Exploring Multi-Connectivity in 6G Using mTRP for GEO Satellites

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Abstract—**The present paper studies the viability of the multi-TRP strategy of 6G for providing reliability, capacity and throughput to the users located at the cell-edge. Specifically, it is considered the use case of two GEO satellites acting as TRPs that serve a VSAT terminal equipped with multiple antennas. The GEO satellites have regenerative capability, and may use precoding techniques to improve the capacity of the system. However, they do not know the channel of the other satellite since Non-Coherent Joint Transmission (NC-JT) has been followed. To develop the detecting and decoding techniques for the multi-TRP GEO satellites, it has been identified the following scenarios when two packets are transmitted from GEO satellites: i) the two packets arrive simultaneously at the same time slot of the receiver (i.e., coherent), ii) the two packets arrive at the same time-slot but with a time-shift (i.e., non-coherent), and finally iii) the two packets arrive at different time slots. The technique of Packet Duplication (PD) has been used to increase the resilience of the communications. For all three cases it has been considered the slot that the two packets arrive at to compute the final throughput, capacity and spectral efficiency. Results consider the different values of TBS, code rates and modulations for the PDSCH channel. Finally, recommendations for the different use cases are provided to update the current 5G NR to 6G to fully support multi-TRP technology over satellite.**

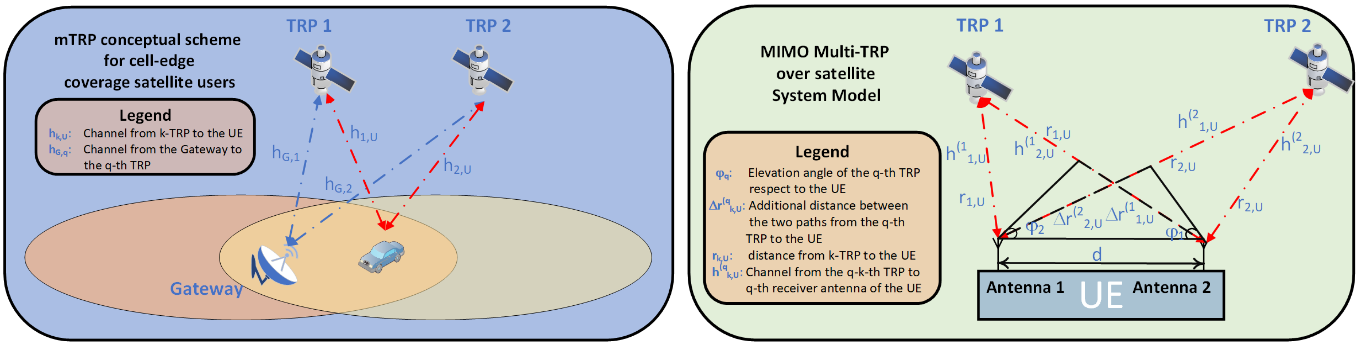
I. Introduction

In 5G NR the integration of terrestrial and satellite networks is key component to the so-called 3D networks. Toward this regard satellite networks are being designed to support multi-band, multi-orbit and multi-satellite connectivity. Thus the devices will be able to connect to multiple base stations simultaneously to support multi-connectivity strategies, which will permit to improve: i) *the coverage in areas with substantial level of inference*, ii) *the capacity to access a greater number of network resources* to allocate more users, iii) *the reliability since it provides redundancy and robustness against network failures* by allowing the devices to keep the connectivity to multiple paths and iv) *to support advanced services such as ultra-reliable low latency communications (URLLC), and mission critical applications* which require a large reliability and low latency. Toward this regard, 3GPP supports the following types of multi-connectivity: i) *Carrier Aggregation*, ii) *Multi-Rate Dual Connectivity*, and iii) *multi-TRP transmission and reception*, formerly named Coordinated Multi-point (COMP) in 4G [1].

From the three multi-connectivity techniques that support 5G NR, this paper will focus on the multi-TRP one. *multi-TRP, mTRP,* enables 5G gNodeB (gNB) base stations to use more than one transmission and reception point (TRP) to communicate with user equipment (UE). By doing so, mTRP helps the carriers to optimize the network performance and robustness [2]. This is especially useful for 5G mmWave broadband communications over satellite. It is well-known that the larger the frequency, the higher the atmospheric impairments. Then, the use of multiple TRPs permits to reduce the risk of potential fading in the desired information introduced by the satellite channel. These satellites may be in the same orbit or different. Nevertheless, the transmission via multiple TRPs with different delays has to take care that packet reordering techniques may be needed at the destination [3].

mTRP supports two strategies Coherent-Joint Transmission (C-JT) and Non-Coherent Joint Transmission (NC-JT) [1]. The mTRP C-JT requires that multiple Transmission Points (TP) transmit the same data with appropriate precoding/beamforming weights. This calls for a full PHY layer to control multiple RF chains/antennas [4]. Therefore, unified MAC and High PHY layers are required. On the contrary, the mTRP NC-JT scheme corresponds to the transmission scheme where transmission of the MIMO layer(s) is performed from two or more transmission points (TPs) without adaptive precoding across the TPs [5]. From both, it has been selected the mTRP with NC-JT for its capability to coordinate coverage and improve performance for cell-edge users such as the expected situations for mobile VSAT. This technology improves coordination and connectivity even in difficult-to-reach regions.

Specifically, it will apply mTRP strategy to two GEO satellites in a single-band configuration to offer service continuity for Mobile VSAT. The primary goal is to ensure that communication stays steady and smooth for mobile users even in difficult circumstances or events that may destroy a single satellite link, with a particular emphasis on the edge coverage area between the two GEO satellites [6]. In these locations, the UE receives lower strength information from the base-station and suffers a higher level of inter-cell interference from neighboring cells [7]. Thus, the employment of multiple independent links by using multi-TRPs augments the robustness of the communications from blockages and beam failures, especially at higher carrier frequencies (e.g. mmWave), which suffer larger attenuation due to atmospheric conditions (e.g. rain, clouds, etc) [8]. By doing so, the use of



(a) (b)

Fig. 1: *a) Conceptual Figure Multi-TRP with two GEO satellites b) MIMO System Model for two GEO satellites using mTRP multi-connectivity*

mTRP removes the cell-edge effect.

Apart from determining the transmission technique for mTRP, two additional considerations are crucial: the choice of functional split and the packet operation mode. The mTRP NC-JT relies on a unified MAC and High-PHY, necessitating coordination and synchronization from the on-ground CU to ensure data delivery. Lower layer split options favoring centralized processing at the CU, such as split options 1-6, 7.3, and 7.2, offer advantages in terms of coordination and synchronization between transmission points. In terms of packet operation mode, 5G-NR supports Packet Splitting (PS) and Packet Duplication (PD). PS increases network throughput by splitting packets across multiple networks, while PD reduces data loss by simultaneously transmitting multiple copies of the same packet over different carriers, ensuring reliable communication. The paper's research innovations focus on defining possible scenarios at the UE when two GEO satellites transmit the same packet via PD and mTRP MC technique, specifying recovery techniques for each scenario, providing target metrics like Capacity, Throughput, and Spectral Efficiency, and offering recommendations to modify 5G-NR specifications for coherent transmissions at the UE. The paper's structure includes sections on problem statement, potential solutions, performance evaluation, and concluding remarks.

II. Problem Statement

A. Scenario Definition

Figure 1a shows the picture at system level for this paper. The UE and a gateway are connected via two GEO satellites using the same frequency band. Specifically, it will be considered that the frequency band that the two satellites transmit the information is the Ka band. This band suffers from important attenuation due to the presence of rain and clouds. So, the use of multiple satellites that may overcome this situation is a realistic assumption. In this case the satellite Ka band for GEO satellites is ranged in the following set of frequencies for the uplink (Earth-Space) [27.5-28.6, 29.5-30] GHz and for the downlink (Space-Earth) [17.8-18.6, 19.7-20.2] GHz. For the sake of simplicity this paper will be focused on the downlink and will take the PDSCH 3GPP channel as the basis for the signal model to evaluate the Multi Connectivity schemes. The carrier frequency to use will be the central frequency of the first set of possible frequencies, i.e., 18.2 GHz. The UE is a mobile VSAT located at the edge of the two GEO satellite beams.

B. Channel Model Definition

From Fig1b, $h_{k,U}$, denotes the channel from the k-th satellite to the User Equipment (UE). The UE is equipped with two antennas, where the channel received by both antennas only differs in phase due to the signal arriving at different time instants. The channel from the k-th GEO satellite to the second antenna of the UE for the n-th transmitted symbol can be formulated as:

$$h_{k,U}^{(2)}[n] = h_{k,U}^{(1)}[n]e^{j2\pi\frac{k}{\lambda}\Delta r_{k,U}^{(2)}} \tag{1}$$

The channel from the k-th GEO satellite to the first antenna of the UE encompasses atmospheric losses, pointing losses, free space losses, and small-scale fading losses. The received signal at the q-th antenna from the k-th mTRP GEO satellite is expressed as:

$$y_{k,U}^{(q)} = \sqrt{P_{R,k}}h_{k,U}^{(q)}[n]x_k[n] + w_{k,U}[n] \tag{2}$$

The transmitted power, $P_{T,k}$, is determined to meet specific link budget requirements. The transmitted signal is precoded since two satellites transmit information to the receiver. The precoder for the k-th mTRP GEO satellite, assuming zero-forcing technique, is:

$$P_{k,U}^{(q)} = \left(h_{k,U}^{(q)*}[n]h_{k,U}^{(q)}[n]\right)^{-1} h_{k,U}^{(q)*}[n] \tag{3}$$

The received signal at the q-th antenna from the k-th mTRP is then:

$$y_{k,U}^{(q)} = \sqrt{P_{R,k}}\exp(\varphi_{k,U}^{(q)})s_k[n] + w_{k,U}[n] \tag{4}$$

Here, $\varphi_{k,U}^{(q)}$ represents the phase shift due to the excess delay of the transmitted signal arriving at the second antenna relative to the first one.

C. Numerology of PDSCH

The mTRP transmission/reception system utilizes two satellites and analyzes the PDSCH channel of 5G-NR, supporting various modulations including QPSK, 16-QAM, 64-QAM, and 256-QAM. Low-density parity-check (LDPC) channel coding is employed for forward error correction (FEC), providing realistic values of the required E_b/N_o for the strategy. The protocol incorporates two block lengths at the input of the channel encoder: $K_1 = 2304$ and $K_2 = 8448$, with the latter being utilized. The transport block size (TBS) varies depending on the code rate employed. The subcarrier spacing in 5G-NR ranges from 15 kHz to 120 kHz, with $\Delta f = 15$ kHz considered for this study. Consequently, the symbol time is $T_S = 1/\Delta f = 66.67\mu s$. With 14 OFDM symbols transmitted in each slot, the normal CP duration for a subcarrier spacing of $\Delta f = 15$ kHz is $4.7\mu s$. Thus, the total slot duration is calculated as $T_{Slot} = 14T_{Symbol} = 933.33\mu s$ [9], [10], [11].

D. Antenna Beamwidth Model

UE Terminal may be equipped with multi-beam antennas or multiple antennas with beams electronically steered. Considering this latter case and assumming parabolic antenna with a wavelength λ and a dish size D, the 3dB beamwidth is determined by the formula: $\Delta BW_{3dB} = \frac{70\lambda}{D}$, [12]. Therefore, for a carrier frequency of 20GHz (downlink of satellite) and a dish size of $D = 1.5m$, the 3dB beamwidth of the parabolic antenna is calculated as:$\Delta BW_{3dB} = 4°$. Consequently, the total beamwidth at 3dB is doubled to $\Delta BW = 8°$. Hence, if the angular separation between the two satellites is less than 8°, both antennas receive packets transmitted from both GEO satellites. Conversely, if the angular separation exceeds 8°, each antenna receives packets from only one GEO satellite.

E. MC-mTRP scenarios with 2 GEO satellites

In all use cases is considered that the $mTRP_1$ GEO satellite transmits at the slot 0, the $mTRP_2$ GEO satellite transmits at the slot p, and the received packed from $mTRP_1$ at the UE is received at slot q. The received packet from $mTRP_2$ at the UE may change its reception slot. For the two first cases, it is received at the same time slot as the packet transmitted by the $mTRP_1$, i.e., slot q. However, for the third case, the signals from the two GEO satellites are received at the UE at different time slots. Specifically, they are received at the slots q and n respectively. Regarding the temporal information, it is denoted as $\tau_{k,U}$ the transmission delay for the transmission of the packet from the k-th mTRP GEO satellite to the User Terminal. The transmission delay between the two packets is denoted as $\Delta\tau_{1,2}$. Similarly, the delay between the time instant in which the two packets are received is formulated as $\Delta\delta_{1,2}$. The transmission-reception scenario for each case is the next:

1) <u>Scenario 1</u>*: The two signals received from the GEO satellites at the UE are received at the same time-slot and temporally aligned.* In this context, it is assumed that the two mTRP GEO satellites transmit the same packet to the User Terminal at different time slots, with both signals received simultaneously or with a very small-time difference between them. This scenario assumes $\Delta\delta_{1,2} \approx 0$, allowing for the summing of the two packets in phase. To accept this scenario, it is necessary to assume negligible or null speed of the user terminal and the ability of the satellite with the shortest slant path to the UE (mTRP2 GEO satellite) to compensate for different transmission paths by delaying its transmission time by $\Delta\tau_{1,2}$ units. This concept can be extended to scenarios with more than two mTRP GEO satellites, with the UE informing the satellites about the required delay via the PDCCH channel or directly transmitting the value of $\tau_{1,2}$. While similar to the time advance concept in 3GPP, this strategy focuses on temporal alignment of packets at the UE when transmitted from different sources, rather than synchronization between uplink and downlink frames.
2) <u>Scenario 2</u>. *The two signals received from the GEO satellites at the UE are received at the same time-slot but not temporally aligned.* In this scenario, the two packets transmitted from the two mTRP GEO satellites arrive at the same time slot but are not perfectly aligned. This results in a non-null time difference $\Delta\delta_{1,2}$ at the reception side, generating interference that needs to be removed. This scenario typically occurs when the UE exhibits mobility that may not be accurately predicted by tracking systems, leading to positional errors preventing coherent signal reception at the UE. It is assumed that both transmitted signals use the same polarization to increase system capacity.
3) <u>Scenario 3</u>. *The two signals received from the GEO satellites at the UE are received at different time-slots.* In this scenario, the two transmitted packets are received at different time slots, resulting in perfect recovery but decreased throughput due to the temporal misalignment. The time difference between the arrival of the two packets at the UE exceeds the duration of a slot. Different solutions for the multi-TRP use case are explored, as detailed in Section III. In all cases, it is assumed that the two GEO satellites transmit identical packets, employing a packet duplication strategy to reduce UE outage probability, particularly for mobile UEs located at the edge of the two GEO satellite beams.

III. Multi-TRP Solutions

The implementation of the mTRP solution requires combining signals received at the UE's antennas from multiple GEO satellites. This study examines a scenario where two satellites simultaneously transmit identical packets to a UE with two antennas, using packet duplication. Three main scenarios are considered for the arrival timing of these packets: simultaneous coherent arrival, misaligned arrival within the same time slot, and arrival in different time slots. To understand the proposed solutions for each scenario, signal combining techniques like MRC, SRC, and EGC are reviewed,

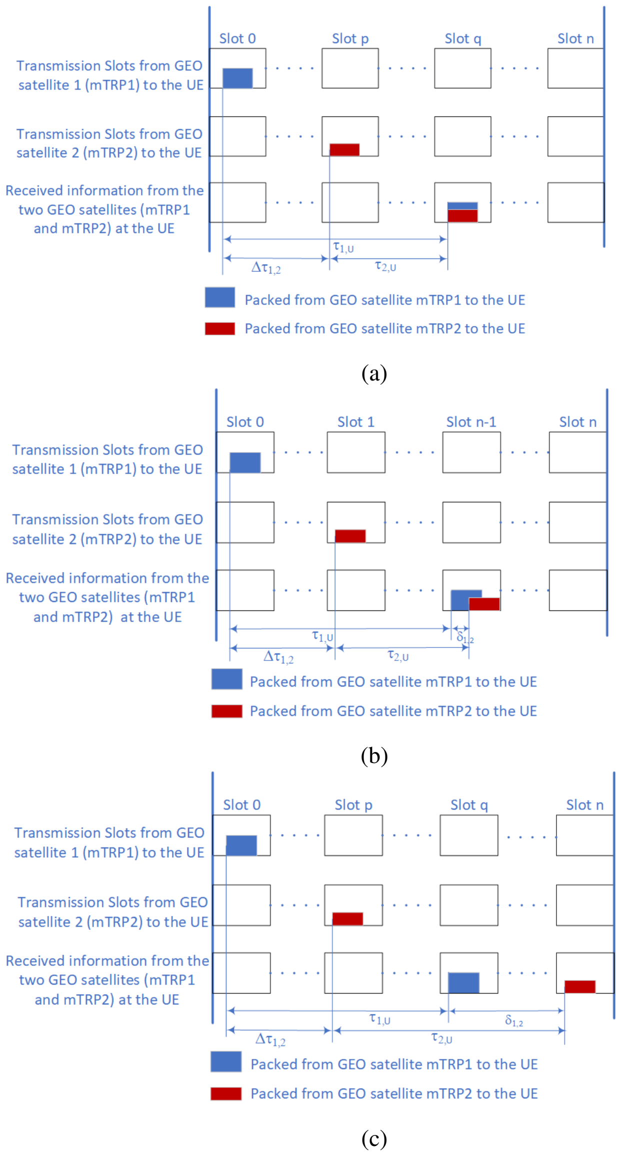


Fig. 2: (a) Scenario 1: Two packets arrive coherently at the same time-slot. (b) Scenario 2: Two packets arrive non-coherently at the same time-slots. (c) Scenario 3: Two packets arrive at different time-slots

considering how they integrate information and their informational requirements. Additionally, metrics such as outage probability, throughput, and capacity provided by these techniques are discussed.

A. Techniques for Combining Spatial Diversity Signals

In this context, the mTRP multi-connectivity technique requires arrays at the reception end. The receiver, with two antennas, receives the same packet from two GEO satellites, necessitating signal integration. For single received signals, techniques like MRC, SRC, and EGC are used to merge information. The fusion function is formulated as [13]:

$$z[n] = \sum_{q=1}^{M=2} w_q r_q^*[n] \tag{5}$$

where w_q is the weight normalizing the signal received at the q-th antenna. Two scenarios are considered: i) only one signal from a GEO satellite is received at the antennas, ii) signals from both satellites are received

1) Spatial Diversity Combining when a signal of GEO satellite is received at the two antennas.: Spatial Diversity Combining when a signal from a GEO satellite is received at two antennas. The combined signal $z[n]$ for the first scenario is formulated as:

$$z[n] = \sum_{q=1}^{M=2} w_q h_{k,U}^{(q)} e^{j\varphi_{k,U}^{(q)}} s[n] + \sum_{q=1}^{M=2} w_q \beta_q[n] \tag{6}$$

where $|h_{k,U}^{(q)}|$ and $\varphi_{k,U}^{(q)}$ represent the amplitude and phase of the channel from the k-th GEO satellite to the q-th antenna. $s[n]$ and $\omega_q[n]$ denote the n-th information symbol and noise value at the q-th antenna. The weights w_q for MRC, EGC, and SRC are defined. The combined expression can be simplified as:

$$z[n] = \omega s[n] s[n] + \rho[n] \tag{7}$$

where ω_s is the weight resulting from spatial filtering, and ρ is the resulting noise signal. $\omega_s[n]$ and $\rho[n]$ are expressed as $\omega_s[n] = \sum_{q=1}^{M=2} w_q h_{k,U}^{(q)} e^{j\varphi_{k,U}^{(q)}}$ and $\frac{\rho}{\sum_{q=1}^{M=2} w_q w_q^*}$, respectively. The signal-to-noise ratio γ after spatial filtering is defined as $\gamma = \frac{|\omega_s|^2 E\{\mathbf{s}^H \mathbf{s}\}}{E\{\rho^H \rho\}}$. Output noise power of the selection combining strategy matches input noise power since it uses information from one antenna. However, MRC and EGC impact output noise. MRC maximizes SNR by match filtering, while EGC averages all signals, requiring time and phase alignment. Table I shows the value of the weights w_q for the combining strategies of MRC, EQC, and SRC respectively.

Table I: Weights for the Spatial combining techniques

Spatial Combining	Expression of weights
MRC	$w_q = \left\| h_{k,U}^{(q)} \right\| e^{-j\varphi_{k,U}^{(q)}}$
EGC	$w_q = \frac{1}{M}$
SRC	$w_q = \begin{cases} 1, & h_{k,U}(q) > h_{k,U}(i) \text{ for all } i \\ 0, & \text{Otherwise} \end{cases}$

2) Spatial Diversity Combining when a signal of GEO satellite is received at the two antennas: Spatial Diversity Combining when a signal of GEO satellite is received at the two antennas. For the second scenario, if two signals impinge coherently at the antennas, the fusion signal for the different combining techniques is as follows [13]:

$$z[n] = \sum_{q=1}^{M/2} w_q \frac{1}{2} h_{k,U}(q) e^{j\varphi_{k,U}(q)} s[n] + \beta_q[n] = \sum_{q=1}^{M/2} w_q s[n] \tag{8}$$

At this point, we can decompose the summation of all channels to $\sum_{k=1}^{2}\left|h_{k,U}^{(q)}\right|e^{j\varphi_{k,U}^{(q)}}=\left|h_{U}^{(q)}\right|e^{j\varphi_{U}^{(q)}}$ where $\left|h_{U}^{(q)}\right|$ and $\varphi_{U}^{(q)}$ represent the amplitude and phase of the joint channel of the signals transmitted by the two GEO satellites. This scenario follows a similar decomposition as the previous one. The spatially combined signal is expressed as $z[n]=\omega s[n]s[n]+\rho[n]$, where ω_s is the weight of the information resulting from spatial filtering, and ρ is the resulting noise signal after filtering. Here, $\omega_s[n]$ and $\rho[n]$ are expressed as $\omega_s[n]=\sum_{q=1}^{M=2}w_q h_U(q)e^{j\phi_U(q)}$ and $\rho=\frac{\sum_{q=1}^{M=2}w_q}{\sum_{q=1}^{M=2}w_q w_q^*}$. Table II shows the value of w_q for MRC, EQC, and SRC respectively.

Spatial Combining	Expression of weights
MRC	$w_q=\left\|h_U^{(q)}\right\|e^{-j\varphi_U^{(q)}}$
EGC	$w_q=e^{-j\varphi_U^{(q)}}$
SRC	$w_q=\begin{cases}1, & h_U(q>h_U(i)) \text{ for all } i=0,\\ 0, & \text{Otherwise}\end{cases}$

Table II: Weights for different spatial combining techniques.

This scenario occurs when the angular separation between the two satellites is smaller than the antenna beamwidth. Two situations arise:

1) **Synchronization Unit**: The satellites undergo synchronization to align their transmitted signals. At reception, the signals can be received coherently, assuming the UE moves at low speed and a network clock ensures synchronization.
2) **Functional Splitting**: Functional splitting between the CU and DU separates signals from the two satellites. The joint channel from the satellites to the q-th antenna of the UE is expressed as $h_U^{(q)}[n]=h_{1,U}(q)e^{j\phi_{1,U}(q)\delta[n]}+h_{2,U}(q)e^{j\phi_{2,U}(q)\delta[n-\Delta\delta_{1,2}]}$ where $\Delta\delta_{1,2}$ is the time delay between the signals received from the two satellites. Depending on $\Delta\delta_{1,2}$, three scenarios emerge: coherent reception, misalignment, and reception at different time slots. Specifically:
   - If $\Delta\delta_{1,2}\approx 0$: The two signals are received coherently, and the joint channel is a flat fading channel. So, the joint channel is:
   $$h_U^{(q)}[n]\approx h_{1,U}(q)e^{j\phi_{1,U}(q)}+h_{2,U}(q)e^{j\phi_{2,U}(q)}e^{j\delta[n]} \tag{9}$$
   In this scenario, the use of FFT does not help to separate the two signals. However, as the two signals are aligned and are the same, the IFFT can be done either at the satellite or at the UE.
   - If $0<\Delta\delta_{1,2}<T_{Slot}$: The two signals overlap in a time slot. Strategies for separating are needed. The IFFT/FFT transform delays in the time domain lead to changes of phases in the frequency domain. So, the channel in the frequency domain will be:
   $$\begin{aligned}H_U^{(q)}[k]=&|H_{1,U}^{(q)}[k]|e^{j\phi_{1,U}[k]}\\&+|H_{2,U}^{(q)}[k]|e^{j\phi_{2,U}[k]}e^{j2\pi kN\Delta\delta_{1,2}}\end{aligned} \tag{10}$$
   Where N is the number of subcarriers. In this scenario, the use of functional splitting permits converting multipath fading in the time-domain to flat-fading channel in the frequency domain, simplifying the equalization process of the two signals. Guard bands in the IFFT have to be used.
   - If $\Delta\delta_{1,2}>>T_{Slot}$: The two signals are received at different time slots. So, only the signal from one satellite is present at the two antennas.

3) Metrics: Outage Probability: The implementation of multi-connectivity techniques necessitates the computation of metrics to measure the enhancements in capacity, outage, and throughput compared to single-connectivity transmission reception. In terms of metrics, the focus will be on evaluating the outage probability and throughput of the TBS packets. Received packets will be deemed erroneous if the CRC after LDPC decoding fails. In the case of receiving information at two different time slots, the following strategy will be employed: If the first arriving packet is correct, the decoding process for the second packet is not initiated. If the first arriving packet fails, it is combined with the second using MRC. If the CRC is successful in this case, the TBS packet is forwarded to upper layers. Otherwise, it is considered that the UE is in outage.

$$\begin{aligned}p(BLER<\gamma_T)=&\,p(BLER_{TBS,1}<\gamma_T)\\&\cdot p(BLER_{TBS,2}<\gamma_T)\end{aligned} \tag{11}$$

BLER of the first slot determines the outage probability. For single slot transmission:

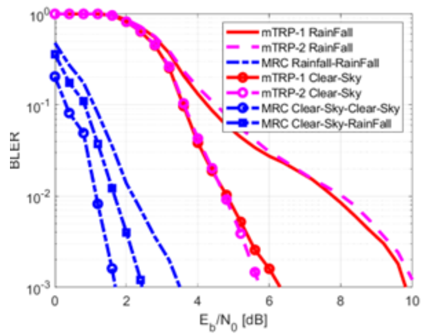
$$p(BLER<\gamma_T)=p(BLER_{TBS,MRC}<\gamma_T) \tag{12}$$

where $p(BLER_{TBS,MRC}<\gamma_T)$ is the BLER resulting from MRC. γ_T is the target BLER (assumed 10^{-3}).

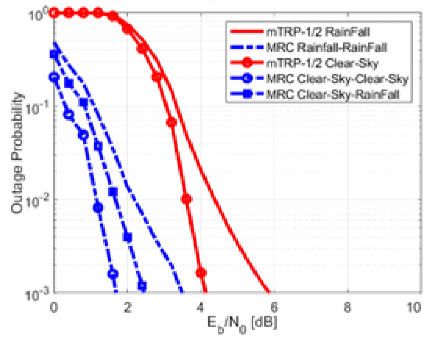
IV. Results

The simulations consider a downlink carrier frequency at 20 GHz with a carrier separation of 15 KHz, a LDPC-Belief Propagation-Soft decoder with 10 iterations, MRC technique is used. Weather conditions are Clear-Sky and Rain-Fall with corresponding rain rates of 0 mm/h and 130 mm/h. The target Block Error Rate (BLER) is set to 10^{-3}. The channel model involves Rician fading with Rician parameter $K=10$ and $K=20$ for two satellites located at longitudes 30° and 60°, respectively. Figure 3 shows the BLER, outage probability and spectral efficiency for the mTRP case. In Figure 3a possible to observe that the BLER of the single-mTRP under Clear-Sky and Rainfall conditions demonstrates a significant reduction in performance. However, with MRC, the performance of all systems improves notably. Even under rainfall conditions, the MRC combination ensures the achievement of the target BLER.

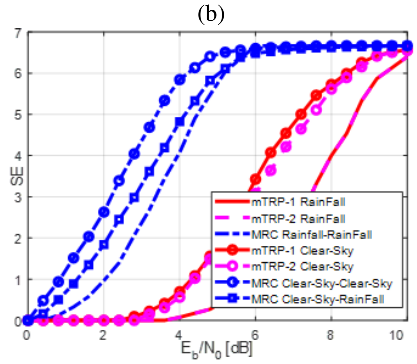
Figure 3b shows the outage probability of the mTRP case. In this scenario, if the first link (mTRP1) fails, the Cyclic Redundancy Check (CRC) of the second link (mTRP2) is checked independently. If the CRC of the second link



(a)



(b)



(c)

Fig. 3: BLER and Outage Probability for QPSK and code rate of 1/4 in (a) and (b); c) shows the spectral efficiency. Markers indicate the scenario: circles mean $MTRP_1$ and $MTRP_2$ in Clear-Sky, dashed lines for rain-fall, and square for $MTRP_1$ in Clear-Sky and $MTRP_2$ in rain-fall

is correct without being combined with the first one, the packet is forwarded to the Media Access Control (MAC) layer. Otherwise, both packets are incorrect and so the UE is in outage. The results show that the gains of the MRC system are approximately 2-3 dB in Clear-Sky conditions and between 3-5 dB in rainfall conditions respect to the single-link. Similar results are obtained when one of the links is affected by rain-fall conditions and the other is in Clear-Sky. The results demonstrate that leveraging diversity in satellite links significantly enhances resilience to atmospheric impairments. Finally, Figure 3c shows the spectral efficiency of the mTRP system. Note as the diversity in elevation angle permits to increase the spectral efficiency.

V. Conclusions

After studying mTRP for GEO is advocated for MRC to merge signals from different satellites and adopt functional split 7.2 to handle minor packet misalignment from multiple GEOs. This approach aligns with the multi-connectivity strategy in 3GPP TS 37.340 to maximize the resulting SNR. It entails connecting four key elements: gateway, two GEO satellites, and User Equipment (UE), with connectivity options. The proposal emphasizes transmitting the same packet from both GEO satellites. Time-Offset Computation and Reporting involve periodic System Information Block (SIB) broadcasts by the gNB to the UE for temporal alignment, leveraging GPS and UTC information. Functional Split 7.2 is recommended to manage time misalignment and packet collisions, using Inverse Fast Fourier Transform (IFFT) properties. The system impacts extend to the physical layer, control channels, and SIB.

VI. Acknowledgments

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References

[1] 3GPP, “TS 38.816 NR. Study on CU-DU Lower Layer Split for NR,” Tech. Rep. v.15.0, 2018.

[2] M. Khoshnevisan, K. Jayasinghe, R. Chen, A. Davydov, and L. Guo, “Enhanced reliability and capacity with multi-trp transmission,” *IEEE Communications Standards Magazine*, vol. 6, no. 1, pp. 13–19, 2022.

[3] M. S. J. Solaija, H. Salman, A. B. Kihero, M. I. SaÄlam, and H. Arslan, “Generalized coordinated multipoint framework for 5g and beyond,” *IEEE Access*, vol. 9, pp. 72 499–72 515, 2021.

[4] D. Lee, H. Seo, B. Clerckx, E. Hardouin, D. Mazzarese, S. Nagata, and K. Sayana, “Coordinated multipoint transmission and reception in lte-advanced: deployment scenarios and operational challenges,” *IEEE Communications Magazine*, vol. 50, no. 2, pp. 148–155, 2012.

[5] S. Varatharaajan, M. Grossmann, and G. Del Galdo, “5g new radio physical downlink control channel reliability enhancements for multiple transmission-reception-point communications,” *IEEE Access*, vol. 10, pp. 97 394–97 407, 2022.

[6] I. telecom, “A complete guide to vsat technology, https://iec-telecom.com/en/news/vsat-guide-plus-vsat-support-services/,” *IEEE Vehicular Technology Magazine*, 2021.

[7] L. Grieco and et al, “Ad-hoc, mobile, and wireless networks,” *Proc. on 19th International Conference on Ad-Hoc Networks and Wireless*, pp. 1–213, Oct. 2020.

[8] International Telecommunication Union (ITU), “Characteristics of precipitation for propagation modelling,” ITU-R, ITU-R Recommendation ITU-R Recommendation 837.7, 2019. [Online]. Available: https://www.itu.int/rec/R-REC-P.837.7-201910-I/en

[9] 3rd Generation Partnership Project (3GPP), “NR; physical channels and modulation; (release 17),” Technical Specification (TS) 38.211, 2021.

[10] ——, “NR; multiplexing and channel coding,” Technical Specification Group Radio Access Network, Technical Specification (TS) 38.212, January 2024, release 17.7.

[11] ——, “NR; physical layer procedures for data,” Technical Specification Group Radio Access Network, Technical Specification (TS) 38.214, January 2024, release 17.8.

[12] C. A. Balanis, *Antenna Theory: Analysis and Design*, 4th ed. Hoboken, NJ, USA: Wiley, 2016.

[13] M. Gans, “The effect of gaussian error in maximal ratio combiners,” *IEEE Transactions on Communication Technology*, vol. 19, no. 4, pp. 492–500, August 1971.