

# Advances on Multi-Transmission Reception Point over Non-Terrestrial Networks for 6G

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## Abstract

This paper explores user connectivity at the edge of satellite beams, focusing on very small aperture terminals (VSATs) that may exhibit varying velocities. All beams providing coverage operate within the same frequency band, leading to the adoption of the multi-transmission reception point strategy (mTRP) to serve these users. Under this strategy, the user equipment (UE) is concurrently linked to multiple new radio (NR) nodes transmitting identical information. In our investigation, a UE is connected to two geostationary Earth orbit (GEO) satellites, and we assess the performance of the physical downlink shared channel (PDSCH) in 5G-NR under this configuration. With both satellites transmitting the same packet, the probability of coverage outage due to UE mobility is reduced, as the UE transitions between the outer coverage areas of the two satellites. To enhance UE connectivity and minimize handovers, a packet duplication strategy is employed with the mTRP framework. Pre-coding techniques are utilized by both GEO satellites to mitigate channel effects, with each satellite adhering to a non-coherent mTRP strategy, meaning each channel retains only its own information. Simulation results are presented, and the implications of the findings are discussed.

## 1 Introduction

The integration of terrestrial and satellite networks is a crucial aspect of 5G NR's development, particularly for the advancement of 3D networks. Satellite networks are being engineered to offer multi-band, multi-orbit, and multi-satellite connectivity, enabling devices to connect to multiple base stations simultaneously. This facilitates the implementation of multi-connectivity strategies, which enhance coverage in interference-prone areas, increase network resource accessibility for more users, improve reliability through redundancy against failures, and support advanced services like ultra-reliable low latency communications (URLLC) and mission-critical applications. 3GPP endorses various types of multi-connectivity, including Carrier Aggregation, Multi-Rate Dual Connectivity, and mTRP transmission and reception (formerly known as Coordinated Multi-point in 4G) [1].

This paper focuses on the multi-TRP technique, one of the three multi-connectivity methods supported by 5G NR. The multi-TRP (mTRP) approach allows 5G gNodeB (gNB) base

stations to employ multiple transmission and reception points (TRPs) to communicate with user equipment (UE). This strategy enhances network performance and robustness by optimizing communication [2]. It is particularly advantageous for 5G mmWave broadband communications via satellite, where higher frequencies are subject to greater atmospheric impairments. Using multiple TRPs helps mitigate potential signal fading caused by the satellite channel. These TRPs may be located in the same orbit or in different orbits. However, when transmitting through multiple TRPs with varying delays, packet reordering techniques at the receiver may be necessary [3].

The multi-TRP (mTRP) technique encompasses two strategies: Coherent-Joint Transmission (C-JT) and Non-Coherent Joint Transmission (NC-JT) [1]. In the mTRP C-JT approach, multiple Transmission Points (TPs) send the same data using synchronized precoding and beamforming weights. This method necessitates a comprehensive Physical (PHY) layer setup to manage multiple RF chains and antennas, along with integrated MAC and High PHY layers [4]. This coordination ensures that all TPs work together to deliver coherent data streams to the user equipment (UE), optimizing signal quality and performance. Conversely, the mTRP NC-JT strategy involves transmitting data from multiple TPs without requiring adaptive precoding across these points [5]. This approach simplifies the transmission process by allowing each TP to operate independently in terms of its MIMO layer transmission. While this method may not offer the same level of data alignment as C-JT, it still provides significant advantages, particularly for improving coverage and performance for cell-edge users, such as mobile Very-Small-Aperture Terminals (VSATs). The selection of mTRP with NC-JT is particularly beneficial for enhancing connectivity and coordination in challenging environments. It is effective in extending coverage and improving service quality in regions that are difficult to reach, making it a suitable choice for scenarios involving mobile VSATs.

The mTRP strategy will be implemented using two GEO satellites in a single-band configuration to ensure uninterrupted service for mobile VSATs. The main objective is to maintain stable and reliable communication for mobile users, even in challenging conditions where a single satellite link might be compromised [6]. This is particularly important in the edge coverage areas where the signals from the GEO satellites are weaker, and users experience higher interference

from surrounding cells [7]. By employing multiple independent links through the multi-TRP approach, the system enhances communication robustness against potential blockages and beam failures, especially at higher carrier frequencies like mmWave. These higher frequencies are more susceptible to atmospheric attenuation from phenomena such as rain and clouds [8]. The multi-TRP strategy mitigates the cell-edge effect by ensuring that users receive more consistent signal quality and reduced interference, improving overall coverage and connectivity in difficult-to-reach areas.

In addition to selecting the appropriate transmission technique for mTRP, two other key factors must be considered: the choice of functional split and the packet operation mode. The mTRP NC-JT approach requires a unified MAC and High-PHY, which necessitates precise coordination and synchronization managed by the on-ground Central Unit (CU) to ensure effective data delivery. When choosing a functional split, options that support centralized processing at the CU—such as split options 1-6, 7.3, and 7.2—are particularly beneficial. These splits enhance coordination and synchronization across multiple transmission points, which is crucial for the success of the mTRP NC-JT strategy. Regarding packet operation modes, 5G-NR offers two primary techniques: Packet Splitting (PS) and Packet Duplication (PD). Packet Splitting (PS) improves network throughput by distributing packets across multiple networks, thereby increasing data transmission efficiency. In contrast, Packet Duplication (PD) enhances data reliability by transmitting multiple copies of the same packet over different carriers. This approach minimizes data loss and ensures more reliable communication, especially in scenarios where link stability may be a concern.

This paper is structured as follows. Section 2 introduces the Signal Model, providing a detailed framework for understanding the signal processing techniques employed. Section 3 details the Scenarios derived from a mTRP transmission, outlining the conditions and parameters that influence the performance outcomes. Section 4 presents the mTRP solutions, analysing different strategies and their implications for multi-TRP systems. Section 5 summarizes the main Results, offering insights and data from the study experiments and analyses. Finally, Section 6 draws the main conclusions, synthesizing the findings and discussing their implications for GEO satellite communications.

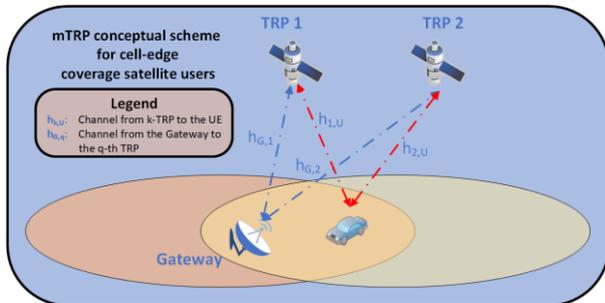


Figure 1. Conceptual Representation of the mTRP system over NTN for cell-edge coverage satellite users

## 2 Signal Model

This paper explores user connectivity at the edge of satellite beams, focusing on VSAT terminals that may have some level of mobility. All beams providing coverage to these users operate in the same frequency band, leading to the use of a multi-TRP strategy for service. In this approach, the UE is simultaneously connected to multiple nodes of the NR network, with both GEO satellites transmitting the same information to the UE. It focuses on the downlink data shared channel (PDSCH) of 5G-NR to assess performance metrics. Since the two GEO satellites have different elevation angles (See Figure 1), they create uncorrelated MIMO channel matrices, which helps reduce the outage probability due to UE mobility. As the UE moves in and out of coverage, a multi-TRP packet duplication strategy is employed to enhance connectivity and minimize handovers. To mitigate channel effects, the GEO satellites use pre-coding techniques. However, the precoding is non-coherent, meaning each satellite only has information about its own communication channel.

The scenario involves a UE, and a gateway connected through two GEO satellites operating in the Ka band. This frequency band, which ranges from [27.5-28.6, 29.5-30] GHz for the uplink (Earth-to-Space) and [17.8-18.6, 19.7-20.2] GHz for the downlink (Space-to-Earth), is susceptible to significant attenuation due to rain and clouds. To address this challenge, the use of multiple satellites is considered, with the focus on the downlink and the PDSCH channel. The downlink carrier frequency is set at 20 GHz (Satellite-to-UE), while the uplink (Gateway-to-Satellite) operates at 28 GHz. The UE is equipped with two antennas located at the edge of the coverage beams from the two GEO satellites. This configuration allows for the implementation of a multi-Transmission Reception (mTRP) strategy.

In this setup, the channel between the gateway and each GEO satellite is represented by  $h_{g,k}$ . The signal received by the UE from the  $k$ -th satellite can be modelled as  $y_k = h_{s,k} \cdot x_k + n_k$ , where  $h_{s,k}$  represents the channel between the  $k$ -th satellite and the UE,  $x_k$  is the transmitted signal, and  $n_k$  is the noise. The mTRP strategy enhances the system's robustness by combining the signals received from both satellites, helping to mitigate the effects of atmospheric attenuation and improve the overall reliability of the connection. The system model accounts for both uplink and downlink channels, with the UE processing the signals received from both GEO satellites through their respective channels. For  $k \in \{1, 2\}$ , let  $h_{k,U}$  represent the channel from the  $k$ -th satellite to the UE (VSAT terminal). The UE is equipped with two antennas. The channels to these antennas differ only by a phase shift due to the slight difference in the time it takes for the signal from a satellite to reach each antenna (See Figure 1). In the figure,  $r_{k,U}^1$  denotes the distance from the  $k$ -th GEO satellite to the  $q$ -th antenna of the UE. If the first antenna is taken as the reference, the distance from the  $k$ -th GEO satellite to the second antenna can be expressed as  $r_{k,U}^2 = r_{k,U}^1 + \Delta r_{k,U}^2$ , where  $\Delta r_{k,U}^2$  represents the additional distance the signal must travel to reach the second antenna. Therefore, the channel from the  $k$ -th GEO satellite to the second antenna of the UE for the  $n$ -th transmitted symbol can be described as follows:

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

Let  $k$  represent the wave number and  $\lambda$  the wavelength of the transmitted signal. The additional path length that a signal must travel to reach the second antenna compared to the first is given by  $\Delta r_{k,U}^{(2)} = d \sin(\theta_{k,U}) \cos(\varphi_{k,U})$  where  $d$  is the distance between the two antennas,  $\theta_{k,U}$  is the elevation angle, and  $\varphi_{k,U}$  is the azimuthal angle of the satellite relative to the UE. The channel from the  $k$ -th GEO satellite to the first antenna of the UE, denoted as  $h_{k,U}^{(1)}[n]$ , incorporates the following effects:

$$h_{k,U}^{(1)} = h_{Atm,k,U}^{(1)} h_{FS,k,U}^{(1)} h_{PL,k,U}^{(1)} h_{SC,k,U}^{(1)} \quad (2)$$

where  $h_{Atm,k,U}^{(1)}$  represents atmospheric losses, which include attenuation due to gases, clouds, fog, rain, and tropospheric scintillation. These atmospheric effects are detailed in ITU-R recommendations P.618 and P.838. The term  $h_{PL,k,U}^{(1)}[n]$  denotes pointing losses,  $h_{FS,k,U}^{(1)}[n]$  represents free space losses, and  $h_{SC,k,U}^{(1)}[n]$  accounts for small-scale fading losses. Free space losses are calculated as follows:

$$h_{FS,k,U}^{(1)} = \left( \frac{\lambda}{4\pi d_{k,U}^{(q)}} \right)^2 \quad (3)$$

For pointing losses, denoted as  $h_{PL,k,U}^{(q)}$ , we assume a fixed value of 0.5 dB. The small-scale fading losses, represented by  $h_{SC,k,U}^{(q)}[n]$ , are modelled using a Rician distribution. Thus, the received signal at the  $q$ -th antenna from the  $k$ -th mTRP GEO satellite can be expressed as:

$$y_{k,U}^{(q)} = \sqrt{P_{R,k}} h_{k,U}^{(q)} x_k[n] + w_{k,U}[n] \quad (4)$$

The received power from the  $k$ -th GEO satellite, denoted  $P_{R,k}$  is given by:

$$P_{R,k} = P_{T,k} G_T G_R / kTB \quad (5)$$

where  $P_{T,k}$  represents the transmitted power,  $G_T$  and  $G_R$  are the gains of the transmitter and receiver antennas,  $k$  is the Boltzmann constant, and  $B$  is the bandwidth of the signal.  $h_{k,U}^{(q)}$  is the channel from the  $k$ -th GEO satellite to the  $q$ -th antenna,  $x_k$  is the modulated packet, and  $w_{k,U}$  is the white complex Gaussian noise with zero mean and unit power at the UE. Since the multiple TRP structure is non-coherent, the precoding is based solely on the information from each satellite's own channel to the UE. This approach is referred to as Non-Coherent Joint Transmission (NCJT). When using a

zero-forcing technique for precoding on the  $k$ -th mTRP GEO satellite, the precoder is defined as:

$$P_{k,U}^{(q)} = \left( h_{k,U}^{(q,*)}[n] h_{k,U}^{(q)}[n] \right)^{-1} h_{k,U}^{(q,*)}[n] \quad (6)$$

Let  $h_{k,U}^{(q,*)}[n]$  the complex conjugate of the channel from the  $k$ -th mTRP GEO satellite to the  $q$ -th antenna of the UE. Thus, the signal received at the  $q$ -th antenna from the  $k$ -th mTRP satellite will be:

$$y_{k,U}^{(q)} = \sqrt{P_{R,k}} \exp\left(\varphi_{k,U}^{(q)}\right) s_k[n] + w_{k,U}[n] \quad (7)$$

Being  $s_k[n]$  the modulated symbol and  $\varphi_{k,U}^{(q)}$  the phase shift caused by the additional delay of the transmitted signal as it arrives at the second antenna compared to the first one. It depends on several parameters such as: the elevation angle of the  $k$ -th mTRP relative to the UE, the distance between the antennas, and the wavelength used. Different scenarios arise because there are two GEO satellites transmitting packets to the UE. The next section details them under different views.

### 3 Scenarios

#### 3.1 General View of the Scenarios

At least the following transmission/reception scenarios have been identified: i) the transmitted signals from the two satellites may be received by the UE in the same time-slot and be temporally aligned, ii) the transmitted signals may arrive in the same time-slot but lack temporal alignment, and iii) the signals from the two GEO satellites may be received at different time slots. The two satellites transmit signals using the same frequency band but may employ different polarizations. The angular separation between the satellites and the antenna beamwidth are also critical factors. In Ka-band transmissions, the antennas are directive, so it is expected that the two antennas will point to the two satellites. This leads to two potential scenarios: i) both satellites fall within the field of view of the two antennas, or ii) each antenna observes only one satellite. In the first scenario, the angular separation between the satellites is smaller than the beamwidth of the antennas. In the second scenario, the angular separation is larger than the beamwidth. Thus, in the first case, the antennas will receive the signals from both satellites under one of the three earlier scenarios: i) temporally aligned in the same time slot, ii) temporally misaligned in the same time slot, or iii) received in different time slots. In the second case, each antenna receives a signal from only one satellite, making only the first and third scenarios possible. If both antennas receive signals from the two satellites, techniques such as spatial filtering at the UE, using satellites with different polarizations, or functional

splitting may be employed to separate the misaligned signals. It is important to note that if the angular separation between the satellites is very small, both satellites will be affected by the same atmospheric impairments, as there is no diversity in the elevation angle.

The transmission-reception scenarios can be summarized as follows:

- a) **Simultaneous and Temporally Aligned Reception:** The two signals from the GEO satellites are received at the UE in the same time slot and are temporally aligned. This occurs when the two mTRP GEO satellites transmit the same packet at slightly different times, allowing the signals to arrive almost simultaneously at the UE. To achieve this alignment, the satellite with the shorter transmission path (mTRP2 GEO) delays its transmission. This scenario assumes the UE has little to no movement, enabling the signals to sum coherently.
- b) **Simultaneous but Temporally Misaligned Reception:** The signals from the two GEO satellites arrive at the UE in the same time slot but are not perfectly aligned, resulting in interference. This misalignment may be due to the UE's mobility, which prevents accurate tracking and leads to errors in predicting the UE's position. The interference caused by this misalignment needs to be mitigated.
- c) **Reception in Different Time Slots:** The signals from the two GEO satellites arrive at the UE in different time slots, meaning they are perfectly recovered but with a loss in throughput. This scenario occurs when the time difference between the signals is greater than the duration of a time slot. Despite the reduction in throughput, packet duplication is employed to minimize outage probability, especially for mobile UEs at the edge of the GEO satellite beams.

### 3.2 Understanding the mTRP channel as a multipath one.

The transmission from the two GEO satellites can be modelled as a multipath channel. The joint channel for the transmission from the two GEO satellites to the  $q$ -th antenna of the UE can be expressed as:

$$h_U^{(q)}[n] = \left| h_{1,U}^{(q)} \right| e^{j\varphi_{1,U}^{(q)}} \delta[n] + \left| h_{2,U}^{(q)} \right| e^{j\varphi_{2,U}^{(q)}} \delta[n - \Delta\delta_{1,2}] \quad (8)$$

where  $\Delta\delta_{1,2}$  represents the time delay between the signals received from the two satellites at the  $q$ -th antenna of the UE. Assuming the angular separation between the two GEO satellites is smaller than the beamwidth of the antennas, the value of  $\Delta\delta_{1,2}$  determines three possible scenarios:

- a) **Coherent Reception ( $\Delta\delta_{1,2} \approx 0$ ):** The signals from both satellites are received in the same time slot and are perfectly aligned, creating a flat fading channel.

Since the signals are aligned and identical, FFT does not help in separating them. The IFFT can be applied either at the satellite or the UE.

- b) **Misaligned Reception ( $0 < \Delta\delta_{1,2} < T_{\text{slot}}$ ):** The signals arrive in the same time slot but are not perfectly aligned. In this case, strategies are needed to separate the signals. The IFFT/FFT transform can help by converting the time-domain multipath fading into a flat fading channel in the frequency domain, simplifying signal equalization. Guard bands in the IFFT process are necessary.
- c) **Reception in Different Time Slots ( $\Delta\delta_{1,2} \gg T_{\text{slot}}$ ):** The signals arrive at different time slots, so only one satellite's signal is received at a time at the UE antennas.

### 3.3 Relationship of mTRP channel and Functional Split.

Note that the interpretation of the mTRP channel as a multipath one, it may impact on the functional split to use. The two packets transmitted by the GEO satellites may be received at the UE in three ways: coherently in the same time slot, in the same time slot but misaligned, or in different time slots. In the first case, where the packets arrive coherently, the multi-connectivity channel can be considered as experiencing flat fading. In the second case, where the packets arrive in the same time slot but not at the same moment, the channel behaves like a multipath channel. Here, IFFT techniques can be used to compensate for small time differences between the packet arrivals. By converting multipath fading into flat fading, IFFT simplifies the decoding process. This influences the choice of functional split, with a split like 7.2, where IFFT is performed at the CU (UE), helping to mitigate the multipath effects caused by the imperfect synchronization of the two satellites.

Finally, after presenting the scenarios, the following section shows the mTRP solutions for decoding the transmitted data using mTRP strategy.

## 4 mTRP solutions

The multi-TRP solution involves combining signals received from multiple GEO satellites at the UE's antennas. In this case, two GEO satellites transmit the same packet to a UE equipped with two antennas, employing a packet duplication technique. Three scenarios are considered for how the packets arrive at the UE: the packets may arrive coherently in the same time slot, they might be misaligned but still within the same time slot, or they could arrive at different time slots. To address these scenarios, various signal combining techniques are used, such as Maximum-Ratio Combining (MRC), Selection Combining (SC), and Equal Gain Combining (EGC). So, the impinged signals have to be fused (See Figure 2).

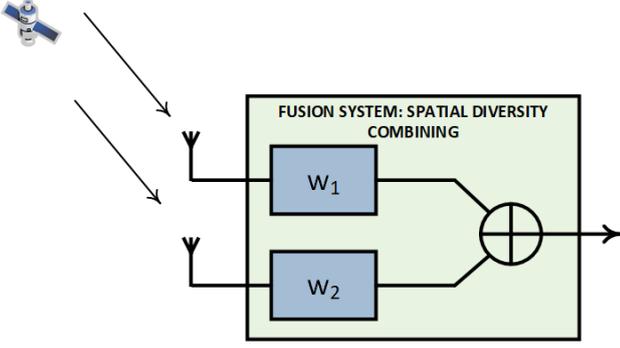


Figure 2. Fusion System: Spatial Diversity Combining.

Each technique is examined for its method of combining the signals and its specific information requirements. Specifically, the fusion function that these techniques demand is equated as [9]:

$$z[n] = \frac{\sum_{q=1}^{M=2} w_q r_q^{\dots}[n]}{\sum_{q=1}^{M=2} w_q w_q^*} \quad (9)$$

where  $w_q$  is the weight used to normalize the signal received at the  $q$ -th antenna,  $r_q$ . The analysis covers two scenarios: the first involves receiving the signal from only one GEO satellite at the antennas (which may vary), and the second involves receiving signals from both GEO satellites at the two antennas. However, here it has been assumed that the two mTRP satellites have enough angular separations to assume that the channels are uncorrelated. If they impinge coherently at the antennas the fusion signal for the different combining techniques are [5]:

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

$$\frac{s[n] \sum_{q=1}^{M=2} w_q \sum_{k=1}^2 |h_{k,U}^{(q)}| e^{j\varphi_{k,U}^{(q)}} + \sum_{q=1}^{M=2} w_q \beta_q[n]}{\sum_{q=1}^{M=2} w_q w_q^*} \quad (10)$$

At this point we can decompose the summation of all channels to  $\sum_{k=1}^2 |h_{k,U}^{(q)}| e^{j\varphi_{k,U}^{(q)}} = |h_U^{(q)}| e^{j\varphi_U^{(q)}}$

where  $|h_U^{(q)}|$  and  $\varphi_U^{(q)}$  are the amplitude and phase of the combined channel for the signals transmitted by the two GEO satellites. Thus, the spatially combined signal is given by:  $z[n] = \omega_s[n]s[n] + \rho[n]$  being  $\omega_s[n]$  the weight applied through the spatial filtering technique, and  $\rho[n]$  denotes the noise resulting from this filtering. Specifically,  $\omega_s[n]$  and  $\rho[n]$  are defined as Table 1 shows. This scenario happens when i) *the two antennas of the UE view the two satellites since the angular separation of the two satellites is lower than the*

*antenna beamwidth and ii) The two antennas of the UE view the two satellites since the angular separation of the two satellites is lower than the antenna beamwidth.* In the first case, it is necessary a synchronization process. This allows the transmitted signals to be aligned so that they can be received coherently. The satellite with the shorter propagation delay to the UE can adjust for the additional delay introduced by the other satellite, ensuring simultaneous and coherent reception. Furthermore, a network clock is needed, and both satellites must coordinate to ensure the packets are transmitted at the same time. It is also assumed that the UE is moving at a low speed. In the second case, the mTRP scenario can be understood as a MIMO system. Specifically, a MIMO transmission-reception scheme of the PDSCH channel of 5G NR from Figure 3. If no functional splitting is implemented between the Central Unit (CU) and the Distributed Unit (DU), the GEO transmitter would be responsible for completing the frame generation process for the Physical Downlink Shared Channel (PDSCH) by performing the Inverse Fast Fourier Transform (IFFT) directly. This approach means that the GEO transmitter handles both the signal processing tasks and the final stage of frame construction without delegating any of these functions to a separate unit. As a result, the entire process of converting the frequency-domain signal into the time-domain, which is essential for proper signal transmission, would be managed entirely within the GEO transmitter itself. This setup can impact the overall efficiency and flexibility of the network, as it centralizes processing tasks and may affect the distribution of workload between network components.

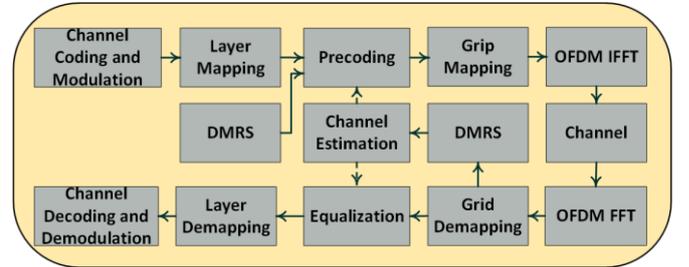


Figure 3. MIMO mTRP 5G NR PDSCH

Table 1. Spatial combining techniques, expressions and objectives when the signal of a mTRP is received in all receiver antennas

Spatial Combining Technique	Expression of weights
Maximum Ratio Combining	$w_q =  h_U^{(q)}  e^{-j\varphi_U^{(q)}}$
Equal Gain Combining	$w_q = 1/M$

Selection Combining	$w_q = \begin{cases} 1, &  h_U^{(q)}  >  h_U^{(i)}  \text{ for all } i \\ 0, & \text{Otherwise} \end{cases}$
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## 5 Results

This paper simulates the downlink shared control channel PDSCH of 5G NR within a multi-Transmission Reception Point (mTRP) setup involving two GEO satellites acting as mTRP nodes and a user equipment (UE) with dual antennas. The simulation parameters are detailed in Table II.

Table II Parameters of the Simulation Results

Parameter	Value
Downlink Carrier Frequency	f=20 GHz
Separation between Subcarriers	$\Delta f=15$ KHz
Number of Symbols	12
Protocol Simulated	PDSCH
Modulation Tested	QPSK
Decoder Used	LDPC-Belief Propagation
Iterations Decoder	10
Spatial Combining Technique	MRC
Weather Conditions	Clear-Sky Rainfall
Clear-Sky [8]	Rain rate of 0 mm/h
Rainfall	Rain rate of 30 mm/h
Code rate simulated	1/4,1/3,2/5, 4/5
Length of the word	8448
Channel Model	Rician K=10 and K=20
Longitude Satellite 1	30°
Longitude Satellite 2	60°
Target BLER	10 <sup>-2</sup>

To analyse the multi-TRP transmission and reception system using two satellites, the PDSCH channel of 5G-NR is employed. This channel supports various modulations, including QPSK, 16-QAM, 64-QAM, and 256-QAM. It utilizes LDPC channel coding for Forward Error Correction (FEC). The results for BLER, throughput, and outage probability incorporate the effects of FEC, allowing for more realistic evaluations of the required Eb/N0.

The PDSCH protocol has two block lengths for channel encoding: K1=2304 and K2=8448. For this case, the block length K2=8448 is used. The Transport Block Size (TBS) varies with the code rate applied. The subcarrier spacing in 5G-NR can be 15 kHz, 30 kHz, 60 kHz, or 120 kHz. In the results provided here, a subcarrier spacing of  $\Delta f=15$  kHz is considered, leading to a symbol duration of  $T_{\text{sym}}=66.67 \mu\text{s}$ . Each time slot comprises 14 OFDM symbols, and with a normal Cyclic Prefix (CP) duration of 4.7  $\mu\text{s}$  for  $\Delta f=15$  kHz, then the total slot duration is: 933.33  $\mu\text{s}$  [10],[11].

The antenna has been assumed parabolic. A key parameter of the scenarios is the antenna beamwidth. For a parabolic antenna with a wavelength  $\lambda$  and dish size D, the 3dB beamwidth is given by:  $\Delta BW_{3\text{dB}}=70\lambda/D$  [12]. For a carrier frequency of 20 GHz (satellite downlink) and a dish size of

D=1.5 meters, the wavelength  $\lambda$  is 0.015 m and the 3dB beamwidth is  $\Delta BW_{3\text{dB}}= 4^\circ$ . Therefore, the total 3dB beamwidth will be double this value:  $\Delta BW= 8^\circ$ .

Figures 4, and 5 depict the block error rate (BLER) and outage probability for the mTRP configuration. Packets will be assumed erroneous if the CRC check fails after LDPC decoding. When packets are received in two separate time slots, the following strategy is applied. If the CRC of the first packet is correct upon arrival at the UE, the second packet will not undergo decoding. However, if the CRC of the first packet is incorrect, it will be combined with the second packet using Maximum-Ratio Combining (MRC). If the CRC of the combined packet is error-free, the resulting TBS packet is passed to the MAC layer. If errors persist, the UE is considered to be in outage. Consequently, the outage probability for packets arriving at different time slots is formulated as:

$$p(\text{BLER}_{\text{TBS}} < \gamma_T) = p(\text{BLER}_{\text{TBS},1} < \gamma_T)p(\text{BLER}_{\text{TBS},2} < \gamma_T)$$

being  $\text{BLER}_{\text{TBS},k}$  the Block Error Rate (BLER) of the Transport Block Stream (TBS) for the  $k$ -th slot. For the second slot it is considered the combination of the two packets using MRC. For a single slot transmission:

$$p(\text{BLER} < \gamma_T) = p(\text{BLER}_{\text{TBS},\text{MRC}} < \gamma_T)$$

Where  $p(\text{BLER}_{\text{TBS},\text{MRC}})$  is the Block Error Rate of the packet that results from the combination of the two antennas using MRC.  $\gamma_T$  is the target BLER to compute the outage probability. In this study case, it has been considered that  $\gamma_T$  is 10<sup>-2</sup>. In this setup, two GEO satellites serve as mTRPs, communicating with a UE equipped with two antennas. The simulated channel conditions encompass Clear-Sky and Rainfall scenarios for both GEO satellites links. Specifically, it assumes Clear-Sky conditions for the link from mTRP1 to the UE and Rainfall conditions for the link from mTRP2 to the UE. These figures compare the performance metrics of individual links against the combined performance using Maximum Ratio Combining (MRC). Figure 4 depicts the Block Error Rate (BLER) of the Transport Block Size (TBS) at the LDPC decoder output, using QPSK modulation with a code rate of 1/3. It highlights the performance impact of different conditions on the BLER, demonstrating how effectively the LDPC decoder handles errors for this modulation scheme. Figure 5 shows the outage probability for individual links and Multi-Rate Combining (MRC) under QPSK modulation, comparing code rates of 1/3 and 4/5. The results show that MRC provides 2-3 dB improvement in Clear-Sky conditions and 3-5 dB enhancement in Rainfall conditions. This performance boost reflects MRC's capability to substantially reduce outage probability and improve system reliability under adverse weather conditions. The observed gains underscore MRC's effectiveness in mitigating

the impact of atmospheric impairments, particularly during severe fading events. By utilizing diversity across satellite links, MRC enhances system resilience and stability. This approach is of interest for GEO satellite communications, especially in challenging weather scenarios. So, MRC into satellite communication systems offers reliable and efficient connectivity despite environmental challenges.

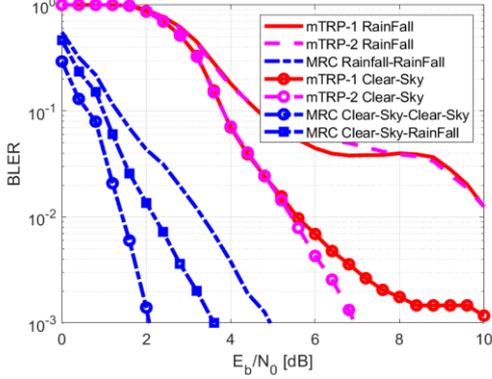


Figure 4. BLER for QPSK modulation and code rate of 1/3, mTRP2 (magenta color line), MRC (blue color line) of mTRP1 and mTRP2 in clear sky (circle marker), rain-fall (dashed marker) in both links and mTRP1 in clear-sky and mTRP2 in rain-fall (square marker).

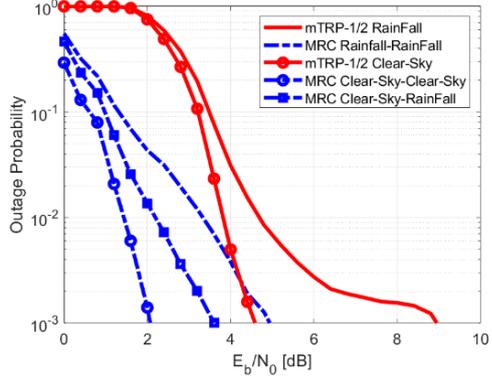


Fig.5a. QPSK modulation Code-Rate of 1/3

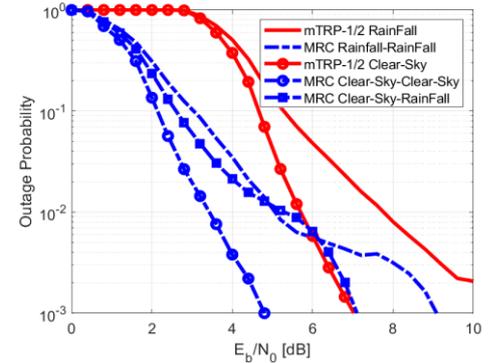


Fig.5b. QPSK modulation Code-Rate of 4/5

Figure 5. Outage Probability for Clear-Sky and Rain-Fall for QPSK modulation and a) code rate of 1/3, b) code rate of 4/5. comparison of mTRP1 (red color line), mTRP2 (magenta color line), MRC (blue color line) of mTRP1 and mTRP2 in clear sky (circle marker), rain-fall (dashed marker) in both links and mTRP1 in clear-sky and mTRP2 in rain-fall (square marker).

## 6 Conclusions

In this paper, various scenarios for packet arrival at the User Equipment (UE) were explored. These include cases where packets arrive simultaneously at the same time slot, are misaligned but at the same time slot, or arrive at different time slots. Additionally, two configurations based on the angular separation between the satellites and the beamwidth of the antennas were examined: when the satellites are closer together than the beamwidth of the antennas and when they are farther apart. In the first case, the directive nature of the antennas means both satellites are affected similarly by atmospheric conditions, such as rain, thus not improving connectivity under such conditions. In the second case, the greater angular separation allows the UE to receive signals from satellites not affected by adverse weather, improving reliability.

The findings of the performance analysis showed that using multiple satellites can mitigate fading caused by atmospheric conditions, ensuring at least one satellite can provide coverage to the UE at the cell edge. Scenarios where packets arrive in the same time slot generally offer higher throughput compared to cases where packets arrive at different times, due to reduced latency from having to wait for packet combination. However, for effective reception, packets need to be synchronized. Although exact simultaneous arrival isn't mandatory if directive antennas are used or if the satellites operate at different polarizations, spatial filtering is required if both packets are received. The knowledge of satellite positions is essential for spatial filtering. Since the satellites are in Geostationary Earth Orbit (GEO), their positions can be predetermined if the UE knows its own location, potentially using GNSS data from the SIB16 signal or Direction-of-Arrival (DOA) techniques such as MUSIC or MVDR. Alternatively, a scanning system can be employed to detect satellite signals, though this is simplified by the fixed latitude of GEO satellites. Moreover, the synchronization of packet transmission is crucial. The protocol ensures that both the gateway and the GEO satellites synchronize the transmission of packets. Control channels in 5G-NR facilitate this by providing UE position and channel estimation to the gNBs coordinated by the gateway. Toward this regard, the System Information Block (SIB) provides essential details on frequency bands, bandwidth, cell identity, and synchronization, ensuring correct timing alignment for decoding. In general, the mTRP scenario can be understood as a multipath channel. The arrival of packets from GEO satellites at the UE might be coherent, misaligned at the same time slot, or at different time slots. In cases where packets arrive coherently, the multi-connectivity channel resembles flat fading. If packets are misaligned but at the same time slot, it presents a multipath scenario. Using techniques like IFFT can help correct small timing differences between packets, simplifying decoding by transforming multipath fading into flat fading. This approach influences the choice of functional split; for example, a split option like 7.2, where IFFT is performed at the CU (UE), can address multipath effects due to imperfect synchronization of the satellites.

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