Consideration on Uplink Interference by 5G in LEO Downlink for Bent-Pipe System

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Bent-Pipe 시스템인 LEO 다운링크에서 5G 에 의한 업링크 간섭에 관한 고찰

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Abstract

This paper shows that uplink interference from 5G is a non-negligible contributor to downlink degradation in bent-pipe LEO systems. Through analytical modelling and preliminary link-level evaluation, it is demonstrated that terrestrial leakage into the LEO uplink can be amplified and forwarded to multiple users within the satellite's downlink footprint. The results highlight that future LEO interference studies need to incorporate uplink-to-downlink interference propagation when bent-pipe payloads are involved, rather than focusing exclusively on the downlink leg.

Ⅰ. Introduction

Non-terrestrial networks (NTN) have become a key component of 5G-advanced and 6G, enabling wide-area coverage, service continuity, and resilient communication in underserved regions. In current 3GPP NTN specifications, low Earth orbit (LEO) satellites typically operate using one of two payload architectures: bent-pipe or regenerative [1]. Although both architectures rely on the ground-based core network to generate and route user data, they differ fundamentally in how they handle radio signals. Regenerative satellites demodulate, decode, and regenerate the waveform before downlink transmission, effectively removing uplink interference. In contrast, bent-pipe satellites perform only frequency translation and amplify-and-forward, forwarding any received signal, including interference, directly to the ground user.

Most existing coexistence studies between 5G terrestrial networks (TN) and NTN focus on downlink interference, analysing how 5G base stations may disrupt the LEO-to-user link through adjacent-band emissions, blocking, or co-channel operation. However, this downlink-centric viewpoint overlooks a critical interference path unique to bent-pipe architectures: uplink interference originating from 5G terrestrial transmitters may be captured by the satellite on its feeder-link uplink, amplified on board, and then forwarded into the LEO downlink footprint.

This observation has important implications. First, interference seen in the LEO downlink is not solely a result of direct terrestrial-to-user coupling, but may also include interference that first entered the satellite through the uplink. Second, the degree of forwarded interference depends on aggregate 5G gNB emissions, antenna sidelobe behaviour, the satellite's receive beam pattern, and the bent-pipe payload gain—factors that are often ignored in existing analyses. Third, because regenerative satellites may remove uplink interference but bent-pipe satellites do not, interference analysis for NTN must distinguish these two architectures, especially in spectrum-sharing scenarios between 5G and NTN.

Ⅱ. System Model

This section describes the modelling framework used to quantify how terrestrial 5G interference entering the LEO uplink of a bent-pipe satellite system is forwarded to the downlink user [2]. The analysis is implemented using a Simulink-based bent-pipe interference model. As depicted in Fig. 1, the system consists of a ground station transmitting the desired NTN uplink waveform, a terrestrial 5G interfering transmitter whose emissions leak into the LEO uplink band, a bent-pipe repeater satellite, and a ground UE receiving the forwarded downlink signal.

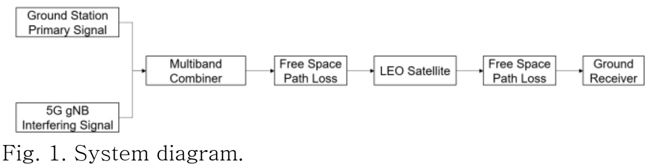


Fig. 1. System diagram.

The desired NTN uplink signal and terrestrial 5G interfering signal are generated as independent baseband waveforms. To efficiently combine these signals at baseband while allowing arbitrary frequency offsets, the model uses the Multiband Combiner block.

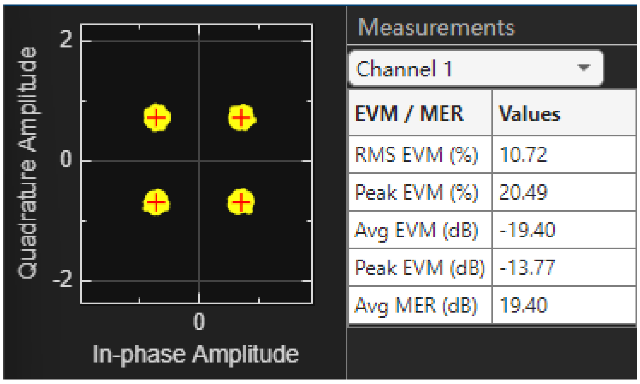
By adjusting the frequency offsets parameter, we simulate different levels of spectral overlap. Representing different severities of terrestrial interference entering the LEO uplink. The combined uplink waveform is passed through a bent-pipe satellite subsystem that performs uplink reception, frequency translation, transponder HPA amplification, downlink frequency shift, and transmission to the ground receiver. Since the payload is transparent, the LEO satellite forwards the interference with the same linearity as the desired signal. Finally, the ground UE receives the downlink signal containing both the desired waveform and any amplified terrestrial interference. The receiver performs downconversion and filtering, QPSK demodulation, error rate measurement, and error vector magnitude (EVM) computation.

Although the Simulink model uses simplified baseband waveforms for clarity, the underlying mechanism directly corresponds to real-world NTN operation. Specifically, terrestrial 5G emissions leaking into an NTN uplink band will be captured by the LEO satellite, and bent-pipe satellites will amplify and forward this interference into the downlink beam. Hence, users within the footprint will observe degraded SINR and performance.

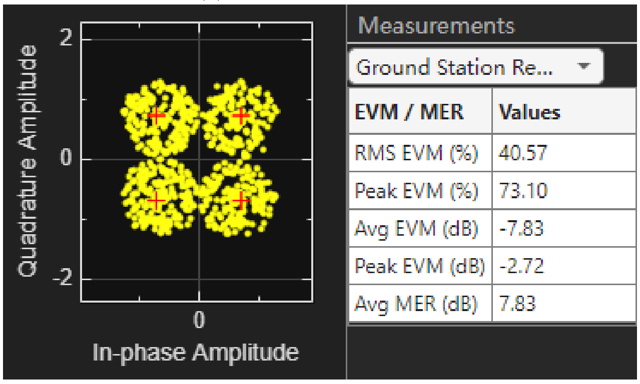
Ⅲ. Numerical Results

As depicted in Fig. 2(a), the reference state exhibits robust modulation quality. An average MER of -19.40 dB and an RMS EVM of 10.72% are indicative of a healthy SINR sufficient for stable QPSK demodulation. The constellation points are tightly clustered around their ideal locations, signalling minimal noise or distortion. However, upon coupling of the uplink interference, the modulation quality collapses. As shown in Fig. 2(b), the average MER plummets by approximately 11.57 dB to -7.83 dB, signifying that the interference power now dominates the link budget, making the system strongly interference-limited. The constellation diagram visually corroborates this failure; the clusters are highly diffused and scattered, with the RMS EVM soaring to 40.57%. This EVM level is characteristic of a highly impaired channel where the margins for reliable symbol detection are almost completely eliminated. This degradation significantly impacts the 5G system's ability to utilise Adaptive Modulation and Coding (AMC). 5G systems rely on AMC to maximise spectral efficiency by dynamically shifting to higher-order modulation schemes, e.g., 64-QAM, when link conditions are favourable. The simulation results demonstrate that the fundamental QPSK modulation, the most robust offered, fails dramatically (7.94 dB MER). This eliminates the system's capacity to deliver required broadband services, e.g., 50 Mbps+ , and forces an effective return to zero spectral efficiency (link outage).

Additionally, in the reference scenario, the error rate calculation shows zero errors for 500400 bits transmitted, resulting in a raw BER that is effectively zero. This confirms an error-free or near-error-free channel environment. However, in the interfered state, 604 errors are recorded over the same number of bits, resulting in a raw BER of 1.207×10^{-3}. This represents a catastrophic performance failure. Modern telecommunication standards require post-FEC BER performance typically lower than 10^{-6}. This would immediately overwhelm the processing capacity of most standard FEC coding schemes, leading to a massive increase in unrecoverable block errors and retransmissions.



(a) Reference state.



(b) Received at the ground receiver.

Fig. 2. Signal constellation.

IV. Conclusion

Through modelling and Simulink-based link-level evaluation, we showed that terrestrial leakage entering the NTN uplink is transparently amplified and forwarded by the satellite, resulting in substantial reductions in MER, severe EVM deterioration, and non-negligible BER at the ground user. These results confirm that downlink interference analysis cannot be treated independently of uplink interference in bent-pipe NTN architectures. Future NTN coexistence studies and spectrum-sharing evaluations should therefore incorporate uplink-to-downlink interference coupling to ensure accurate assessment of user-side performance and system robustness.

REFERENCES

[1] *Study on New Radio (NR) to Support Non-Terrestrial Networks*, 3GPP TR 38.811, V 15.4.0, Sept. 2020.

[2] T. M. Braun and W. R. Braun, "Introduction," in *Satellite Communications Payload and System*. IEEE Press, NJ, USA: Wiley, 2021, pp. 45 – 55.