5G Interference Measurements for Simulated TDD Symbol Based Scheduling And Radar

Abstract—**Abstract: This paper introduces a novel simulation framework and mathematical model to analyze radar interference in 5G Time Division Duplexing (TDD) systems, focusing on critical parameters such as Transmission Time Interval (TTI) and Resource Block allocation. The model provides a foundation for evaluating interference dynamics and informs the simulation of varying TTI strategies. The results reveal that interference impacts can be mitigated through adaptive scheduling strategies, though at the cost of throughput, a critical trade-off for system optimization. These findings offer actionable insights into the balance of performance and co-existence in 5G and radar system deployments.**

Index Terms—**5G, Radar, DL, UL, Scheduler, MAC, MCS, CQI, Spectrum, CoExistance, Symbol, TTI, Matlab, Model, Harq**

I. Introduction

The increasing demand for efficient spectrum utilization has driven the need for 5G and radar systems to coexist in shared frequency bands, such as the Citizens Broadband Radio Service (CBRS) band [1], [2]. This band is also occupied by high-power radar systems, including military radars like the SPN-43 air traffic control radar [3], [4], which must operate concurrently with terrestrial 5G networks. This coexistence introduces significant challenges, as radar signals can severely disrupt 5G Time Division Duplexing (TDD) systems. These systems, which use the same frequency for uplink and downlink, are especially susceptible to external interference. With 5G supporting critical applications like autonomous systems and industrial IoT, ensuring reliable communication in these shared spectrum environments has become a priority.

Symbol-level scheduling, a key feature of 5G TDD systems, provides finer granularity in resource allocation compared to traditional slot-based scheduling. This granularity allows for dynamic adjustments to Transmission Time Interval (TTI) configurations and resource assignments, which can reduce radar interference. However, implementing symbol-level scheduling presents challenges such as managing collision probabilities, retransmissions, and fairness among users. While prior studies have broadly explored radar interference, most focus on slot-based scheduling from legacy cellular systems or analyze high-level system impacts. These studies lack a detailed investigation into symbol-level scheduling and its potential for interference mitigation in realistic scenarios. Furthermore, there is a gap in simulation tools capable of quantifying the performance of advanced scheduling techniques under shared spectrum conditions.

In this paper, we address the challenge of symbol-level interference in TDD systems by introducing a simulation framework that models radar interference at the symbol level. This platform facilitates the analysis of various scheduling strategies, TTI configurations, and channel conditions, providing insights into critical performance metrics such as throughput, retransmission rates, and collision probability. By capturing the dynamic interactions between radar pulses and 5G transmissions, our work supports the development of effective coexistence mechanisms. Unlike existing research that emphasizes static or slot-level scheduling, our study focuses on symbol-level experimentation to offer a deeper understanding of 5G and radar coexistence.

Our key contributions are as follows:

- Development of a simulation framework for modeling radar interference at the symbol level in 5G Time Division Duplexing (TDD) systems.
- Comprehensive analysis of radar interference impacts on critical 5G parameters, including Transmission Time Interval (TTI) and Resource Block Group (RBG) allocations.
- Actionable insights into interference avoidance strategies to enhance coexistence between radar and 5G systems.

II. Related Work

The coexistence of radar and 5G systems in shared spectrum environments has been a prominent area of research, with numerous studies analyzing the mutual impact of interference. For example, [5], [6], and [7] examine the degradation of the 5G system performance caused by radar signals, highlighting issues such as reduced throughput and increased error rates. In contrast, studies such as [8] and [9] focus on the effects of 5G interference on the performance of the radar system, underscoring the bidirectional nature of the challenge of co-existence.

Although these studies provide valuable information on the impacts at the system level, they often overlook the role of scheduling strategies in mitigating interference. A key advancement in 5G compared to 4G is the introduction of symbol-based scheduling [10], [11], which allows for a finer allocation of resources than the slot-based scheduling used in 4G [12], [13]. Symbol-based scheduling allows for more precise interference management by dynamically adjusting resource assignments, making it a promising technique for reducing periodic short bursts of radar interference.

Symbol-based scheduling also brings the flexibility to adapt Transmission Time Intervals (TTI), which can minimize the duration of vulnerable transmission blocks and reduce the overlap between radar pulses and 5G transmissions. Advanced techniques, such as the integration of xAPPs and Edge Computing, further enhance the potential of symbol-based scheduling by enabling real-time adaptive interference avoidance strategies. These innovations present opportunities for significant performance improvements, particularly in shared spectrum environments.

Recent research has explored specific aspects of symbol-based scheduling. For example, [14] and [15] investigate machine learning approaches for real-time symbol scheduling, while [16] studies the impact of symbol-based allocation on uplink performance in network slicing. Furthermore, studies such as [17] evaluate the benefits of TTI adjustments for traffic management, demonstrating the potential of dynamic scheduling to improve performance metrics.

Despite these advances, there is a lack of comprehensive research that focuses on the effectiveness of symbol-based scheduling to mitigate radar interference. Existing studies primarily address high-level system impacts or focus on slot-based scheduling strategies, leaving a significant gap in understanding how symbol-level scheduling can improve radar-5G coexistence. Furthermore, robust simulation tools are scarce to evaluate symbol-level interference and scheduling techniques under realistic conditions.

This paper addresses these gaps by presenting a detailed analysis of symbol-level scheduling strategies for 5G TDD systems in shared spectrum environments. Our simulation platform models radar interference at the symbol level and evaluates the impact of various scheduling strategies on critical performance metrics, including throughput, retransmission rates, and collision probability. By providing novel insights into the trade-offs and potential of symbol-based scheduling, this work contributes practical solutions to improve spectrum sharing and interference mitigation in 5G networks.

III. System Model and Design

Radar transmissions often overlap with the serving cell of a 5G TDD network, causing significant interference for User Equipment (UEs) and disrupting critical functionalities such as resource scheduling and data transmission. These challenges are particularly severe in environments with high-power radar signals, which can overwhelm 5G transmissions. To address these issues, we developed a simulation platform to model radar interference at the symbol level in 5G TDD systems, enabling the quantification of performance impacts and the exploration of mitigation strategies.

The simulation platform, implemented using MATLAB's Wireless Network Simulator, is designed to analyze the coexistence of 5G and radar systems. It supports the detailed exploration of symbol-level scheduling strategies under varying interference scenarios and includes:

- Configurable Transmission Time Interval (TTI) schemes,
- Adjustable radar parameters, such as pulse width (τ_r) and Pulse Repetition Interval (PRI),
- Advanced logging capabilities for key performance metrics: throughput, retransmission rates, and collision probability.

The concept of operations the system model is targeted to simulate is illustrated in Figure 1.

A. Mathematical Model for Collision Probability

Collisions occur when radar pulses overlap with 5G symbols. To quantify this interference, we model the expected percentage of interference (I) as:

$$I = \frac{Slot_C \cdot Block_C}{Block_{Slot}}$$

where:

- $Slot_C = \frac{\text{Slot Duration}}{\text{PRI}}$: Represents the overlap between the radar pulse interval and the 5G slot duration.

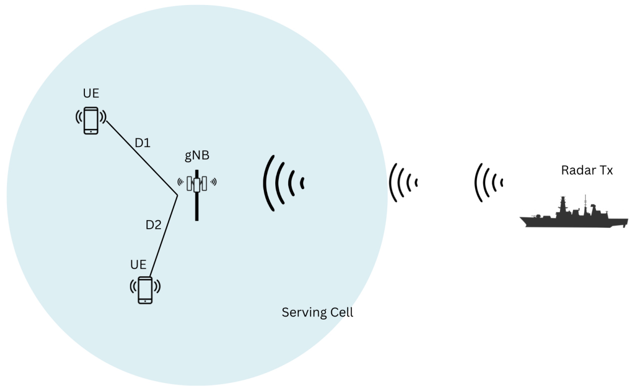

Fig. 1: Simulation Con-Ops of High Power Radar Interference on a 5G TDD Cell

- $Block_C = \lceil \frac{\text{Pulse Width}}{\text{TTI}\cdot T_s} \rceil \cdot Offset$: Calculates the proportion of affected transmission blocks.
- $Block_{Slot} = \lceil \frac{\text{Symbols per Slot}}{\text{TTI}} \rceil$: Determines the total number of transmission blocks per slot.

1) Assumptions: The following assumptions are made:

- Radar signals are significantly stronger than 5G transmissions, causing total data loss upon overlap.
- Radar pulses fully overlap the 5G bandwidth, affecting all resource blocks in the time window.
- The simulation assumes a normal cyclic prefix with 14 symbols per slot.

B. Simulation Parameters and Configurations

The physical layer parameters used are shown in Table I. A subcarrier spacing (SCS) of 15 kHz was chosen, corresponding to a 1 ms slot duration, which aligns with the AN/SPN-43 radar's 1 ms Pulse Repetition Interval (PRI) [18]. This alignment ensures radar pulses synchronize with 5G slot boundaries, allowing accurate modeling of interference dynamics.

TABLE I: PHY Layer Parameter Settings

Parameter	Values
Symbol Lengths	[552 548 548 548 548 548 548 548 548 548 552 548 548 548]
Nfft	512
Sample Rate	7680000
Symbols Per Slot	14
Slots Per Subframe	1
Slots Per Frame	10

IV. Experimentation Setup

The model ran varying the number of UEs from 5,10,15, and 50 for TTIs 2,4,7 for each. This was done to minimize any abnormality that could occur with the scheduler distributions. Each simulation ran for 100 frames.

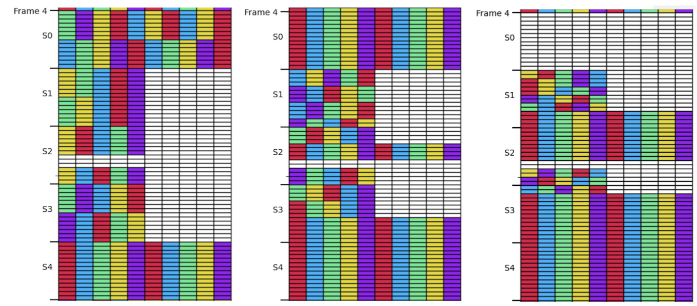

Fig. 2: Scheduler comp for 5 UEs no Interference [Left to Right: TTI= 7,4,2]

The static configuration values across each run for the gNb were as follows:

- Scheduler: Round Robbin
- Static MCS of 5 for each UE
- 15KHz Sub-Carrier Spacing
- 20 Resource Blocks of BW (10 RBGs)
- A roughly even Slot pattern of 2D1S2U where S is (8D2G4U).
- Slot pattern periodicity of 5ms (10 slots per Frame with 15KHz SCS)
- Each UE at a simulated distance of 300m.
- Each UE with a simulated BitRate of 10Mbps in both DL and UL directions.

The Radar configurations were:

- Radar Pulse width of 60 uS
- Radar Priodicity of 1 mS
- Radar BW of 5 MHz
- Radar offset such that symbol index 2 [1 .. 14] was interfered with.

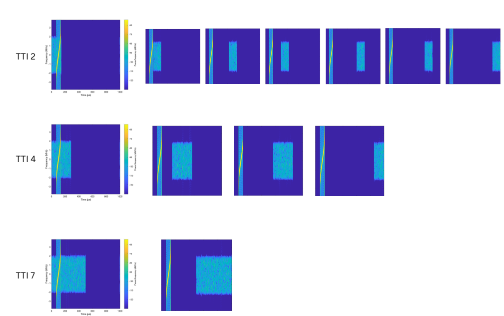

Fig. 3: Spectrogram of Radar Interference for TTIs 2, 4, and 7

V. Expectation of Results

The estimated block collision percentages are derived from the system parameters detailed in Sec. IV and calculated using the simplified model introduced in Sec. III-A. These percentages are directly compared in Fig. 3, where the impact of different TTI configurations on block collisions is clearly illustrated. For example, when the TTI is set to 7, approximately half of the transmitted blocks experience interference. In contrast, with a TTI of 2, only one out of seven blocks overlaps with the radar pulse. This demonstrates how shorter TTIs significantly reduce the probability of block collisions, thereby mitigating the effects of interference.

- **TTI = 7:** 50% of symbols impacted.
- **TTI = 4:** 25% of symbols impacted.
- **TTI = 2:** 14.2% of symbols impacted.

Our other assumptions about the varying TTI:

- **Shorter TTIs:** Will minimize the duration of vulnerable transmission blocks but increase control overhead, reducing throughput.
- **Longer TTIs:** Should maximize efficiency but would likely be more susceptible to radar interference.

A lower MCS (Modulation and Coding Scheme) was deliberately selected to ensure that any link adaptation algorithm in the simulation would not influence block retransmissions. Preliminary testing at a simulated range of 300 meters indicated an MCS of 28 under normal conditions. However, to minimize the impact of path loss on the results and isolate the effects of radar interference, a significantly lower MCS was chosen. This approach ensured 100% packet success in the absence of interference, allowing the analysis to focus solely on packet loss caused by simulated radar interference. By eliminating path loss as a confounding factor, the results became easier to interpret and directly attributable to interference dynamics.

VI. Results

Fig 4 is the box plot results of multiple interference testing varying the number of UEs. We can see from the results that the TTIs observed in the simulate are higher than predictions done in sec III-A. We can equate this to HARQ procedures causing the same block to hit interference multiple times causing additional retransmissions.

High bit rates were chosen for the available bandwidth to maximize resource scheduling. However, as shown in Figure 2, not all symbols were allocated.

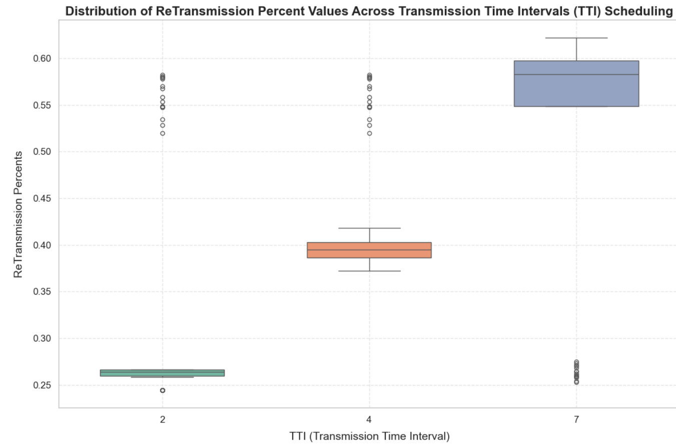

Fig. 4: Box Plot showing Re-Transmissions percentages per TTI

Despite this, the resources that were scheduled exhibit a uniform distribution. This uniformity stills shows even symbol allocations when no interference is present. We can also see that when no interference is present the resource allocation for the 5 UEs tested in fig 5 is still 20% per UE and is consistent for the test duration.

For **TTI = 2**, the results reveal low overall throughput at the cell level, with minimal variation among UEs. Resource allocation is highly uniform and stable, demonstrating strong resilience to interference. This configuration, however, introduces significant trade-offs: the smaller TTI requires more frequent transmissions, leading to higher overhead and reduced efficiency for the same amount of data.

In contrast, **TTI = 7** achieves the highest overall throughput, but this comes with greater variability in performance among UEs and reduced fairness in resource allocation. Resource distribution exhibits noticeable fluctuations as UEs compete for limited resources, and the larger TTI makes the system more sensitive to interference, which can significantly disrupt performance. These trade-offs make TTI = 7 unsuitable for highly dynamic or interference-prone environments. However, it is well-suited for enhanced mobile broadband (eMBB) applications where maximizing throughput is the primary objective.

TTI = 4 strikes a balance between the two extremes. Cell throughput is higher than TTI = 2 but lower than TTI = 7, with moderate variation in performance among UEs. Resource allocation remains relatively stable, with only minor fluctuations, making it a compromise between fairness, resilience to interference, and efficiency.

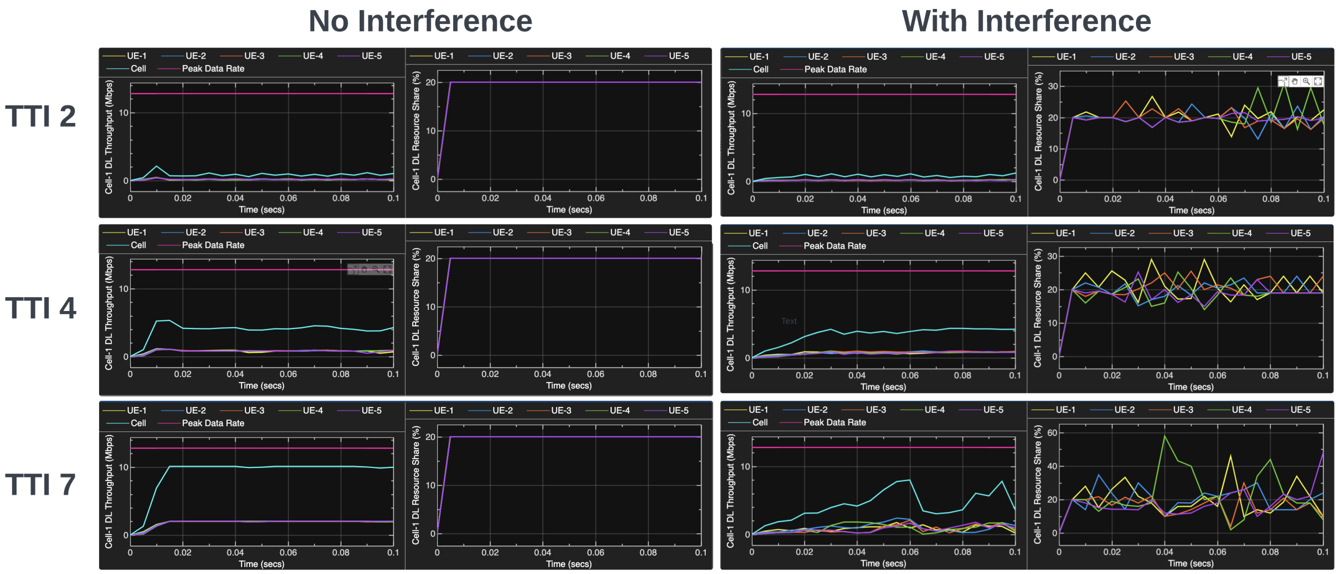

Fig. 5: DL Throughput and Resource Share % for 5 UE and various TTIs with and without interference

The trade-offs in this configuration are less pronounced, offering a practical middle ground that makes TTI = 4 suitable for scenarios requiring a balance between moderate throughput, low latency, and interference tolerance. Overall, these findings underscore the importance of selecting TTI configurations based on the specific trade-offs and performance needs of the application.

Figure 6 is a good visual representation of the unequal distribution of resources from the scheduler when radar signals are present. The scheduler prioritizes retransmissions over "new" transmissions. We can compare the TTI of 7 distribution for 15 UEs to the the bottom right image in Figure 5.

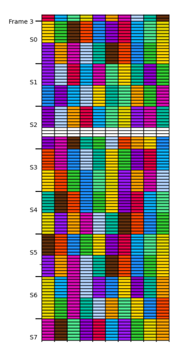

Fig. 6: Example of uneven scheduled resources due to interference for TTI=7 with 15UEs

VII. Use Cases

Developing a simulation platform provides a practical way to study how pulsed radar signals interfere with 5G Time-Division Duplexing (TDD) systems. This platform supports various radar and communication system configurations, allowing researchers to assess performance impacts under different interference scenarios. Users can adjust radar signal characteristics and 5G system parameters to analyze the interactions between these systems, identify performance degradation, and determine operational thresholds. The presented example demonstrates the impact of different Transmission Time Intervals (TTIs) and their resilience to periodic radar signals.

A key use case is modeling the effects of diverse radar signals on 5G systems. By adjusting parameters like pulse width and Pulse Repetition Interval (PRI), researchers can quickly analyze how these factors influence 5G TDD signal performance. The platform also enables detailed analysis of 5G performance metrics such as throughput and block error rates. By varying 5G settings—including TTIs, Modulation and Coding Schemes (MCS), and Resource Block Group (RBG) allocations—researchers can identify configurations that minimize interference from radar pulses.

The platform also extends its capabilities to advanced spectrum management techniques for emerging 6G applications, such as spectrum avoidance and dynamic sharing. Features like cognitive radio, priority-based access, and machine learning-driven spectrum predictions help manage interference more effectively. These tools allow researchers to evaluate and develop advanced spectrum-sharing strategies and interference mitigation techniques for both current and future communication networks.

The platform's flexibility in supporting various TTI configurations is particularly beneficial for specific application scenarios. For instance, TTI = 2 is highly suitable for ultra-reliable low-latency communication (URLLC) applications, where consistent resource allocation and resilience to interference are critical requirements. By leveraging the platform's ability to model and analyze symbol-level interference, researchers can fine-tune scheduling strategies to optimize performance for low-latency use cases, ensuring reliable communication even in challenging interference environments. This capability highlights the potential of the platform in addressing the stringent requirements of advanced communication systems.

VIII. Conclusion

This study presents a detailed investigation into the impact of radar interference on 5G Time Division Duplexing (TDD) systems, focusing on the trade-offs between Transmission Time Interval (TTI) configurations. Simulated results, as shown in Figures 4 and 5, closely align with the mathematical predictions, demonstrating that shorter TTIs (e.g., TTI = 2) reduce retransmission rates by limiting the overlap between radar pulses and scheduled blocks. However, these configurations come at the cost of higher overhead and reduced system throughput.

Larger TTIs (e.g., TTI = 7) maximize throughput under interference-free conditions but exhibit greater susceptibility to radar disruption, resulting in uneven resource allocation and reduced fairness among users. Conversely, TTI = 4 strikes a balance, offering moderate throughput and resilience, making it a practical choice for scenarios requiring both efficiency and interference tolerance.

The results reveal that HARQ (Hybrid Automatic Repeat Request) mechanisms exacerbate retransmissions under interference, as overlapping blocks are frequently retransmitted. This contributes to the discrepancy between simulated results and idealized predictions. Despite this, the consistent resource allocation observed across UEs in interference-free scenarios underscores the robustness of the scheduling process.

Ultimately, the findings highlight the importance of tailoring TTI configurations to specific use cases. Shorter TTIs are well-suited for Ultra-Reliable Low-Latency Communication (URLLC) applications, where interference mitigation is paramount, while larger TTIs are ideal for enhanced mobile broadband (eMBB) scenarios prioritizing throughput. The balance achieved by TTI = 4 further emphasizes the need for adaptive scheduling strategies that dynamically adjust to varying interference patterns and application demands.

References

[1] Federal Communications Commission (FCC), "Wireless Telecommunications Bureau and Office of Engineering and Technology Announce Procedures for Spectrum Access System to Begin Initial Commercial Deployments in the 3.5 GHz Band," Federal Communications Commission, Tech. Rep. DA 20-110, 2020, accessed: 2024-11-20. [Online]. Available: https://docs.fcc.gov/public/attachments/DA-20-110A1.pdf

[2] ——, "3.5 GHz Band Overview," 2021, accessed: 2024-11-20. [Online]. Available: https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

[3] P. Hale, J. Jargon, P. Jeavons, M. Lofquist, M. Souryal, and A. Wunderlich, "3.5 ghz radar waveform capture at point loma," *NIST TN 1954*, 2017.

[4] D. G. Bodnar and J. D. Adams, "Switchable-polarization study on an/spn-43a antenna," Engineering Experiment Station, Georgia Institute of Technology, Tech. Rep., 1975, accessed: 2024-12-02. [Online]. Available: https://repository.gatech.edu/bitstreams/98f20e43-5bf2-42ca-8fb5-326d45d88487/download

[5] H.-J. Hong, S. W. Choi, C. Sup Kim, and Y. J. Chong, "Interference measurement between 3.5 ghz 5g system and radar," in *2018 International Conference on Information and Communication Technology Convergence (ICTC)*, 2018, pp. 1539–1541.

[6] T. Ranstrom, P. Pietraski, and S. Pattar, "5g pusch channel estimation and decoding subject to high-power pulse radar interference," in *MILCOM 2022 - 2022 IEEE Military Communications Conference (MILCOM)*, 2022, pp. 437–441.

[7] J. A. DeVault, B. H. Kirk, A. F. Martone, R. M. Narayanan, and K. D. Sherbondy, "A proposed paradigm for evaluating spectrum sharing between a cognitive radar and 4g/5g communications," in *2022 IEEE Radar Conference (RadarConf22)*, 2022, pp. 1–6.

[8] J. A. DeVault, J. A. Kovarskiy, B. H. Kirk, A. F. Martone, R. M. Narayanan, and K. D. Sherbondy, "Lte interference effects on radar performance," in *2021 IEEE Radar Conference (RadarConf21)*, 2021, pp. 1–6.

[9] B. Kim, M. kang, H. Kim, and S. Park, "A study of radar interference effects analysis using simulation," in *2019 International Conference on Information and Communication Technology Convergence (ICTC)*, 2019, pp. 1076–1078.

[10] 3GPP, "NR; Physical channels and modulation," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 38.211, 04 2018, version 15.2.0. [Online]. Available: https://www.3gpp.org/DynaReport/38211.htm

[11] 3rd Generation Partnership Project (3GPP), "NR; Physical layer procedures for control (Release 15)," 3GPP, Technical Specification 38.213, Dec 2020, version 15.9.0. [Online]. Available: https://www.3gpp.org/DynaReport/38213.htm

[12] ——, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 15)," 3GPP, Technical Specification 36.211, Jun 2018, version 15.2.0. [Online]. Available: https://www.3gpp.org/DynaReport/36211.htm

[13] ——, “Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 15),” 3GPP, Technical Specification 36.213, Jun 2018, version 15.2.0. [Online]. Available: https://www.3gpp.org/DynaReport/36213.htm

[14] A. A. Esswie and K. I. Pedersen, “Madrl based scheduling for 5g and beyond,” *IEEE Wireless Communications Letters*, vol. 11, no. 8, pp. 1661–1665, 2022.

[15] ——, “Multi-user preemptive scheduling for critical low latency communications in 5g networks,” in *2018 IEEE 88th Vehicular Technology Conference (VTC-Fall)*. IEEE, 2018, pp. 1–6.

[16] O. G. Al Taee, A. O. Al Janaby, and Y. M. Abbosh, “5g uplink performance of symbol-based schedulers with network slicing,” *EAI Endorsed Transactions on Wireless Spectrum*, vol. 7, no. 26, 2021.

[17] E. Fountoulakis, N. Pappas, Q. Liao, V. Suryaprakash, and D. Yuan, “An examination of the benefits of scalable tti for heterogeneous traffic management in 5g networks,” *arXiv preprint arXiv:1702.05899*, 2017.

[18] Radar Tutorial, “AN/SPN-43 Radar Information,” 2024, accessed: 2024-12-02. [Online]. Available: https://www.radartutorial.eu/19.kartei/07.naval/karte041.en.html

[19] Next Generation Mobile Networks, “5g tdd uplink: Enhancements and evolution,” Next Generation Mobile Networks Alliance, Tech. Rep., 2022, accessed: [06-2024]. [Online]. Available: https://www.ngmn.org/wp-content/uploads/220117-5G-TDD-Uplink-White-Paper-v1.0.pdf

[20] GSMA, “3.5 ghz 5g tdd synchronisation,” GSMA, Tech. Rep., 2020. [Online]. Available: https://www.gsma.com/connectivity-for-good/spectrum/wp-content/uploads/2020/04/3.5-GHz-5G-TDD-Synchronisation.pdf