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Automatic Carrier-in-Carrier Power Control: Increased Link Margin and Availability in Carrier-in-Carrier Links

A technical description of Automatic Carrier-in-Carrier Power Control (ACPC) and its ability to increase effective link margin and availability in a Carrier-in-Carrier link.

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1. Abstract

Satellite networks are subject to channel degradations due to rain and other environmental factors. In order to ensure a target link availability, network designers must be aware of the rain region (equivalently the probability of given amounts of rain loss occurring) on both sides of a link, and design the terminals and operating point to include the required link margin.

Satellite network operators typically lease power equivalent bandwidth (PEB) from satellite owners. In clear sky operation, the terminals on both sides of the link transmit with radio frequency (RF) power on the ground such that they utilize the PEB on the satellite that has been assigned to that link. The presence of rain or other environmental attenuation (such as dust) lowers the RF power received at the satellite relative to clear sky conditions. In principle, terminals with sufficient RF power could increase their transmit power during rain loss conditions to compensate for the loss, and maintain the PEB on the satellite.

However, with traditional links that are not utilizing DoubleTalk® Carrier-in-Carrier® (CnC) technology, the modems themselves cannot in general automatically compensate for rain loss because the modems do not have enough information to determine which side of the link the rain loss is occurring. With traditional non-CnC links, proper implementation of rain loss compensation is a more complex system level function. For this reason, rain loss compensation is not often implemented in practice in traditional links.

Comtech's patent-pending Automatic Carrier-in-Carrier Power Control (ACPC) mechanism solves the power control optimization problem in a very general way for CnC links. It provides a unique opportunity for modems on both sides of a CnC link to automatically measure and compensate for rain loss while maintaining a fixed PEB on the satellite during all conditions. In addition to automatically compensating for rain loss, ACPC also enables CnC modems to share link margin between modems (i.e. a modem experiencing clear sky conditions can effectively give excess link margin to a distant end modem experiencing rain conditions, thereby further enhancing overall availability). This feature is implemented using values measured by the modems and general rain model knowledge (i.e. a system level implementation is not required).

The net effect of ACPC technology is a significant increase in effective link margin and availability for CnC links while ensuring no increase in the PEB at the satellite.

2. ACPC Overview

A broad objective of any satellite link is to maximize the link availability under all operating conditions, respecting the antenna gain, Effective Isotropic Radiated Power (EIRP), and other constraints associated with the ground equipment, as well as the PEB constraints of the satellite. Comtech's patent-pending ACPC technology meets this objective in a very general way over a wide range of operating conditions.

In a typical CnC link, two terminals make a point-to-point connection through a satellite. CnC technology allows the terminals on each end of the link to share the same satellite bandwidth. Figure 1 illustrates this situation.

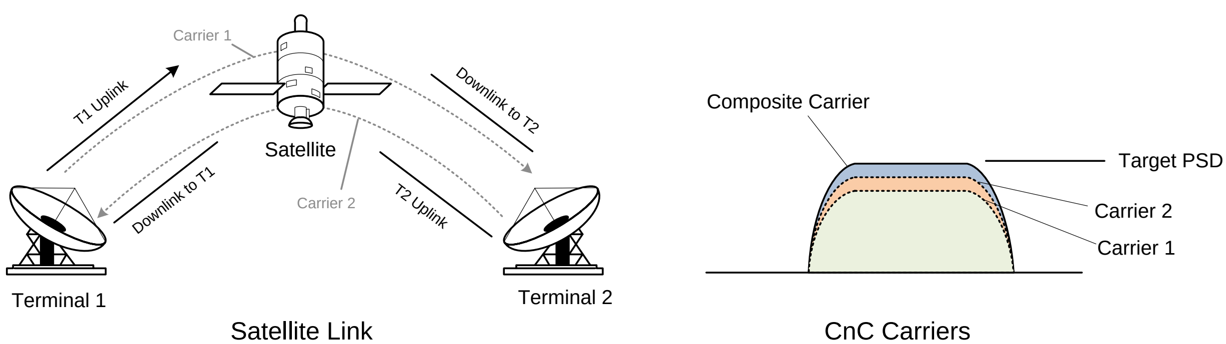

Figure 1: Point-to-Point Carrier-in-Carrier Satellite Link

Since the two carriers share the same bandwidth, the Carrier 1 and Carrier 2 signals are combined at the satellite into a Composite Carrier. The Composite Carrier has a power spectral density (PSD) that is the sum of the PSDs of the two input carriers. Network service providers lease power equivalent bandwidth (PEB) on satellite from satellite owner/operators. The PEB of the Composite Carrier is directly related to its PSD (i.e. the Composite Carrier is using its allotted PEB if and only if it is operating at the target PSD). From the standpoint of leased bandwidth costs, only the PEB/PSD of the composite carrier is important. The network service provider is free to allocate the relative powers of Carrier 1 and Carrier 2 whatever way is desired, as long as the PSD of the composite carrier is equal to the target PSD.

Environmental factors such as rain affect the power levels and signal-to-noise ratios (SNRs) of the carriers received at the satellite, and at the ground terminals. In general, rain can occur on either side of the link, and when present, affects both the uplink and downlink on each side. This is illustrated in Figure 2.

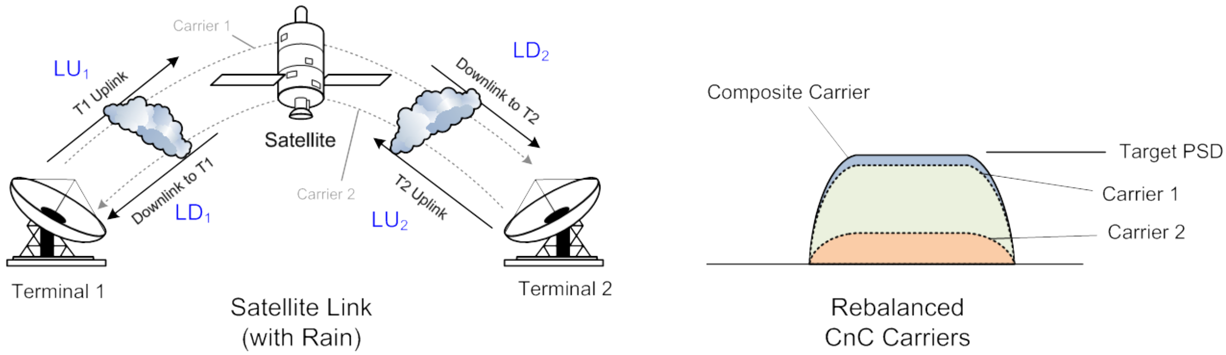

Figure 2: Point-to-Point Satellite Link with Rain

On a given side of the link, when rain (or other environmental loss such as dust) is present, attenuation is caused in both the uplink and downlink paths. The downlink path experiences additional SNR loss due to increased sky noise temperature due to rain. The total uplink and downlink loss factors on the Terminal 1 side of the link are shown as LU_1 and LD_1 in Figure 2. On the Terminal 2 side, these factors are LU_2 and LD_2.

In a traditional non-CnC link, in general the link modems alone do not have enough information to uniquely determine the loss terms LU_1, LD_1, LU_2, and LD_2. However, in a CnC link, each modem receives and processes a downlink composite carrier containing both carriers. In this case, the modems have sufficient information to uniquely determine and track changes to each of the loss terms. A key aspect of the ACPC algorithm is making measurements on both sides of the link to make an accurate determination of LU_1, LD_1, LU_2, and LD_2. In order to make this determination, modems share information with each other via a low overhead (0.5%) modem-to-modem communication channel.

Once the loss terms are known, the ACPC algorithm compensates for the loss terms in two steps. First, the modems can compensate for the uplink loss factors LU_1 and LU_2 by increasing the transmit RF power appropriately on each side of the link, within the constraints of the available terminal RF power. This maintains constant PEB on the satellite, and eliminates the detrimental effect of LU_1 and LU_2.

Because of the presence of downlink losses LD_1, and LD_2, simple compensation of uplink attenuation may not optimize the overall link availability. In order to optimize availability, in the second step the modems rebalance the link by changing the relative transmit power of each modem, while keeping the PEB on the satellite constant. Figure 3 illustrates the ACPC algorithm logic flow.

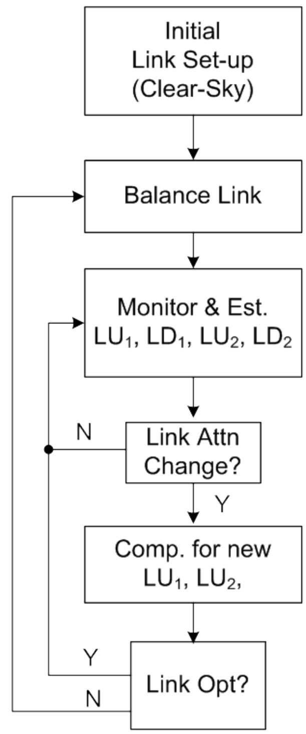

Figure 3: ACPC Logic Flow Diagram

3. ACPC Affect on Link Availability

ACPC dramatically improves overall link availability. Exact quantification of the net affect depends on link parameters of the specific terminals and satellite. Worst case (i.e. minimum possible) improvement can be characterized as a function of parameters that are known or can be readily measured or calculated for a given link. The most important parameters in determining the minimum improvement in link margin include:

a. Clear-sky link margin
b. Clear-sky Carrier-in-Carrier ratio, "R"

Clear Sky Link Margin: This is the link margin achieved in clear-sky conditions with the given satellite and ground terminal equipment. This can be estimated by standard satellite link calculation tools, and/or measured directly in operation. For optimal satellite utilization, the clear-sky link margin corresponds to the link margin achieved at each terminal when the PEB on the satellite is equal to the occupied bandwidth.

CnC Ratio: The CnC ratio R is illustrated in Figure 4.

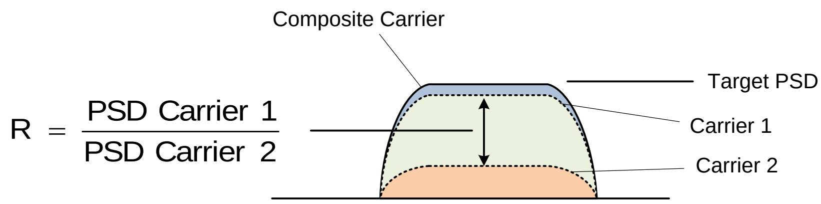

Figure 4: CnC Ratio in Composite Carrier

During the initial link set-up, the clear-sky link margins for each terminal should be set equal to each other. The ratio of carrier PSDs that makes the link margins equal at each terminal is the clear-sky CnC ratio, R. In the case where the terminals have equal antenna sizes, use the same modulation/FEC operating modes, and have satellite parameters such as G/T and EIRP that are equal towards each terminal, the expected value of R = 0 dB. That is, in this “symmetric” case, the PSD levels at the satellite that result in a given margin are the same for each terminal.

However, it is important to note that parameters such as different sized terminal antennas on the ground, and/or different satellite G/T and/or EIRP towards each terminal can make the optimal clear sky value of R not equal to 0 dB. Typical clear-sky R values are in the range of ± 3 dB for most practical systems, and can be calculated by using link budget analysis tools, and/or measured directly from the modems during the initial link set-up.

Table 1 shows the minimum Ku-band link margin improvement realized by using ACPC over a range of typical values of clear sky link margin, and clear sky CnC ratio. Table 2 shows the same data for Ka-band operation. Depending on which side of the link the rain is occurring and other factors, the ACPC link margin improvements will often be greater than shown in Table 1 or Table 2. However, these tables represent the deterministic minimum improvements that will be realized over any operating condition in the bands of interest.

R (dB) Clear Sky	Link Margin (dB) Clear Sky T1/T2	Weather	Minimum Link Margin Improvement (dB)
0	4	Rain T1 or T2	2.05
0	5	Rain T1 or T2	2.26
0	6	Rain T1 or T2	2.43
0	7	Rain T1 or T2	2.55
0	8	Rain T1 or T2	2.65
0	9	Rain T1 or T2	2.73
± 3	4	Rain Worst Case Side	1.14
± 3	5	Rain Worst Case Side	1.28
± 3	6	Rain Worst Case Side	1.38
± 3	7	Rain Worst Case Side	1.47
± 3	8	Rain Worst Case Side	1.53
± 3	9	Rain Worst Case Side	1.58

Table 1: Minimum ACPC Link Margin Improvements (Ku-Band)

R (dB) Clear Sky	Link Margin (dB) Clear Sky T1/T2	Weather	Minimum Link Margin Improvement (dB)
0	8	Rain T1 or T2	5.8
0	10	Rain T1 or T2	6.4
0	12	Rain T1 or T2	7.0
0	14	Rain T1 or T2	7.6
0	16	Rain T1 or T2	8.2
0	18	Rain T1 or T2	8.8
± 3	8	Rain Worst Case Side	4.2
± 3	10	Rain Worst Case Side	4.8
± 3	12	Rain Worst Case Side	5.4
± 3	14	Rain Worst Case Side	6.0
± 3	16	Rain Worst Case Side	6.6
± 3	18	Rain Worst Case Side	7.2

Table 2: Minimum ACPC Link Margin Improvements (Ka-Band)

As seen in Table 1 and Table 2, for given values of clear sky Link Margin and CnC Ratio the net effect of the ACPC is different depending on the satellite frequency band of operation. This is because the rain models have different characteristics in these different bands.

In any band, rain causes signal attenuation in both the uplink and downlink directions. The uplink frequency is higher than the downlink frequency in satellite communications, and this leads to an uplink attenuation that is higher than the downlink attenuation. However, rain also causes additional downlink degradation due to the increase in sky noise temperature due to rain and clouds.

In the Ku-band, transmit and receive frequencies are relatively close together, and this leads to a downlink attenuation that is a significant fraction of the uplink attenuation. When the ITU rain model is considered, the additional effect of increased sky noise temperature makes the overall downlink degradation due to rain higher than the uplink degradation. When considering the minimum possible ACPC improvement, this means that for Ku-band the main advantage of ACPC comes from the ability of the ACPC system to share margin between terminals (i.e. give extra margin to the downlink on the side where it is raining).

In Ka-band, the uplink and downlink frequencies are spaced further apart. The uplink attenuation is therefore significantly higher than the downlink attenuation, and overall uplink degradation to SNR is larger than the downlink degradation, even when the increase in downlink sky noise temperature is considered. In the Ka-band case, ACPC provides benefits from both significantly increasing uplink power, and from margin sharing. This leads to a bigger overall benefit at Ka-band frequencies.

4. Conclusions

ACPC is a powerful tool that enables yet another significant step forward in performance of satellite communications systems. As seen in Table 1 for Ku-band networks, for Terminals that have asymmetric satellite link parameters, leading to an optimal clear-sky CnC Ratio of up to $\pm$ 3 dB, ACPC always adds at least 1.0 dB of link margin. For comparison, 1.0 dB performance improvement is roughly the same as the performance improvement between older Turbo Product Code (TPC) forward error correction (FEC), and the latest state-of-the-art Low Density Parity Check (LDPC) FEC. For symmetric, or nearly symmetric links, where $R \cong 0$ dB, ACPC adds at least 2.0 dB of link margin. This is roughly equivalent to the performance difference between LDPC FEC and even older FEC based on Viterbi Reed Solomon algorithms. Symmetric or nearly symmetric links are the most common in practical CnC applications.

As seen in Table 2 for Ka-band networks the ACPC improvement is even higher, in the range of 4 to nearly 9 dB. For Ka-band networks, ACPC increases link margin by roughly 50%.

ACPC optimizes link margin and link availability over all operating conditions, and represents yet another step forward in performance optimization of satellite links. Contact us for additional information on how ACPC can benefit your network.

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