changed to represent various climates and paths. Such simulators also permit the quality of service to be accurately assessed under given propagation conditions.

SUMMARY AND CONCLUSIONS

The evolution of distributed digital services to DTH/SOHO customers has led to a new type of low margin terminal that is susceptible to a range of propagation phenomena that did not used to affect large terminals, such as cloud, tropospheric scintillation, and drizzle events. Large terminals can still use extreme value predictions to calculate the likelihood of an outage, but small terminals need both combined effects prediction models and second order propagation event predictions to evaluate the likely quality of service. The trend towards pricing of services by the delivery of un-errored bits and the throughput rate will lead to the integration of error-detection and correction procedures, combined effects models, and second order propagation event prediction methods.

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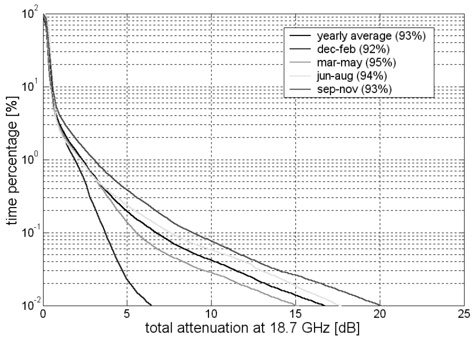

Fig. 1A: Seasonal effects on total attenuation at 18.7 GHz (ITALSAT Spino d'Adda)

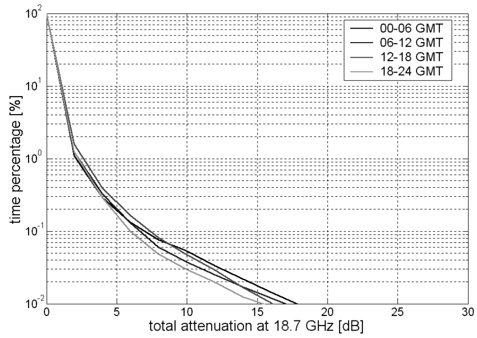

Fig. 1B: Diurnal effects on total attenuation at 18.7 GHz (ITALSAT Spino d'Adda)

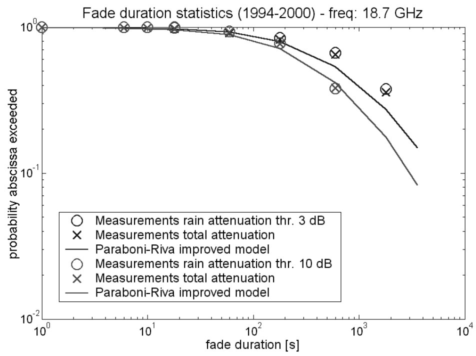

Fig. 1C: Statistics of rain attenuation event duration at 18.7 GHz (ITALSAT Spino d'Adda)

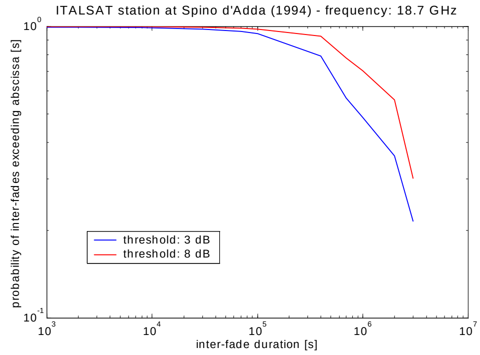

Fig. 1D: Statistics of rain attenuation inter-event duration at 18.7 GHz (ITALSAT Spino d'Adda)