Implementing Adaptive Power Control as a 30/20-GHz Fade Countermeasure

Dennis G. Sweeney, *Member, IEEE*, and Charles William Bostian, *Fellow, IEEE*

***Abstract*— Satellite systems in the 30/20-GHz band are very susceptible to outages due to rain-induced fades. In order to reduce the impact of these fades, it has been proposed that the power of a transmitting ground station be adjusted during the fade to compensate for the additional attenuation. Real-time frequency scaling of attenuation from the downlink to the uplink shows promise for estimating the uplink attenuation for uplink power control (ULPC). A scaling-type ULPC algorithm using 20-GHz attenuation scaled to 30 GHz is presented. The limitations of such an algorithm and the effects of scintillation on ULPC are explored. The algorithm is tested using OLYMPUS fade data measured on the 14° elevation OLYMPUS to Blacksburg, VA path. An ULPC scheme employing a beacon at the uplink is also presented. It offers better performance than scaled downlink attenuation ULPC.**

***Index Terms*— Adaptive systems, fading channels, fade countermeasures, power control, rain attenuation, satellite communication, satellite systems, uplink power control.**

I. Introduction to Adaptive Control

At the present time, the bulk of commercial satellite traffic is carried in the 6/4 GHz satellite allocation. The need for greater capacity has pushed satellite system designers to go to the 14/12 GHz allocation and there is an additional but largely unused allocation at 30/20 GHz. The OLYMPUS program sponsored by the European Space Agency (ESA) and NASA's Advanced Communications Technology Satellite (ACTS) are two experiment programs that are exploring the potential of 30/20 GHz.

Unfortunately, a major drawback to the use of these higher frequencies is rain attenuation. Fig. 1 shows a typical rain fade measured on the OLYMPUS Blacksburg, VA path at 12.5, 20, and 30 GHz. It is clear that the fading problem becomes more severe as the frequency increases. At 6/4 GHz, the effects of rain attenuation are small and can be easily overcome by built in system margins. The transmitter power required to operate a 30/20-GHz system with a fixed margin to overcome rain fades is prohibitively large. In addition, such high power with its accompanying problems of intermodulation and interference would only be needed for a few hours a year.

The problem of rain-induced fades can be overcome with site diversity, but site diversity is expensive since it requires two complete earth stations and a link to connect them together. A number of adaptive techniques have been suggested to deal with this problem. They fall into two major categories, the first being some kind of adaptive power control. This power control could be applied to the uplink, the downlink, or both. A second type of fade countermeasure is resource sharing such as time reserved in a TDMA frame, or data rate adjustments which change the energy per bit.

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The authors are with the Center for Wireless Telecommunications, Bradley Department of Electrical Engineering, Virginia Tech, Blacksburg, VA 24061 USA.

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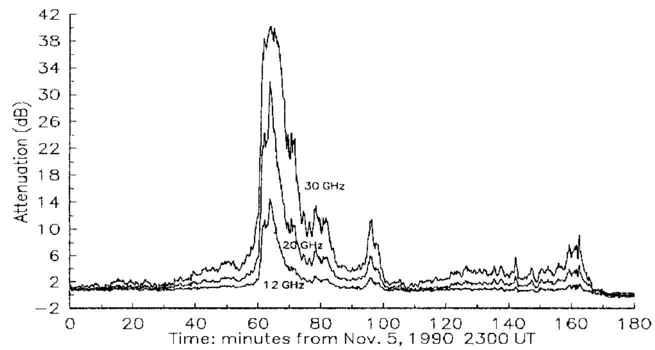

Fig. 1. Fade measured on the OLYMPUS-Blacksburg link on November 5 through 6, 1990 at 12.5, 20, and 30 GHz. Receiver dynamic range limits 30 GHz attenuation to 38 dB.

This paper deals with some aspects of applying simple open loop ULPC to a 30/20-GHz satellite link. It examines the performance of ULPC where the downlink fade is scaled to predict the uplink fade and it also examines the use of a beacon at the uplink to drive ULPC.

II. OLYMPUS at Virginia Tech

In August 1990, the Satellite Communications Group at Virginia Tech began an experiment program which simultaneously measured the signal strength of the 12.501 9/19.770 5/29.6557 GHz (12.5/20/30 GHz) OLYMPUS beacons at Blacksburg, VA, USA [1]. As viewed from Blacksburg, OLYMPUS could be seen at an elevation angle of 14.5°.

The Virginia Tech earth station consisted of four receiving terminals. The 20- and 30-GHz terminals had 1.5-m (5 ft) and 1.2-m (4 ft) antennas, respectively. The 12.5-GHz terminal used a 3.6-m (12 ft) antenna. All the antennas are prime focus paraboloids. A second 20/30 GHz terminal was part of a short baseline diversity experiment. Fig. 2 is a block diagram of the system.

The 12.5-GHz receiver can measure a fade up to 18 dB. Beyond this point it loses frequency lock. The 20- and 30-GHz receivers exploit the frequency lock at 12.5 GHz and the fact that the three beacons are derived from a single source. This permits the 20- and 30-GHz receivers to measure down to their respective noise floors. They can measure a fade of 38–40

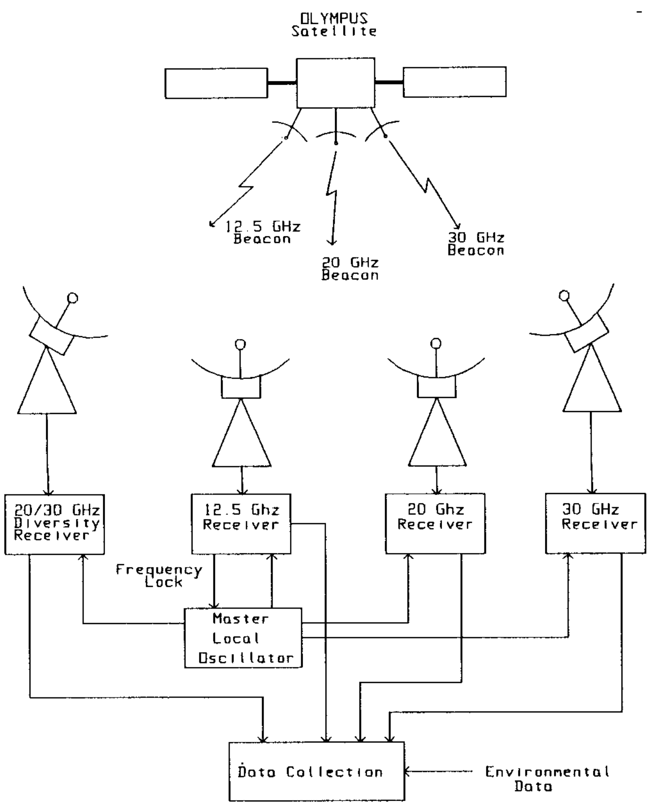

Fig. 2. Block diagram of Virginia Tech OLYMPUS experiment.

dB. Each receiver has a measurement resolution of 0.05 dB. The signal strength output from each beacon receiver is passed through a 3-Hz low-pass filter and the result is sampled and recorded at a ten samples per second rate. The 3-Hz low-pass filter sets the ultimate receiver noise bandwidth and it insures that the Nyquist sampling criterion is met. Environmental data such as air temperature and wind speed and direction are also recorded. Data recorded with this system was used to test ULPC algorithms.

III. Implementing an ULPC Algorithm

Japanese [2] and Comsat tests [3] suggest that real-time frequency scaling of attenuation may be used for ULPC. A simple fade countermeasure would be to measure the downlink attenuation and scale it by some appropriate factor in order to estimate the uplink attenuation. This value for uplink attenuation can then be used to control uplink transmitter power or adaptive coding. In order to implement a successful control algorithm, it is necessary to know the instantaneous ratio between attenuations at the uplink and downlink frequencies. Both the Comsat and Japanese tests reported that this ratio is not a constant but neither addressed its variability. A beacon at the uplink frequency could also be used to estimate uplink attenuation. At the expense of a 30-GHz receiver, such a system potentially offers greater accuracy.

Fade slope has also been suggested as a parameter to drive ULPC [4]. Upon further investigation, it appears that fade slope cannot be employed to drive ULPC [5]; therefore, attention was focused on real-time frequency scaling.

Several scaling relationships are available to scale long term attenuation statistics [6]. A study was undertaken to compare the ratio used to scale statistics with the measured real time ratio [7]. The fixed scaling ratio given in [6] was chosen for the study

$$\frac{A_2}{A_1} = \frac{\phi(f_2)}{\phi(f_1)} \quad \text{where} \quad \phi(f) = \frac{f^{1.72}}{1 + 3 \times 10^{-7} f^{3.44}}. \tag{1}$$

A_2 and A_1 are the attenuations in dB at frequencies f_2 and f_1 in gigahertz, respectively. A scaling ratio of approximately 1.97 is obtained from the OLYMPUS beacon frequencies. The resulting study suggested that frequency scaling of attenuation can be used in real time if the dynamic range is limited. Fades up to approximately 6 dB at 20 GHz could be scaled in real time to 30 GHz with reasonable accuracy even though there is no real-time deterministic relationship between the 20- and 30-GHz attenuation.

In addition to rain-induced attenuation, there is attenuation due to atmospheric gases, water vapor, and scintillations that must be considered. Using the ITU-R algorithm [8], the attenuation due to atmospheric gases (predominantly oxygen) in clear air from Blacksburg to OLYMPUS was calculated as 0.42 dB at 30 GHz and 0.23 dB at 20 GHz. The gaseous attenuation at 20-GHz scales to 30 GHz with a ratio of 1.77. This is close to the rain attenuation scaling ratio of approximately 1.97 obtained from (1) above. The change in gaseous attenuation during a storm is expected to be relatively small, so the control error introduced by ignoring this change in attenuation should be small.

The attenuation introduced by water vapor is a more serious problem since it is larger in magnitude than the oxygen attenuation and it is actually less at 30 GHz than at 20 GHz. Attenuation due to water vapor is predominantly a function of humidity and temperature, both of which are likely to change during a storm. Using the method outlined in [8], the water vapor attenuation on the Blacksburg to OLYMPUS path was estimated to increase from 1.07 to 2.24 dB at 20 GHz and from 0.74 to 1.40 dB at 30 GHz for an increase in relative humidity from 50% to 100% at 20°C.

If the increase in relative humidity is due to the storm, then there will be an increase in path attenuation of 1.17 dB at 20 GHz and 0.66 dB at 30 GHz. If the ULPC algorithm cannot distinguish between rain and water vapor attenuation, it will scale the 1.17 dB of additional 20-GHz attenuation by a factor of approximately 1.97. This will result in an estimate of 2.34 dB of additional 30-GHz attenuation. In actuality, the 30-GHz attenuation will have increased by only 0.66 dB and the result is an overcompensation of 1.68 dB. This is a potentially large error, but water vapor attenuation depends on a number of factors and their change during a storm is difficult to quantify. We decided to ignore this source of error for our initial tests and it does not appear that this assumption introduced significant errors in practice.

Scintillations represent a different problem. Scintillations (in decibels) scale with the ratio of $(f_2)/(f_1)^{7/12}$ where f_2 and f_1 are the frequencies of interest [9]. This results in a scaling ratio from 20–30 GHz of approximately 1.27. Scaling the scintillations by the same factor as the rain attenuation 1.97 will amplify the effect of the scintillations on the uplink.

The Comsat ULPC experiments [3] were reasonably successful in counteracting the effects of scintillation at 14/11 GHz. This was possible because Comsat used the same antenna for both the uplink and the downlink. The only delay in the system was that of the controller and one earth-to-satellite round-trip time, so the scintillations on the downlink are still correlated with uplink scintillations. The 20- and 30-GHz antennas for the Virginia Tech OLYMPUS experiment are not co-located, so the up and downlink scintillations in our data are not correlated.

Delay in the control system can also decorrelate scintillations so that it is not possible for the ULPC to compensate for them. Systems which have some type of centrally arbitrated power control may experience delays on the order of seconds, so it was desired to investigate the effect of delay. If it is not possible to compensate for the scintillations, the 20 GHz signal can be smoothed or filtered so the ULPC follows the fade envelope. This should reduce the errors caused by scintillations, but filtering may introduce its own errors due to filter delay.

IV. ULPC ALGORITHM

A simple difference equation was chosen for a predictor ULPC algorithm

$$\hat{A}_{30}(t|t-kT) = fA_{30}(t-T) + bA_{20}(t-kT) + e(t) \quad (2)$$

where the error $e(t) = \hat{A}_{30}(t|t-k\mathrm{T}) - A_{30}(t)$.

T is the data sample interval ($T = 0.1$ s for our data), $A_{30}(t)$ is the actual value of 30-GHz attenuation at time t, $\hat{A}_{30}(t|t-kT)$ is the estimate of 30-GHz attenuation at time t obtained from the value of the 20-GHz attenuation at time $t-kT$ and the previous value of A_{30}, which is $A_{30}(t-T)$. In operation, the actual values of 30-GHz attenuation A_{30} are not available so it is necessary to predict or estimate the present 30-GHz attenuation from the previous estimate. Driving the algorithm with the previous estimate, (2) becomes

$$\begin{aligned}\hat{A}_{30}(t|t-kT) &= bq^{-k}\sum_{i=1}^{\infty} f^i A_{20}(t-iT)\\ &= bq^{-k}\sum_{i=1}^{\infty} f^i q^{-i} A_{20}(t)\\ &= \frac{q^{-k}b}{1-fq^{-1}}\, A_{20}(t) \quad (3)\end{aligned}$$

where q^{-1} is the delay operator and k is the number of delays in the prediction. Equation (3) is an infinite impulse response (IIR) single-pole low-pass filter. Such a filter supplies the desired smoothing and the attenuation scaling factor is the "dc" gain of the filter. It can be obtained by setting $q^{-1} = 1$ with the result

$$\text{Scale Factor} = \frac{b}{1-f}. \quad (4)$$

The 3-dB bandwidth of the filter can be obtained by setting $q = e^{j\omega T}$ and solving for the value of ω where the magnitude of (3) equals $1/\sqrt{2}$. The result is

$$\mathrm{BW(Hz)} = \frac{1}{2\pi T}\,\mathrm{arcos}\left(\frac{-f^2+4f-1}{2f}\right). \quad (5)$$

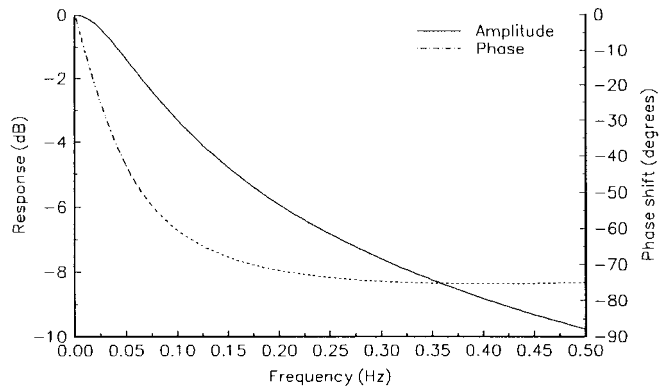

Fig. 3. Gain/Phase plot for one second predictor.

Fig. 3 is a gain/phase versus frequency plot of filter used as a 1 s predictor.

A 30-GHz beacon at or close to uplink can also be used for ULPC. In this case, the current 30-GHz attenuation can be determined from past 30-GHz attenuation measurements. Equation (3) was modified to become a predictor for a 30-GHz beacon driven ULPC

$$\hat{A}_{30}(t|t-kT) = \frac{q^{-k}b}{1-fq^{-1}}A_{30}(t). \quad (6)$$

V. TESTING THE ULPC ALGORITHM

The algorithm was tested on a number of selected 30/20-GHz fade events recorded on the OLYMPUS-Blacksburg, VA path. These fades were observed between November 1990 and May 1991. The data set contains 26 events and 66 h of data. No attempt was made to be exhaustive, but the data set does contain a variety of events representing the conditions during winter, spring, and early summer months in Blacksburg. Table I lists the chosen events.

In addition, only those data that represented 30-GHz fades greater than 1 dB and less than 12 dB were used. A 30-GHz fade greater than 12 dB was considered an outage. Conditioning on 30-GHz fade may be somewhat unrealistic. In an actual system, the 30-GHz attenuation level is what is being estimated/predicted, but conditioning on fades greater than 0.5 dB at 20 GHz would increase the effect of scintillations. In practice, this conditioning is determined by system margins and the above conditioning was chosen in the absence of any firm data on system margins. In addition, conditioning on the 30-GHz fade avoided having to set a 20-GHz baseline reference. The work of Dissanayake [10] shows how this might be done.

Parameter identification software published by Matlab [11] was used to obtain the values of f and b, which produce the minimum squared error (MSE) in (3) for each event. The resulting values of f and b define the optimum scaling factor and filter bandwidth for each event and each delay. These values of f and b should represent the best performance that

TABLE I
SUMMARY OF RMS ERROR (DECIBELS) WITH 1 s DELAY

			20 GHz attenuation scaled to 30 GHz		30 GHz predicting 30 GHz	
Date DD/MM/YY	Time UTC	ITU-R scaling (dB)	Composite scale & filter (dB)	Optimum scale & filter (dB)	Composite filter (dB)	Optimum filter (dB)
05/11/90	2300-0200	0.75	0.65	0.51	0.40	0.40
10/11/90	1100-1300	0.85	0.62	0.55	0.62	0.56
17/11/90	0500-0700	0.43	0.36	0.35	0.36	0.35
28/11/90	2000-2100	1.24	0.88	0.86	0.93	0.90
07/01/91	1500-1600	0.62	0.70	0.39	0.23	0.23
08/01/91	2200-2400	0.67	0.49	0.48	0.34	0.34
20/01/91	0500-0900	1.42	1.32	0.35	0.14	0.14
06/02/91	1100-1500	0.84	0.73	0.28	0.18	0.18
06/02/91	0600-1000	0.76	0.69	0.68	0.44	0.43
03/03/91	2100-2400	0.70	0.56	0.52	0.35	0.34
07/03/91	0000-0300	1.92	1.95	1.55	0.32	0.32
22/03/91	1100-1300	0.91	0.76	0.49	0.47	0.47
26/03/91	2000-2300	1.98	1.83	0.57	0.22	0.22
05/01/91	1300-1500	0.60	0.55	0.51	0.22	0.22
08/04/91	2000-2300	0.79	0.75	0.60	0.55	0.54
09/04/91	0400-0600	0.74	0.77	0.48	0.49	0.49
09/04/91	2200-0200	1.66	1.56	1.46	0.80	0.79
15/04/91	0800-1000	1.19	1.11	1.09	0.48	0.48
24/04/91	1200-1500	0.94	0.75	0.72	0.69	0.67
30/04/91	0200-0400	1.95	1.82	1.17	0.35	0.34
06/05/91	1700-1900	1.51	1.02	1.00	1.18	1.16
12/05/91	1900-2200	1.74	1.57	1.48	0.61	0.61
14/05/91	2000-2200	1.50	1.24	0.98	0.74	0.74
19/05/91	1300-1600	0.91	0.96	0.33	0.20	0.20
21/05/91	0700-0900	0.83	0.79	0.53	0.33	0.28
Weighted RMS error		1.229	1.017	0.721	0.439	0.429

TABLE II
COMPOSITE FILTER PARAMETERS

20 GHz downlink attenuation scaled to 30 GHz				
delay (sec)	f	b	scale factor DC gain	Bandwidth Hz
0	0.96447	0.06871	1.9338	0.05759
1	0.95320	0.09061	1.9359	0.07630
5	0.96868	0.06039	1.9285	0.05064
10	0.96316	0.07091	1.9246	0.05975
20	0.95718	0.08216	1.9185	0.06967

30 GHz beacon measured attenuation predicting 30 GHz				
delay (sec)	f	b	scale factor DC gain	Bandwidth Hz
1	0.91311	0.08682	0.9997	0.14477
5	0.94437	0.05553	0.9982	0.09113
10	0.93353	0.06619	0.9957	0.10952
20	0.92141	0.07805	0.9931	0.10952

is possible for the event. From the optimum value for each event, a time weighted average of scaling factor and bandwidth was then obtained for the entire event set. Table II contains these composite scale factors and bandwidths. For 20 GHz attenuation scaled to 30 GHz with no delay, the composite scale factor is approximately 1.93. This is very close to the 1.97 statistical scale factor obtained from the chosen ITU-R algorithm. The Table II also contains the composite scale factors and bandwidths for ULPC driven by a beacon near the uplink.

Karasawa and Matsudo [12] report that rain fades can be separated from scintillations through the use of a 0.004-Hz low-pass filter. Depending on the event, the optimum filter bandwidths produced by the process described above range from 0.006 to 0.25 Hz. The weighted average bandwidth is 0.06–0.08 Hz. This is roughly a factor of ten greater than that reported by Karasawa and Matsudo. This suggests that filters considerably broader than 0.004 Hz can be used to separate rain fades from scintillations in some events.

Delays of 0, 1, 5, 10, and 20 s were chosen for the 20-GHz downlink driven ULPC. A 1-s delay represents a typical minimum value for an ULPC system that operates on telemetry or is centrally arbitrated. The longer delays were chosen to investigate how fast the algorithm deteriorates with time.

For UPLC driven by 30-GHz beacon at the uplink, delays of 1, 5, 10, and 20 s were chosen. For obvious reasons, the estimation case with no delay was deleted. Fig. 4 plots error as

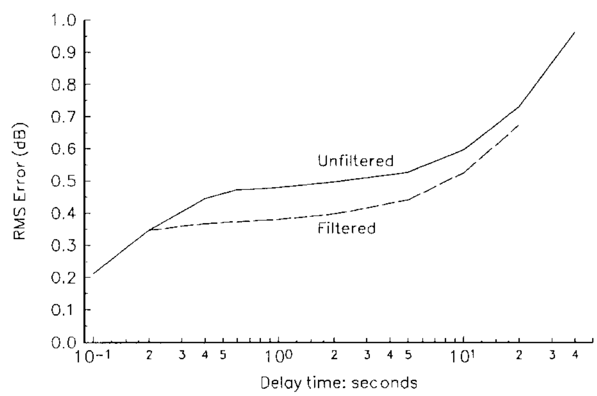

Fig. 4. Root mean square (rms) error versus delay for 30-GHz beacon measured attenuation predicting 30 GHz for November 5–6, 1990 event.

a function of delay for ULPC driven by a beacon at the uplink for the November 5 through 6, 1990 event. The error was obtained by taking the difference between the predicted value of 30-GHz attenuation and its actual value. As expected, the error increases quickly with delay up to about 0.5 s. This is due to the decorrelation of the scintillations. Also as expected, the filtering improves the performance, but the error performance is relatively constant from 0.5 s up to about 10 s of delay, which suggests that the underlying fade process is a very low frequency phenomenon.

VI. OVERALL ALGORITHM PERFORMANCE

Table I contains the rms error with 1 s delay for all the events in the data set. Using this table, it is possible to compare the performance of ULPC driven by downlink scaled attenuation or ULPC using attenuation obtained from a beacon at the uplink frequency with either optimum or composite scaling and filtering.

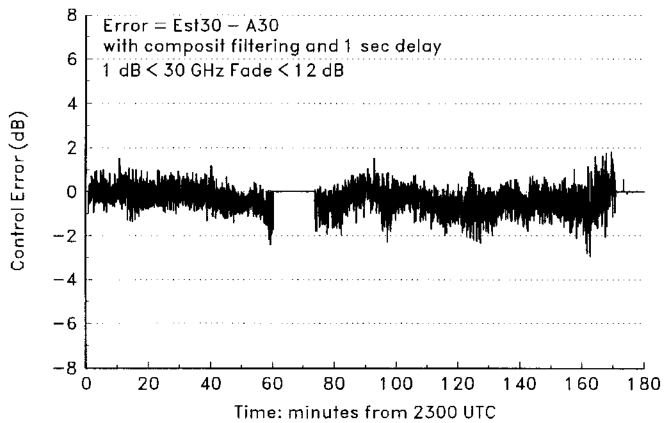

Fig. 5. Control error: 20-GHz downlink attenuation scaled to 30 GHz for November 5 through 6, 1990.

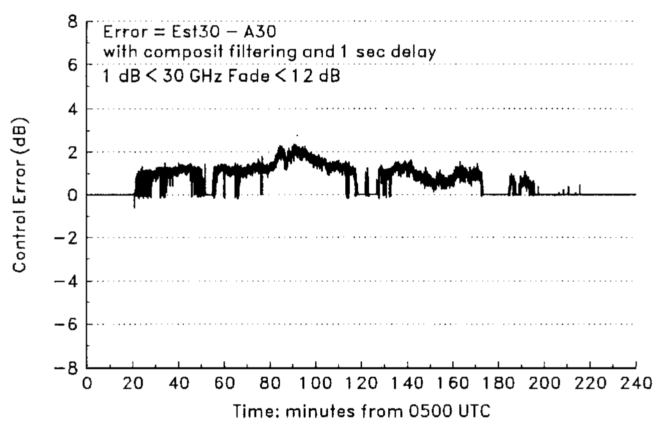

Fig. 6. Control error for the January 20, 1991 event. The bias toward over prediction is a result of using the composite scale factor of 1.93 rather than the optimum scale factor of 1.31, the lowest scale factor in the event set.

A weighted average error for the entire event set was calculated for each of the various scaling and filtering options and it is tabulated at the bottom of Table I. The unfiltered scaling with the ITU-R derived factor produced the poorest performance with 1.13-dB rms error for the event set. The composite scaling with filtering improved algorithm performance to 1.02-dB rms. This is a worthwhile improvement.

Since the scaling factor without filtering is 1.97 and the composite scaling factor with filtering is 1.93, it is possible to compare these two cases to assess the value of filtering. In all events except for January 7th, March 7th, and April 9th, filtering improved algorithm performance. Nevertheless, the ITU-R derived scale factor with no filtering is only marginally better for these three events.

The 0.72-dB rms error for the optimum scaling and filtering is clearly better than the composite scaling and filtering. The average performance of 1.02 dB for the composite shows that there is a penalty to be paid for the convenience of a single valued algorithm.

If better ULPC performance is desired, prediction using a beacon at the uplink frequency clearly has the edge. The composite filtered 30-GHz beacon driven ULPC resulted in only 0.44 dB of rms error. The optimum filter resulted in only a marginal increase in performance to 0.43-dB rms, so finding

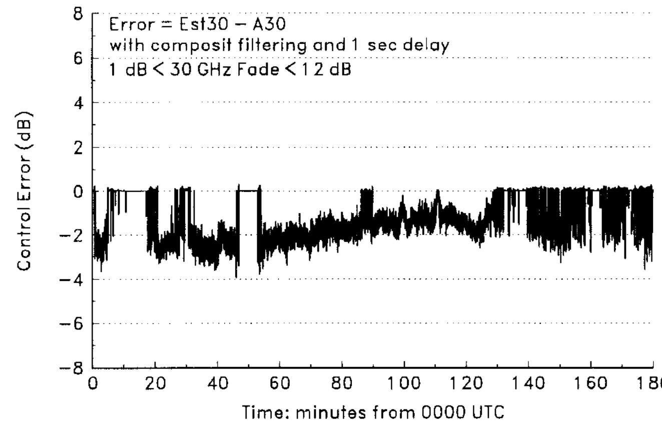

Fig. 7. Control error for the March 7, 1991 event. The bias toward under prediction is a result of using the composite scale factor of 1.93 rather than the optimum scale factor of 2.50, the highest scale factor in the event set.

the optimum filter for the 30-GHz beacon driven ULPC is not as critical as in the scaling case. The use of a beacon at the uplink does not always guarantee better performance, however. An examination of the composite scaling performance for the November 10th, November 17th, November 28th, and May 6th events reveals that 20 GHz scaled to 30 GHz performed as well as or better than the beacon at the uplink driven algorithm.

Fig. 5 is the control error using the composite scaling filter for the November 5 through 6, 1990 event that is plotted in Fig. 1. The average scale factor for this event is very close to the composite value so mean error is approximately zero. The resulting rms error is primarily due to uncompensated scintillations. The composite scaling filter over predicts for the event in Fig. 6 and under predicts for the one in Fig. 7. These two events represent the minimum and maximum optimum scale factors found in the event set. Fig. 8 plots the average scaling factor versus 20 GHz attenuation for all tested events between January 1991 and May 1991. Fig. 8 shows that the scaling factor is less than 2.5 for 90% of the time and it is less than 1.5 for only 10% of the time. Thus, the maximum and minimum scale factors of 2.5 and 1.31 found in this event set are representative of the entire period as well. Fig. 8 also shows that the scale factors tend to decrease as the attenuation increases. This is consistent with the analysis in [7].

Fig. 8 also includes a plot of the 1.97 scaling factor obtained from (1) and an attenuation sensitive scale factor obtained from the ITU-R recommendations [6]. This scale factor is given by

$$\frac{A_2}{A_1} = \left(\frac{\phi_2}{\phi_1}\right)^{1-H(\phi_1,\phi_2,A_1)} \tag{7}$$

where

$$\phi(f) = \frac{f^2}{1+10^{-4}f^2}\; H(\phi_1,\phi_2,A_1)$$
$$H(\phi_1,\phi_2,A_1) = 1.12\times10^{-3}(\phi_2/\phi_1)^{0.5}(\phi_1 A_1)^{0.55}$$

A_2 and A_1 are the attenuations in decibels at frequencies f_2 and f_1 in gigahertz, respectively. Either scale factor would work, but the fixed scale factor can be easily compared to the simple low-pass structure produced by the Matlab analysis.

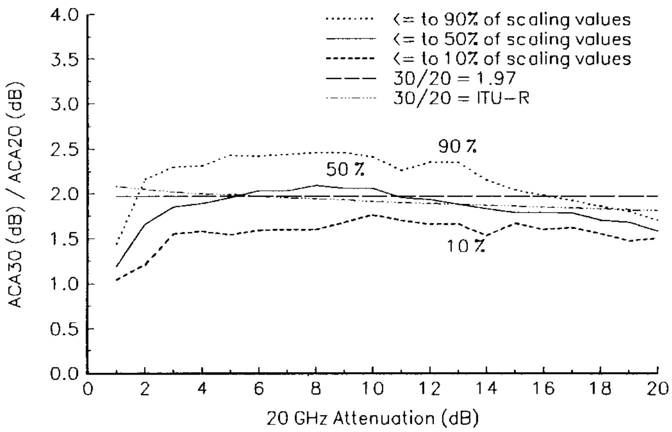

Fig. 8. Average scaling factor versus 20-GHz attenuation for the entire period from January 1991 to May 1991. A fixed scaling ratio of 1.97 and the ITU-R attenuation dependent scaling ratio are plotted for comparison.

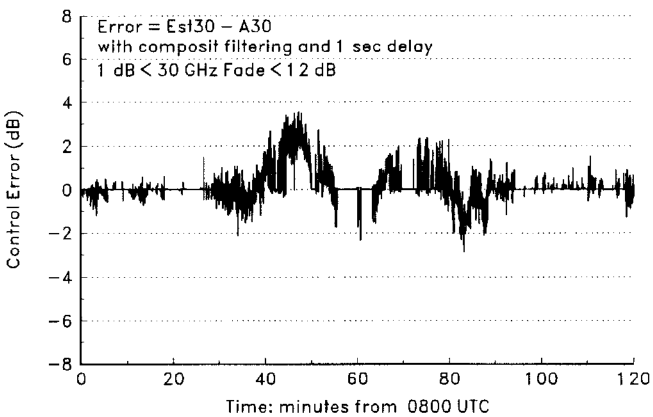

Fig. 9. April 15, 1991 event showing scale factor change during the event.

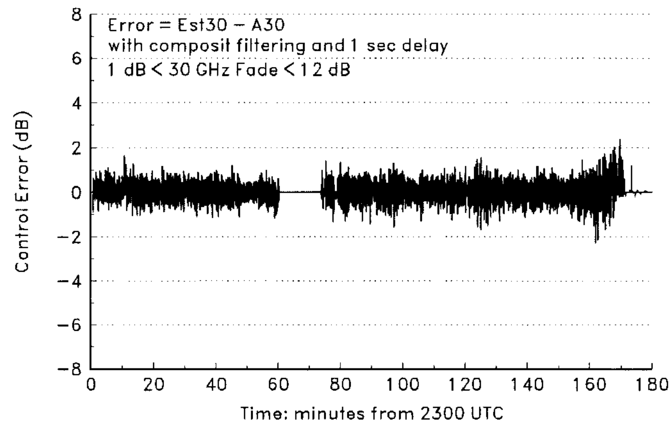

Fig. 10. Control error: 30 GHz predicting 30 GHz for November 5 through 6, 1990. Event attenuation is plotted in Fig. 1.

For some events, the scaling factor is not constant during the event. The attenuation that results from a convective rain event may be different from the attenuation that results from a thunderstorm event even though the rain rate in each event is the same. The reason for this is that drop size distributions are different in the two events. The distributions can also change during an event [7]. An example of this effect can be seen in the April 15, 1991 event shown in Fig. 9. The optimum scale factor for this event is 1.85, which is not far removed from the 1.93 composite scale factor, but during part of the event composite scaling under predicts and during another part of the event it over predicts. This change during the event suggests that the analysis of [7] may be somewhat simplistic in implying that the scaling factor is constant for attenuations less than 6 dB at 20 GHz. However, these changes do not appear to be great enough to prevent downlink scaled attenuation from successfully driving an ULPC algorithm.

Fig. 10 shows the error that results from uplink attenuation predictions obtained using a beacon at the uplink. Typical of this type of ULPC, the mean error is zero and the rms error is a result of uncompensated scintillations.

VII. Summary of the ULPC Experiment

ULPC can be implemented with scaled downlink attenuation data if the dynamic range of the power control is limited to approximately 10–12 dB. The observed scaling factor for a number of events is relatively constant for most storms, but there appears to be significant differences in real-time scaling factor from storm to storm despite the fact that the average observed scaling factor of 1.93 agrees closely with the 1.97 ITU-R derived statistical scaling factor.

Water vapor and oxygen attenuation do not appear to be significant factors, although this bears additional study due to the potentially large error caused by water vapor attenuation. Because of the separate antennas used in the Virginia Tech OLYMPUS experiment, it was not possible to compensate for scintillations. A simple IIR low-pass smoothing filter was implemented to reduce the impact of scintilations.

Twenty-six events totaling 66 h of attenuation data were examined. Optimum scaling factors and filter bandwidths were calculated for each event and a time weighted average scale factor and bandwidth were calculated for the event set. Filtering improves the algorithm performance in almost all cases, but some loss of performance occurred due to use of the composite scaling factor. The type of error varied from event to event. Some events suffered more from incorrect scaling, while scintillation was a major source of error in others.

Uplink attenuation was estimated by scaling downlink attenuation data, and this attenuation was used to drive an ULPC algorithm. In addition, uplink attenuation obtained from a 30-GHz beacon at the uplink frequency was used to drive the ULPC algorithm. The 30-GHz beacon driven ULPC offers significantly better performance than scaled downlink attenuation driven ULPC.

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Dennis G. Sweeney (M'96) received the B.S. degree (electrical engineering) from Virginia Tech, Blacksburg, VA, the M.A. degree from Catholic University of America, Washington, DC, and the M.S. and Ph.D. degrees (electrical engineering) from Virginia Tech, in 1972, 1975, 1986, and 1992, respectively.

He is currently a Research Assistant Professor with the Center for Wireless Telecommunications CWT) at Virginia Tech. His current interests include ISM band spread spectrum wireless applications, wireless propagation issues, radio frequency circuit design, and satellite systems. Previously, he worked with the Virginia Tech Satellite Communications Group from 1984 to 1992, where he was involved in radar and beacon measurement of satellite slant path propagation. He was also worked at Jet Propulsion Laboratories, Pasadena, CA, with global positioning systems applications.

Charles William Bostian (S'67–M'67–SM'77–F'92) was born in Chambersburg, PA, on December 30, 1940. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from North Carolina State University, Raleigh, in 1963, 1964, and 1967, respectively.

After a short period as a Research Engineer with Corning Glassworks, Corning, NY, and two years of service as a U.S. Army officer, he joined the faculty at Virginia Tech, Blacksburg, VA, in 1969 and is currently a Clayton Ayre Professor of electrical engineering. From 1972 through 1988 he headed Virginia Tech's Satellite Communication Group. Since 1993 he has directed the University's Center for Wireless Telecommunications (CWT), which helps create new products and services for the State's employers. He is the coauthor of *Solid State Radio Engineering* (New York: Wiley, 1980) and *Satellite Communications* (New York: Wiley, 1986). His primary research interests are in satellite and wireless telecommunications, RF design, and in the interactions of technology and business.

Dr. Bostian is a former chair of the IEEE-USA Engineering R&D Policy Committee. He has served as Associate Editor for IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION. His teaching has been recognized by a number of awards and he is a member of the Virginia Tech Academy of Teaching Excellence. During the calendar year 1989, while on leave, he was as an IEEE Congressional Fellow on the staff of Representative Don Ritter, working on legislative issues related to the U.S. electronics industry and economic competitiveness.