Feasibility and Opportunities of Terrestrial Network and Non-Terrestrial Network Spectrum Sharing

Hao-Wei Lee, Abdelkader Medles, Chun-Chia Chen, Hung-Yu Wei

***Abstract*—Wireless networks in 6G require enhanced coverage and system capacity to support the rapid growth of IoT devices and bandwidth-consuming multimedia. Combining the Non-terrestrial network (NTN)'s extreme coverage and terrestrial network (TN)'s high spectral efficiency, NTN-TN integrated network is a promising solution for the 6G wireless network. NTN-TN spectrum sharing is crucial for enhancing 6G NTN-TN integrated network performance. However, the co-channel inter-system interference will degrade the spectral efficiency. This paper focuses on the spectrum sharing between mobile satellite services (MSS) and mobile networks. The spectrum sharing mechanism and co-channel interference in 6G NTN-TN integrated systems are comprehensively studied. The paper employs a 3GPP-calibrated simulator to evaluate and compare two methods: normal pairing, where TN and NTN operate in the same direction, and reverse pairing, where TN and NTN operate in opposite directions. The results show that the reverse pairing outperforms the normal pairing in TN and NTN. We observe that NTN has a marginal interference impact on TN. The paper also analyzes the interference pattern and provides insights into the design of the interference mitigation method. The last part of the manuscript provides research topics and potential interference mitigation techniques that can be applied to NTN-TN spectrum sharing.**

***Index Terms*—NTN-TN integrated network, NTN-TN spectrum sharing, interference mitigation, reverse pairing.**

I. Introduction

6G networks strive for seamless, ubiquitous services through terrestrial and satellite network integration. Enhanced satellite launching technologies make satellite-based mobile services economically feasible and energy-efficient. To meet the spectrum demands of high-throughput applications, integrating Non-Terrestrial Networks (NTN) and Terrestrial Networks (TN) emerges as a promising 6G solution, expanding coverage and boosting capacity [1].

The scarcity of spectrum has led to a growing interest in spectrum sharing between NTN and TN. For example, the Federal Communications Commission (FCC) in January 2017 sought comments on allowing 5G operation in the 12.2-12.7 GHz band, which is already used for Fixed Satellite Service (FSS). The FCC is concerned about the potential disruption of legacy services and is seeking input from industries [2]. Meanwhile, some satellite and terrestrial operators are exploring collaboration opportunities to address the spectrum scarcity issue. For instance, in August 2022, T-Mobile announced a coverage extension plan that SpaceX will provide mobile service in rural areas using T-Mobile's spectrum. These events highlight the urgent need for efficient spectrum utilization.

NTN-TN spectrum sharing could enhance integrated network capacity, leveraging unutilized satellite spectrum in cities and terrestrial spectrum in rural areas [3]. Additionally, NTN-TN spectrum sharing could increase throughput, expand user coverage, and provide cost-effective advantages, obviating costly RF front-end component adjustments in user equipment, such as filters, duplexers, and amplifiers.

However, co-channel interference is a technical concern that could disrupt spectrum sharing if the systems are not spatially isolated [4]. Fortunately, the user distribution of the two networks is geographically complementary, which could reduce inter-system interference [5]. Thus, NTN-TN spectrum sharing is a promising solution to address spectrum scarcity and a key component of intensifying integrated networks.

In this research, we first introduce the system architecture of the NTN-TN integrated networks in section II. We evaluate the general spectrum sharing scenarios in NTN-TN integrated networks and provide the observations of the interference root cause in section III. The discussion of possible interference mitigation methods for vulnerable links in NTN-TN spectrum sharing is also offered in section IV. The contributions can be summarized as follows.

- We provide an overview of NTN-TN integrated network architectures and possible spectrum sharing scenarios. The corresponding interference patterns of each sharing scenario are also introduced.
- We evaluate the feasibility of NTN-TN spectrum sharing by the inter-system interference influences on SINR with a simulator calibrated against 3GPP TR 38.863. In addition, we provide the design philosophy of the interference mitigation method for each link based on the insights drawn from the observations and analyses of evaluation results.
- In this research, we provide promising interference mitigation techniques and discuss the enhancements direction of those techniques for spectrum sharing in 6G NTN-TN integrated networks.

II. NTN-TN system architecture and sharing scenarios

The proposed NTN-TN integrated networks, illustrated in Fig. 1, aim to provide mobile services over NTN's coverage area. In this architecture, TN is primarily responsible for offering mobile services in highly populated regions, such as urban areas, owing to its higher deployment cost and greater

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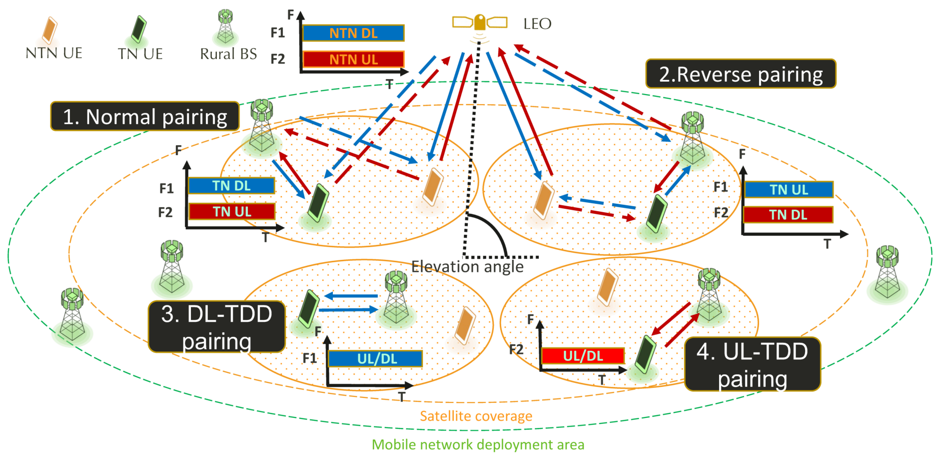

Fig. 1. NTN-TN spectrum sharing system architecture, possible spectrum sharing scenarios, and corresponding interference patterns. Green and yellow icons represent TN and NTN components, respectively.

capacity. As a result, operators usually deploy base stations (BSs) more densely in cities to cater to the high number of users and ensure better connectivity. Conversely, in less populated areas, such as suburban and rural areas, operators prefer to deploy BSs more sparsely to reduce costs while maintaining an adequate level of service. In the proposed NTN-TN integrated networks, NTN would provide mobile services for users in rural areas.

To pursue a high throughput user experience, user equipment (UE) in the coverage follows the maximum received signal quality policy (e.g., Reference Symbol Received Power (RSRP)) to connect to either a TN BS or the NTN BS (i.e., satellite). Applying this policy also implies that a UE in TN's coverage would prioritize TN over NTN, as stated in the NTN-TN adjacent channel coexistence study report TR 38.863.

In the following subsection, we delve into the components of the NTN-TN integrated network and explore potential spectrum sharing scenarios.

A. TN BS

Within NTN-TN integrated networks, every TN BS comprises three sectors, each equipped with a planar array antenna which is commonly used in 5G gNB for directional transmission. Directional transmission concentrates the signal toward the desired direction to enhance transmission antenna gain and reduce interference in the unwanted direction. After the UE association, optimal beam direction is determined via beam measurements, refining signal quality, and ensuring efficient transmission.

B. NTN BS

The proposed NTN-TN integrated network utilizes a quasi-earth-fixed multi-beam Non-Geostationary Satellite Orbit (NGSO) with a regenerative payload as the NTN BS. Communication satellites can be categorized based on their orbit, beam trajectory, and signal processing capabilities. The following contexts introduce the characteristics of each category and explain why we consider quasi-earth-fixed multi-beam NGSO with regenerative payload as NTN BS in the proposed NTN-TN integrated network.

According to the satellite's orbit, satellites can be categorized as Geostationary Satellite Orbit (GSO) and NGSO. GSO, which orbits the Earth at the same speed as the planet's rotation, remains stationary relative to a specific location on the ground. This feature makes them ideal for providing continuous coverage to a specific region, such as for television broadcasting or weather observation. However, the high altitude of GSOs (about 36,000 km) results in a significant latency or time delay that can cause problems for real-time applications such as voice or video calls. NGSO, on the other hand, orbits the Earth at lower altitudes and faster speeds, resulting in lower latency and enabling real-time communication. NGSO can provide global coverage by forming constellations, and their closer proximity to Earth also allows for smaller and cheaper ground-based communication devices. Because NGSOs are not stationary relative to the ground, they require more satellites to ensure continuous coverage, and the need for handovers between satellites, as they move across the sky, can cause signal interruption. Considering NGSO offers more targeted coverage, lower launch costs, and potentially higher data rates while mitigating the signal delay issue associated with GSOs, we consider NTN using NGSO to provide mobile service.

The NGSO's beams can be quasi-earth-fixed or earth-moving. Quasi-earth-fixed beams encompass an area temporarily, while earth-moving beams slide over Earth's surface, necessitating frequent handovers. Due to reduced frequent inter-beam handover requirements, quasi-earth-fixed beams, boasting lower signaling overhead, are favored for NTN service links.

Satellites can be transparent or have a regenerative payload, with the latter using sophisticated processors to regenerate signals for reliable communication. Regenerative payload satellites with full gNB functionality can provide radio access or cellular backhaul connectivity to remote areas, making them a crucial enabler for 5G and beyond. Therefore, we consider a regenerative payload satellite with full gNB functionality as the NTN BS in our study.

C. User equipment

In the proposed NTN-TN integrated network, the UE is assumed to be a typical handset with GNSS capability, as currently considered in Rel-18. The UE can connect to either TN or NTN within the extreme coverage of the integrated network. However, when connecting to an NGSO, unlike connecting to a TN BS, a UE would experience the Doppler effect due to the NGSO's velocity. To compensate for this effect, an NTN UE would perform a frequency pre-compensation by computing the frequency Doppler shift based on the UE position and the satellite ephemeris, as specified in [6].

D. NTN-TN spectrum sharing scenarios

This subsection provides an overview of the frequency configuration options for spectrum sharing between NTN and TN networks. First, we introduce the frequency configuration candidates for NTN-TN spectrum sharing. Then, we elaborate on the interference patterns of each candidate.

Currently, frequency bands are typically classified into Frequency Division Duplex (FDD) and Time Division Duplex (TDD) bands. In practice, most NTN systems operate in FDD mode since the guard time in TDD mode would limit the spectrum efficiency. In this scenario, both NTN and TN use the same DL and UL spectrum, which is referred to as normal pairing (Fig. 1, scenario 1).

To enhance NTN UL operation, a static sharing and interference mitigation method called reverse pairing has been proposed [7] (Fig. 1, scenario 2). Reverse pairing leverages the BS's antenna directivity to reduce TN interference on NTN UL. Under reverse pairing, the TN DL spectrum is shared with NTN UL, while the TN UL spectrum is shared with NTN DL.

When TN operates in TDD mode, the scenarios where NTN DL shares the spectrum with TN and NTN UL shares with TN are referred to as DL-TDD pairing (Fig. 1, scenario 3) and UL-TDD pairing (Fig. 1, scenario 4), respectively.

Fig. 1 illustrates the interference patterns of normal and reverse pairing. The solid and dashed arrows represent the signals and inter-system interference, respectively. The interference patterns of DL-TDD pairing and UL-TDD pairing are neglected since they can be composed of the interference pattern components of normal pairing and reverse pairing.

III. Evaluation results and observations

The first aim of our simulations was to evaluate inter-system interference's impact on SINR in normal and reverse pairings. The second is to analyze the key factors affecting the severity of the interference. The last purpose is to give interference mitigation design principles according to the key factors affecting interference. In the following contexts, we use the term aggressor and victim to indicate the transmitter that causes interference to a communication link and the receiver of the communication link.

A. Simulation environment

For evaluation, a snap-shot based system simulator, which is a part of Mediatek 3GPP standard team simulator, was built and calibrated against TR 38.863 [8] in Rel-17. NTN and TN operate in FDD mode with 100MHz bandwidth. A multibeam LEO satellite with a 600km altitude and a 250km radius coverage is simulated. The LEO satellite employs a frequency reuse factor of 3 to reduce intra-beam interference.. TN BSs are deployed within NTN coverage with 0.1 BS/km^2 deployment density, inspired by Taiwan. The TN BS donwtilt angles are set to 10 and three degrees in urban and rural areas, respectively. The TN BSs are equipped with a non-AAS antenna with 17 dBi maximum directional antenna gain. The transmission power levels for the satellite and TN BSs are set at 53 dBm and 46 dBm, respectively. The maximum transmission power of UE is considered to be 23 dBm. All UEs follow the UL power control model in section 9.1 TR 36.942. 2RB and 10MHz UL bandwidth are allocated for each randomly scheduled NTN UE and TN UE, respectively. All UEs are assumed to be fully buffered. NTN and TN channel models refer to section 6.6 in TR 38.811 and section 7.4 in TR 38.901, respectively.

Since the interference pattern of DL-TDD and UL-TDD could be constructed from the pattern components of normal pairing and reverse pairing, the SINR in DL-TDD and UL-TDD would be somewhere in between the SINR of the normal and the reverse pairing. Thus, the simulation of DL-TDD and UL-TDD are omitted. The simulation also omitted scenarios where the satellite was the aggressor due to limited spaces and marginal interference from the satellite.

B. SINR simulation results under the effect of inter-system interference

The evaluation results in Fig. 2 reveal that NTN has a limited interference impact on TN. This is evident from the TN UL and DL SINR levels, which remain close to the SINR without spectrum sharing in both reverse and normal pairing scenarios. In reverse pairing, TN UL SINR experiences a minor degradation of 0 to 1 dB. Moreover, as the elevation angle decreases, there is a corresponding reduction in SINR degradation. This trend is primarily due to the satellite-to-ground propagation loss increasing faster than the increase in the TN BS antenna gain, especially at lower elevation angles.

In normal pairing, TN UL experiences a minor average SINR loss of 0.3 dB, which is negligible. These results suggest that both reverse and normal pairing methods are effective in maintaining good SINR levels for TN, with reverse pairing being slightly more efficient in reducing interference. Therefore, our first observation is that NTN has a limited interference impact on TN.

> **Observation 1:** *NTN has a limited interference impact on TN.*

Fig. 3 presents the average NTN SINR in normal pairing, reverse pairing, and non-spectrum sharing scenarios. In NTN DL, the reverse pairing achieves an SINR level close to the SINR of the non-spectrum sharing scenario, while the average SINR of the normal pairing has a 5 dB gap to

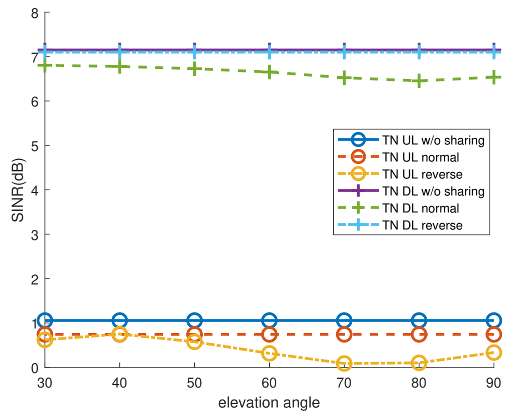

Fig. 2. Limited impact on TN in NTN-TN spectrum sharing.

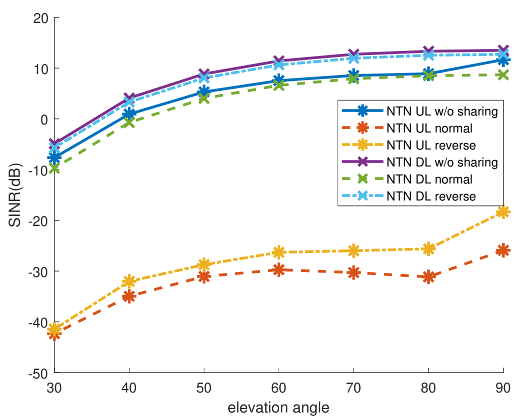

Fig. 3. Limited impact on NTN DL but a disruptive impact on NTN UL in NTN-TN spectrum sharing.

the SINR of non-spectrum sharing. Thus, the interference from TN BS significantly impacts NTN DL more than from TN UE. In contrast, for the NTN UL, the reverse pairing has an SINR level 10 dB higher than the normal pairing. Since the TN BS has beamforming capability and applies a downtilt angle, the aggregated TN BS interference has a minor impact on NTN UL compared to the aggregated TN UE interference. Therefore, reverse pairing is a preliminary interference mitigation method for the spectrum sharing of NTN UL and DL.

Fig. 3 also shows that TN interference has a non-negligible effect on the NTN UL. The NTN UL SINR of the reverse pairing and the normal pairing drop 30 dB and 40 dB from the SINR of non-spectrum sharing, respectively. In addition, the average SINR of the reverse and the normal pairing has a 20 dB and 30 dB gap to the minimum required SINR level for NR operation, i.e., -10 dB. Therefore, interference mitigation mechanisms are indispensable when NTN shares the radio resources that NTN UL uses with TN.

> **Observation 2:** *The reverse pairing has a better SINR than the normal pairing in NTN UL and DL.*
> **Observation 3:** *Interference mitigation methods for spectrum sharing between NTN UL and TN are indispensable.*

C. The interference distribution analysis of NTN UL in reverse pairing

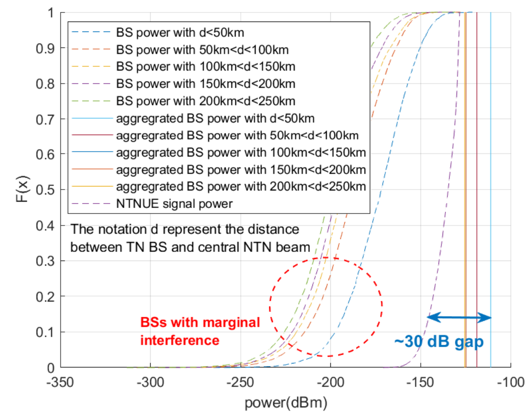

Fig. 4. CDF of TN BS to NTN UL interference power when elevation angle of the beam center is 70 degrees in reverse pairing. The wide distribution of TN BS highlights the need for interference measurements to mitigate interference. The harmful interference from the aggregated BSs within concentric circles emphasizes the importance of considering all BSs within the NTN coverage.

Fig. 4 shows the CDF of TN BS interference power received at the satellite when the elevation angle of the beam center is 70 degrees, the aggregated BS interference power, and the received signal power CDF of NTN UEs to further analyze the root cause of BS-to-satellite interference in the NTN UL reverse pairing. By comparing the CDF of the interference power from the BSs to the center of the NTN beam at different distances, we observe that the level of the BS interference power is not necessarily inversely proportional to the distance between the BS and the beam center.

Mitigation for NTN UL in reverse pairing: The aggregated BS interference power of concentric circles is larger than the received UE signal power, so an interference mitigation method should consider each BS in the NTN coverage when sharing the radio resources of an NTN beam with TN. Meanwhile, a large part of BSs has harmless interference power. Thus, precise and effective distinguishing BSs which interfere with NTN UL operation is a critical issue of the feasibility and spectral efficiency enhancement in NTN UL reverse pairing.

> **Observation 4:** *The aggregated BS interference overpowers the NTN UE's signal power received at the satellite.*
> **Observation 5:** *Measurement methods of distinguishing BSs with high interference power are required.*

D. The analysis of TN impact on NTN DL

Fig. 5 displays the relationship between NTN DL SINR decrease and the distance to the nearest TN BS (in the reverse pairing) or TN UE (in the normal pairing), respectively.

In reverse pairing, the decline in NTN DL SINR is influenced by the nearest TN UE's proximity and line of sight (LOS)/non-line of sight (NLOS) status. In NLOS, TN UE proximity has minimal impact on NTN DL interference. Conversely, NTN DL SINR degradation decreases swiftly in LOS with increasing distance from the nearest TN UE.

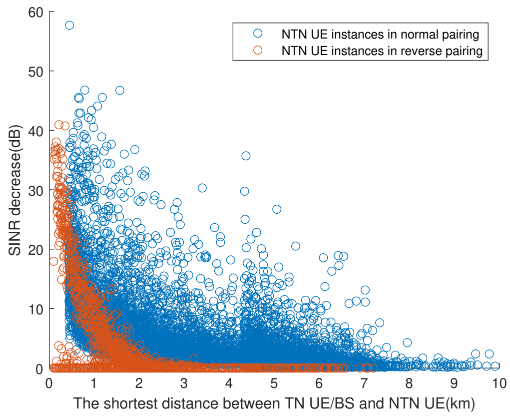

Fig. 5. Impact of distance on NTN DL SINR reduction: Comparison of regularity between normal and reverse pairing.

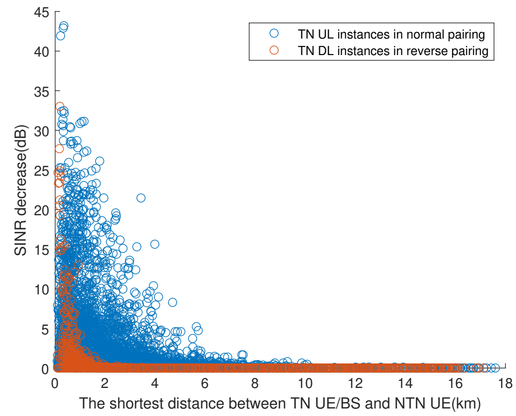

Fig. 6. Impact of distance on TN DL and TN UL SINR reduction: Comparison of regularity between normal and reverse pairing.

For the normal pairing, when the interference is from a TN BS, the NTN DL SINR decrease is no longer solely determined by the nearest TN BS distance and LOS/NLOS condition. The beamforming direction of the adjacent TN BSs can cause greater interference power than the nearest TN BS to the NTN UE. Hence, the adjacent TN BS beamforming directions significantly affect the NTN DL SINR.

Observation 6: *Identifying the dominant interference sources of NTN DL is easier in the reverse pairing than in the normal pairing.*

Mitigation for NTN DL in reverse pairing: The existing cross-link interference (CLI) mechanism developed by 3GPP in R16 can serve as a baseline mechanism since the interference pattern of NTN DL in reverse pairing is similar to CLI. However, accurately detecting the interfering TN UE is critical to improving NTN DL performance. The extreme coverage of the NTN beam causes considerable overhead for a satellite to coordinate numerous TN BSs in the beam coverage to find the interfering TN UE. Therefore, effectively identifying the TN UEs causing interference to the NTN DL is crucial in designing an interference mitigation mechanism. Interference detection for NTN UE can be used as a baseline solution.

Mitigation for NTN DL in normal pairing: The NTN BS may require precise geographic location information of the NTN UE, making it challenging to identify the TN BS and beamforming direction causing severe interference. Accurately identifying the TN BS and beamforming direction that cause interference to the NTN UE is vital in improving the performance of NTN DL in normal pairing, considering the interference pattern is similar to inter-cell interference in the cellular network.

E. The analysis of NTN UL impact on TN.

Fig. 6 shows how NTN UL affects TN DL and TN UL SINR degradation. As the distance between the TN UE and the nearest NTN UE increases, the TN DL SINR degradation decreases rapidly. Moreover, the receiving beamforming direction of the TN BS also impacts the TN UL SINR decrease, with interference being more severe when an NTN UE is in the receiving beamforming direction. Since NTN UL has less impact on TN DL than on TN UL, TN DL is less sensitive to NTN UE's interference than TN UL.

Observation 7: *TN DL is more robust to NTN UE's interference than TN UL.*

Mitigation for TN DL in reverse pairing: Given that only a few TN UEs are severely interfered with by NTN UL in DL (Observation 1), TN UE can detect nearby interfering NTN UEs and avoid using the radio resources used by them. This is a more practical solution, especially considering the long round-trip time of NTN.

Mitigation for TN UL in normal pairing: As shown in Fig. 2, only a few TN BSs will be severely interfered with by NTN UL in UL. Therefore, TN BS can use the same interference mitigation method as above, where it avoids using the radio resources used by NTN UEs in the directions where an NTN UE is detected, to reduce the interference from NTN UL.

IV. NTN-TN SPECTRUM SHARING RESEARCH OPPORTUNITIES

This section discusses the research challenges and opportunities of NTN-TN spectrum sharing in 6G in this section. First, interference mitigation techniques for NTN-TN spectrum sharing will be explored. Then, the technical challenges of interference monitoring will be presented. Lastly, we examine the inter-system coordination and UE association topics in 6G NTN-TN spectrum sharing.

A. Interference monitoring and measurement

Most interference mitigation methods rely on pathloss information between aggressor-victim pairs, but obtaining measurements for numerous pairs in NTN extreme coverage introduces significant overhead. For instance, coordination between TN and NTN can be established to configure reference signals on specific radio resources for interference measurement, especially when the operation of TN/NTN is hindered by inter-system interference. However, this approach may necessitate additional signaling between satellites, TN base stations, and user equipment, underscoring the importance of developing less overhead measurement mechanisms to effectively mitigate NTN-TN spectrum sharing interference [9].

Another technical challenge is that received TN power is much stronger than received NTN power in TN coverage. According to Fig. 2, TN intra-system interference overpowers the NTN-to-TN interference observed by the tiny SINR degradation. BSs and TN UEs could fail to detect the NTN reference signals because of the overpowered TN inter-system interference. A coordinated measurement mechanism could increase the NTN reference signal measurement accuracy.

In light of the growing NTN constellation in the 6G time frame, the TN system may face potential interference challenges caused by NTN. To ensure the TN's operation, it could be important for TN to devise a robust detection method that can accurately identify the satellites causing interference. Developing an effective interference detection mechanism will enable TN to take appropriate mitigation actions and maintain seamless coexistence with NTN, thereby optimizing overall spectrum utilization in the 6G landscape.

B. Interference mitigation techniques

In this subsection, we provide an overview of promising interference management techniques, including static, semi-static, and dynamic techniques, for NTN-TN networks.

Power control: Power control is a well-known technique in TN for reducing harmful interference [10]. Power control methods are particularly effective when interfering users are nomadic since the UE antenna is typically omnidirectional, especially in a lower frequency band. To ensure the reliable operation of NTN systems, low complexity and interference-perceptive power control methods for TN UEs are crucial research areas.

Beamforming and downtilt angle: Spatial interference mitigation techniques could reduce interference from TN BSs to satellites. One common static technique is to deploy base stations with a lower downtilt angle, which can help to reduce interference. However, a more promising approach is to use dynamic spatial interference mitigation techniques, such as base station beamforming [11]. By adaptively configuring the antenna pattern of the base station, it is possible to minimize interference to the satellite and maximize the throughput of the TN. This approach can be particularly effective with satellite orbit information, which can help optimize TN UE scheduling based on the current antenna pattern. Lastly, we believe jointly minimizing inter-system interference and maximizing TN throughput could further improve the spectral efficiency of NTN-TN integrated networks.

NTN frequency pattern reuse: The frequency reuse pattern of the NTN system offers opportunities for TN to access the idle NTN channels without causing harmful interference. The frequency reuse pattern, a common approach for avoiding inter-beam interference in the NTN, involves assigning different NTN channels to adjacent NTN beams. Thus, TN could reuse the idle NTN channel of the NTN covering NTN beam based on the frequency reuse pattern to enhance spectral efficiency [12]. However, this technique could also cause additional interference with neighboring NTN beams. Therefore, researchers need to investigate how to combine NTN frequency pattern reuse with other interference mitigation techniques to increase spectral efficiency while avoiding harmful TN-to-NTN interference.

Bandwidth allocation and scheduling: In NTN-TN spectrum sharing, bandwidth allocation, and scheduling mechanisms are crucial for maximizing system spectral efficiency while ensuring the users' quality of service (QoS) requirements. One approach to mitigating harmful interference in such scenarios is to allocate non-overlapping frequency sub-channels or different time slots to vulnerable users [13]. However, this requires close cooperation between NTN and TN. For example, if NTN identifies NTN user equipment (UEs) in proximity to specific TN base stations with corresponding beam directions through measurement, NTN would need to communicate to those TN base stations about the specific frequency range to be used by NTN UEs with fragile links. Subsequently, the TN base stations could intelligently schedule radio resources to TN UEs located far away from those NTN UEs, effectively avoiding inter-system interference while maintaining high spectral efficiency.

Several strategies of frequency allocation and scheduling mechanisms are worth investigating, including joint optimization of bandwidth allocation and scheduling, and machine learning algorithms for predicting user behavior and traffic demand.

Multiple Access Design: Implementing specific multiple access methods can help mitigate interference in NTN-TN spectrum sharing. Techniques like non-orthogonal multiple access (NOMA) and rate-splitting multiple access (RSMA) focus on interference suppression at the receiver end to enhance SINR [14]. Despite their potential to achieve higher spectral efficiency than other methods, such as FDMA, these techniques often necessitate advanced receiver designs and additional information exchange between transmitters and receivers.

Given the extreme coverage scope of the NTN system, introducing NOMA or RSMA could bring about considerable signaling overhead, posing substantial challenges. For instance, when integrating RSMA into NTN-TN spectrum sharing, there might be a need for NTN and TN to exchange specific portions of their data streams. This exchange implies that enhanced coordination and synchronization are essential between NTN and TN. While the theoretical advantages of NOMA and RSMA are compelling, the practical implementation, particularly of RSMA in NTN-TN spectrum sharing, presents many challenges. When applying a novel multiple access scheme such as NOMA or RSMA to NTN-TN integrated system, efficient management and communications overhead need to be carefully investigated.

Integrated communication and sensing: The integration of communication and sensing presents a unique opportunity to improve the performance of both systems [15]. In traditional communication networks, inter-cell interference is often seen as a problem that needs to be mitigated. However, in sensing networks, such interference can contain valuable information about targets of interest that can enhance the overall sensing performance. We can extract additional gains in sensing performance by receiving integrated communication and sensing signals from unintended cells or UEs.

Conversely, sensing networks empowered by integrated communication and sensing signals can provide information on potential interference sources to the NTN-TN integrated networks. This information can be used for further radio resource management, enabling better interference coordination and radio spectrum allocation. Thus, integrated communication and sensing signals for harmful interference source detection in NTN-TN integrated networks are worth studying.

V. Acknowledgments

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VI. Conclusion

In 6G, opportunistic spectrum usage of the under-utilized spectrum might provide valuable spectrum resources for wireless services. A system-level simulation and analyses of NTN-TN spectrum sharing are delivered. According to the simulation results, the reverse pairing outperforms the normal pairing. The NTN has a minor impact on TN in reverse and normal pairing. The analyses of interference influences offer design concepts of interference mitigation mechanism design. In summary, reverse pairing has fewer key factors affecting inter-system interference than normal pairing. Making designing simple and practical interference mitigation mechanisms easier. With proper spectrum-sharing mechanisms, NTN-TN spectrum sharing could dramatically enhance spectrum utilization and provide extraordinary seamless coverage.

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VII. Biography Section

Hao-Wei Lee received the B.S. degree in Electrical Engineering and Computer Science Undergraduate Honors Program and the M.S. degree in Institute of Communications Engineering from National Chiao Tung University, Hsinchu, Taiwan, in 2015 and 2017, respectively. He is currently working toward the Ph.D. degree in communication engineering with the Graduate Institute of Communication Engineering from National Taiwan University, Taipei, Taiwan. He was an Intern with MediaTek from 2020 to 2022. His research includes D-TDD, NTN, spectrum sharing, interference mitigation, as well as 3GPP LTE and NR standards.

Abdelkader Medles is a Senior Technical Manager at MediaTek. He earned his PhD in electrical engineering from Telecom Paris in 2004. He worked in research and development of the physical layer for 3GPP WCDMA, LTE and 5G standards successively in Icera Semiconductor, Mstar and MediaTek. Since he joined MediaTek in 2014 he led an algorithm and architecture team for the design of the user equipment modem and contributed to the definition of 5G specifications as a research team leader and 3GPP delegate. He also led a proof-of-concept research and prototyping team for 5G NTN technology.

Chun-Chia Chen received B.S., M.S., and Ph.D. degrees in Computer Science from National Tsing Hua University (NTHU), Taiwan, in 1999, 2001, and 2007. He currently worked as a senior engineer in MediaTek. He actively participates in 5G mobile communication,6G mobile communication, artificial satellites, cellular radio, millimeter wave communication, satellite communication, and telecommunication traffic.

Hung-Yu Wei is a Professor in Department of Electrical Engineering and Graduate Institute of Communications Engineering, National Taiwan University. He received the B.S. degree in electrical engineering from National Taiwan University, the M.S. and the Ph.D. degree from Columbia University. He joined Department of Electrical Engineering at the National Taiwan University in 2005. He served as Associate Department Chair and Interim Department Chair during 2019 2022. His research interests include wireless networks, IoT, and fog/edge computing. He is the Chair of IEEE 1935 working group for edge/fog management and orchestration standard. He served as program officer for Taiwan's NSTC 6G program.

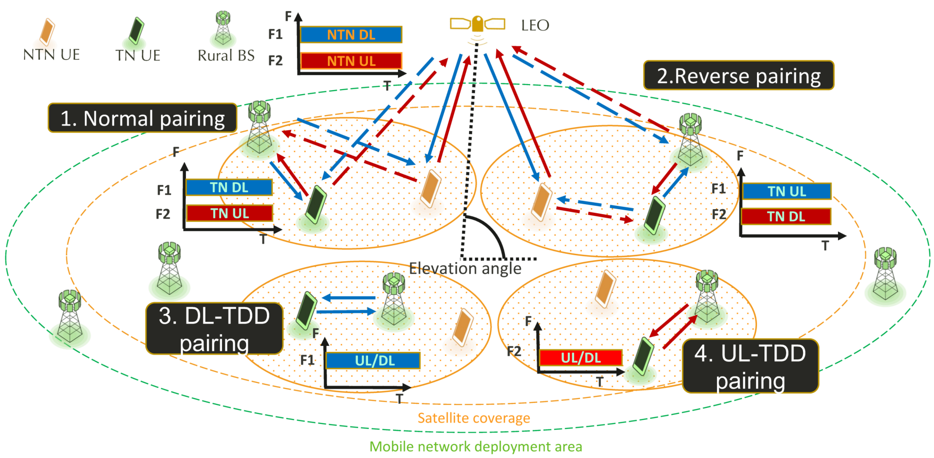

Fig. 1. NTN-TN spectrum sharing system architecture, possible spectrum sharing scenarios, and corresponding interference patterns. Green and yellow icons represent TN and NTN components, respectively.

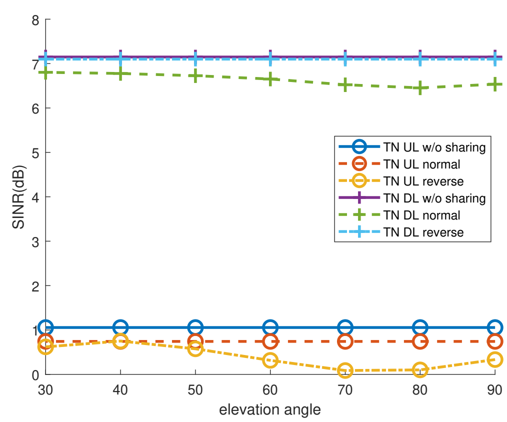

Fig. 2. Limited impact on TN in NTN-TN spectrum sharing.

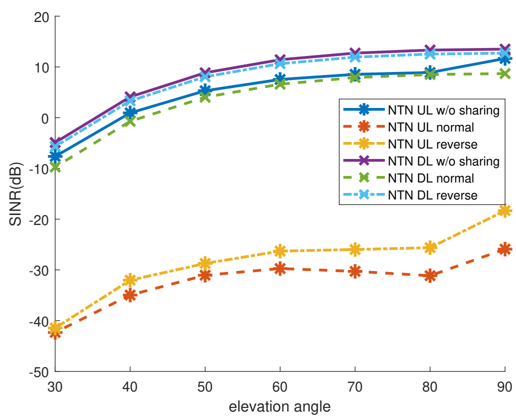

Fig. 3. Limited impact on NTN DL but a disruptive impact on NTN UL in NTN-TN spectrum sharing.

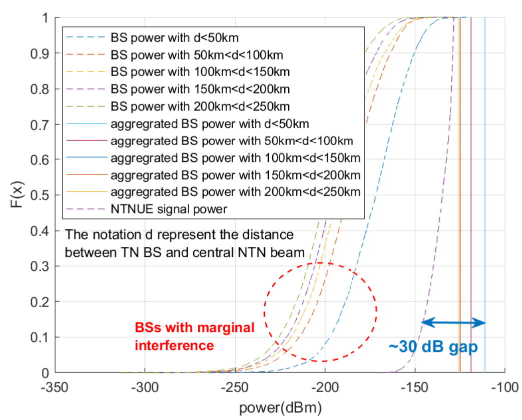

Fig. 4. CDF of TN BS to NTN UL interference power when elevation angle of the beam center is 70 degrees in reverse pairing. The wide distribution of TN BS highlights the need for interference measurements to mitigate interference. The harmful interference from the aggregated BSs within concentric circles emphasizes the importance of considering all BSs within the NTN coverage.

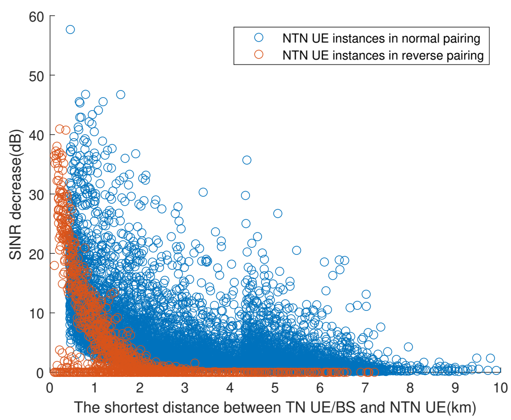

Fig. 5. Impact of distance on NTN DL SINR reduction: Comparison of regularity between normal and reverse pairing.

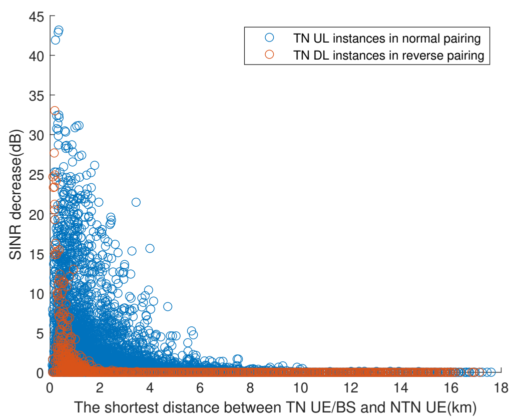

Fig. 6. Impact of distance on TN DL and TN UL SINR reduction: Comparison of regularity between normal and reverse pairing.