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

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***Abstract*—Abstract: This paper presents a novel approach for simulating radar interference within 5G Time Division Duplexing (TDD) resource schedulers, focusing on the impact on critical 5G gNB system parameters such as Transmission Time Interval (TTI) and Resource Block Group (RBG) allocations. As spectrum sharing becomes increasingly prevalent, interference within 5G spectrum bands has become more common, necessitating new methodologies to address these challenges. The coexistence of deterministic radar systems and telecommunications networks in the same spectrum introduces unique opportunities for understanding the complex nature of 5G transmission block collisions and their impacts on the system level. We propose a method to identify and simulate these effects by developing a mathematical model that estimates block collisions based on 5G and Radar system parameters. This study contributes to the development of robust 5G systems capable of coexisting with radar operations in shared spectrum environments.**

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

I. Introduction

The new allocation of spectrum for 5G [1] [2], particularly in Band 78 (3.5 GHz), which is part of the broader C Band and overlaps with the Citizens Broadband Radio Service (CBRS), introduces new complexities, especially concerning coexistence with radar systems. This band is shared by various radar systems, including military radar systems such as the SPN-43 air traffic control radar [3], which are expected to remain operational alongside terrestrial 5G systems. This coexistence raises critical challenges for maintaining the performance and reliability of both systems, as interference could severely impact their respective functionalities. Therefore, effective spectrum sharing strategies are essential to address these challenges, especially given the increasing demand for wireless communication resources and the scarcity of available frequencies.

In this paper, we propose a model to identify and mitigate the impact of scheduling changes when aligned with radar interference in shared spectrum environments. A significant advancement in 5G over 4G technology is the introduction of symbol-based scheduling allocation, which allows for finer control compared to traditional slot-based scheduling. In 4G, users are allocated resources at the slot level, which can lead to periodic bursts of interference if radar signals coincide with the scheduled slots. In contrast, symbol-based scheduling enables more granular resource allocation, which can help in reducing short bursts of interference from radar systems by dynamically adjusting allocations to avoid overlapping with radar pulses. For example, reducing the Transmission Time Interval (TTI) can minimize the duration of blocks, thus allowing for more precise interference avoidance. Moreover, integrating symbol-based scheduling with xAPPs and Edge Computing could provide further opportunities to avoid interference from radar signals altogether.

The problem we address in this paper revolves around ensuring effective coexistence between 5G and radar systems operating in the same frequency band. Specifically, we investigate how symbol-based scheduling in 5G can be leveraged to mitigate interference from radar signals. The goals of this research are to (1) model the interactions between radar pulses and 5G TDD scheduling, (2) analyze the impact of different scheduling strategies on minimizing interference, and (3) propose and evaluate potential interference avoidance techniques using symbol-level allocations.

Our key contributions are as follows:

- We develop a simulation framework that models radar interference at the symbol level within 5G Time Division Duplexing (TDD) resource scheduling.
- We analyze the impact of radar interference on critical 5G parameters such as Transmission Time Interval (TTI) and Resource Block Group (RBG) allocations.
- We provide insights into interference avoidance strategies to enhance coexistence mechanisms for radar and 5G systems.

II. Related Work

Several studies have investigated the system-level impact of radar interference on 5G communications. For instance, the works in [4], [5], and [6] have analyzed how radar signals can affect 5G system performance, including the degradation of throughput and increased error rates. Additionally, the effects of 5G interference on radar system performance have also been considered in the literature [7], [8], highlighting the bidirectional nature of the coexistence problem.

However, there has been limited research focusing on the impacts of radar interference based on scheduling allocations. A significant technological advancement from 4G to 5G is the introduction of symbol-based scheduling allocation [9], [10], which provides more flexibility compared to the slot-based scheduling used in 4G [11], [12]. This flexibility allows for finer-grained resource allocation, potentially reducing periodic short bursts of interference from radar systems if specific strategies are applied.

One key hypothesis motivating this work is that symbol-based allocation can help mitigate radar interference by minimizing the duration of vulnerable transmission blocks through reduced Transmission Time Interval (TTI). By dynamically adjusting scheduling allocations at the symbol level, the likelihood of interference overlap can be reduced. Furthermore, advanced techniques such as the use of xAPPs and Edge Computing in combination with symbol-based scheduling offer promising opportunities for avoiding interference from radar signals altogether.

There is current work on the utilization of symbol based scheduling and applications of changing the types of symbol allocations for various use cases. Such as the challenges in addressing real time symbol scheduling changes [13], [14] alongside machine learning. There is additional work addressing UL performance impacts of for symbol based allocation in network slicing [15], and utilize TTI changes for traffic management [16].

Despite the promising potential of these techniques, there is a lack of comprehensive studies that explore the effectiveness of symbol-based scheduling in mitigating radar interference in 5G networks. This paper aims to fill this gap by providing an in-depth analysis of symbol-level scheduling strategies and their impact on coexistence with radar systems, offering novel insights and potential solutions for improved spectrum sharing.

III. Problem Statement

Our system model aims to minimize interference between radar and 5G systems in shared spectrum environments. A key goal in shared spectrum environments is to ensure resource allocation fairness while optimizing scheduling efficiency and minimizing retransmissions caused by radar interference. Our model allows for systems parameters changes to be quantified to better understand, address, and quantify differences in performance.

The parameters are shown in Table I.

Contraints:

Fairness Constraint: $S_u \geq R_{\min},\ \forall u \in [1, N_u]$

Resource Allocation Constraint: $\sum_{u=1}^{N_u} S_u \leq R_{\text{total}}$

Collision Constraint: $P_{coll} = \frac{\tau_r}{PRI} \leq \epsilon_1$

Retransmission Constraint: $R_r \leq \epsilon_2$

The scheduler is designed to optimize resource allocation and system performance. The optimization process aims to balance the trade-offs between minimizing collision probability (P_{coll}) and retransmission rate (R_r), both of which are influenced by the Transmission Time Interval (TTI) and resource allocation decisions. This is captured in the following objective function:

Objective Function:

$$\min_{TTI, \{S_u\}} \ \alpha \cdot P_{coll} + \beta \cdot R_r \tag{1}$$

TABLE I: Parameters used in the system model

Category	Parameter Description
System Resources	$R_{\textbf{total}}$: Total available resources (e.g., symbols, resource blocks).
	$R_{\textbf{min}} = \frac{R_{\textbf{total}}}{N_u} \cdot \gamma$: Minimum share of resources per user, where $\gamma \leq 1$.
Users	N_u: Total number of users.
	S_u: Resources allocated to user u, where $S_u \geq R_{\text{min}}$.
Scheduler Parameters	TTI: Transmission Time Interval.
	RBG: Resource Block Group.
Radar Parameters	τ_r: Radar pulse width.
	PRI: Pulse repetition interval.
	B_r: Radar bandwidth.
Performance Metrics	P_{coll}: Probability of collision between radar pulses and 5G transmissions.
	R_r: Retransmission rate due to interference.
	$\eta_u = \frac{S_u}{R_{\textbf{total}}}$: Scheduling efficiency for user u.
	$\eta_{\textbf{system}} = \sum_{u=1}^{N_u} \eta_u$: Total system scheduling efficiency.

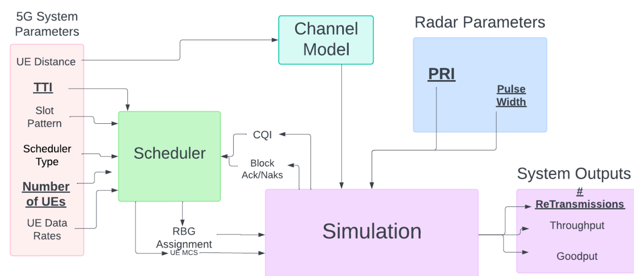

Fig. 1: Simulation IO Overview

where α and β are weighting factors representing the relative importance of minimizing collisions and retransmissions, respectively.

The optimization guides the scheduler to adapt the TTI dynamically in response to system conditions. By analyzing the current collision probability and retransmission rate, the scheduler updates the TTI to balance resource utilization efficiency and interference resilience. This dynamic behavior is expressed as:

Dynamic TTI Update:

$$TTI(t+1) = f(TTI(t), P_{coll}(t), R_r(t)) \tag{2}$$

Here, f represents the decision logic that adjusts the TTI based on real-time measurements of $P_{coll}(t)$ and $R_r(t)$. For example, if $P_{coll}(t)$ increases the decision logic would reduce the TTI interval such that the retransmission rate (R_r) would also decrease.

IV. System Model Design

Built on a MATLAB-based TDD scheduling example, the platform has been enhanced to include radar interference

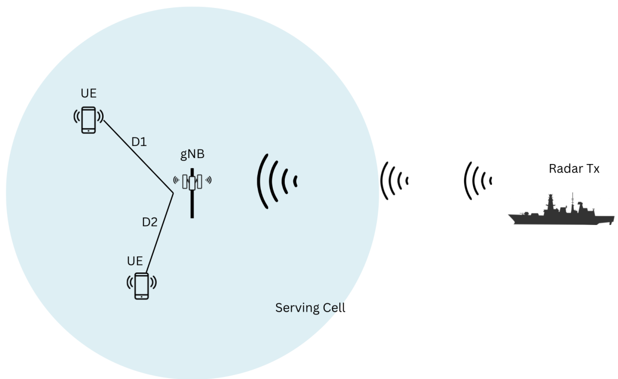

Fig. 2: Simulation Con-Ops of High Power Radar Interference on a 5G TDD Cell

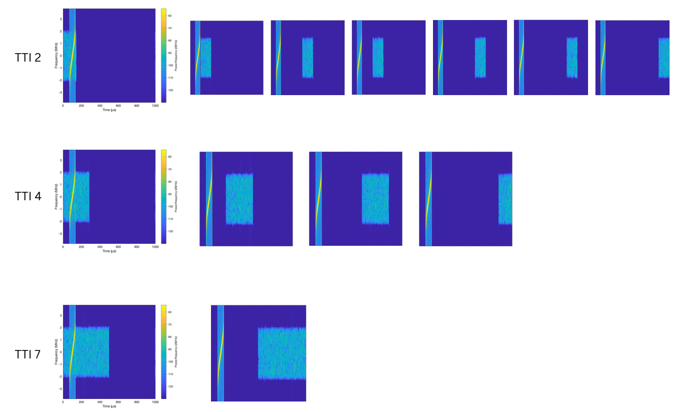

Fig. 3: Spectrogram of Radar interference for TTIs 2,4,7

modeling, advanced logging for detailed performance metrics. The model allow for changes in the scheduler TTI (Transmission Time interval), the number of users, and the simulated distances from the gNb.

As seen in Figure 1 there are many inputs and outputs to the modeling system. This investigation using the model highlights the impacts of TTI changes with various numbers of UEs attached. Other variables outlined in the model are held static.

A. Assumptions

One of the key assumptions made was that the radar signal is much greater than the gNb signal to a UE such that any overlap in the IQ would cause a complete loss for the given packet. The signal strength for the radar pulse is not attenuated to model radars at large distances (e.g. ¿¿ 10Km). We assume that the radar transmitter is close enough that the Radar Pulse Signal Strength is significantly stronger than that gNB to UE link. The power differences are visualized in Figure 3. This model does not consider ”weak” low power radar signals as interference and their potential impacts. . Another key assumption is that the Radar Pulse is much larger in frequency bandwidth than the transmitted 5G signals. Radars are commonly large in frequency as to increase the Radar Resolution [17]. We assume that the radar pulse will completely overlap the 5G BW such that if there is a direct interference in Time that all symbols in each PRB are effected equally. The large radar signal compared the 5G transmission burst is highlighted in Figure 3.

B. IQ Manipulation for Radar Pulse Injection

The matlab model this simulation is based on leverages the Wireless Network Simulator [18]. The IQ/Phy layer for this model, and specifically the Symbol Based Allocation strategy, sends an IQ sample equal to the slot length each time. The IQ sample length is static for each block transmitteded between the gNb and the UE. This is how we can see the TTI Symbol start length change so easily in Figure 3. This allowed for the logic of adding a radar pulse ”colliding” for each slot fairly easy. By adding the radar pulse to the IQ value for each transmitted block (Which is of Slot Length) we would only still have interference once. For example with the Physical layer parameters defined below each PHY later transmission is a 7680 complex double array. The parameter settings of PHY layer is shown in Table II

TABLE II: 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

The matlab model allocates the IQ data as per the TTI. The simulation then sends each TTI grouping to each UE. Our RF Generation determines if the SLOT has interference and then inputs the radar signal at the precise timing interval and transmits that signal across all TTI generated waveforms for the slot. As you can see in 3 that the radar pulse is on the 2nd symbol in the slot. Thus as each TTI is generated we can see that the 1 out of the 7 for TTI are interfered with, 1 out of 4 for a TTI of 4, and 1 out of 2 for the TTI of 7.

V. Use Cases

The devloping a simulation platform is a powerful tool for exploring how pulsed radar signals interfere with 5G Time-Division Duplexing (TDD) systems. Building a model can help support a variety of radar and communication system configurations. This enables researchers to assess performance impacts under different interference scenarios and system configuration. This specific platform’s versatility allows users to adjust both radar signal characteristics and 5G system parameters, allowing for a detailed understanding of the interactions between these systems and enabling insights into performance degradation and thresholds for effective operation.

A primary use case is the platform’s ability to model diverse radar signals and the effects on 5G users. By adjusting specific parameters like pulse width and Pulse Repetition Interval (PRI) we can quickly understand how durations and intervals affect 5G TDD signal performance. Similarly, this model allows an in-depth analysis of interference effects on 5G performance metrics, such as throughput and transmission block errors. Additionally, by varying 5G settings—including Transmission Time Interval (TTI), Modulation and Coding Schemes (MCS), and Resource Block Group (RBG) allocations, researchers can identify configurations that minimize interference due to radar pulses.

Expanding beyond 5G, the platform models advanced spectrum management techniques relevant to emerging 6G applications, such as spectrum avoidance and dynamic sharing strategies. Techniques like cognitive radio, priority-based access, and machine learning-driven spectrum predictions allow for smarter interference management. Through the integration of these advanced strategies, the platform helps researchers evaluate robust spectrum-sharing approaches and develop cutting-edge interference mitigation tactics for both current and future communication networks.

VI. Mathematical Model for Expected Collision Rate Between 5G Transmissions and Radar Pulses

A. Overview

Collisions between 5G transmissions and radar pulses occur when both signals overlap in time and frequency. In our simulations the radar pulse is much larger than the 5G transmission bandwidth so our model is only concerned about the overlap in time. By modeling the probability of such overlaps, we can estimate the expected collision rate. The model considers the following parameters:

- **5G Parameters:**
  - Transmission Time Interval (TTI)
  - Symbol duration
  - Number of symbols per TTI
  - Modulation and Coding Scheme (MCS)
  - Slot Duration
- **Radar Parameters:**
  - Pulse Width (τ_r)
  - Pulse Repetition Interval (PRI)

B. Assumptions

To simplify the model, the following assumptions are made:

1) **Synchronization:** The 5G transmissions and radar operate with precision clocks and thus any *drift* between the radar pulse and 5g symbol are considered negligible.
2) **Frequency Overlap:** The radar and 5G systems operate in the same frequency band, resulting a radar pulse completely overlapping the 5G signal.
3) **Normal CP** We assume that Normal Cyclic Prefix is used and that there are 14 symbols per slot.
4) **Radar PRI** We assume that Radar Pulse Repetition intervals are greater or equal to than the largest 5G slot duration of 1ms (15KHz SCS).
5) **Radar Pulse** We assume that the radar is only a single wideband pulse for a specific duration, PW (Pulse Width).
6) **Uniform Scheduler Distribution** The assumption that a scheduler will allocated its resources to users evenly and fully utilize the time and frequency resources.

C. Definitions of Key Parameters

- **Symbol Duration (T_s):** The duration of a single 5G OFDM symbol.
- **Slot Collisions($Slot_C$):** The overlap of the pulse repetition interval to the 5G slot.

$$Slot_C = \frac{Slot_{Duration}}{PRI}$$

- **Block Collisions ($Block_C$):** The percentage of blocks that will be interfered.

$$Block_C = ceil(\frac{PW}{TTI \cdot T_s}) \cdot Offset$$

where $Offset$ is an integer 1, or 2 depending on if the symbol overlaps with another.

- **Blocks per Slot ($Block_{Slot}$) :** The number of blocks in a given slot.

$$Block_{Slot} = ceil(\frac{Symbols_{Slot}}{TTI})$$

D. Percentage of Estimated Interference

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

E. Estimations

- 15KHz SCS
- 1ms Slot Duration
- T_s 71us
- PRI = 1ms
- PW = 70us
- TTI = 4

$$\frac{\frac{1ms}{1ms} \cdot ceil(\frac{70us}{4 \cdot 71us}) \cdot 1}{ceil(\frac{14}{4})} = \frac{1}{4} = 25\%$$

The probability that a single 5G symbol is affected by radar interference (P_{symbol}) is equal to the radar duty cycle:

$$P_{\text{symbol}} = D_r = \frac{\tau_r}{\text{PRI}}$$

Extending our estimations we expect the following percentage of collisions between the radar pulse and our block transmissions for each TTI simulated:

- TTI = 2: 14.2%
- TTI = 4: 25%
- TTI = 7: 50%

VII. Simulation Methodology

A. Experimental Variables

1) Radar:

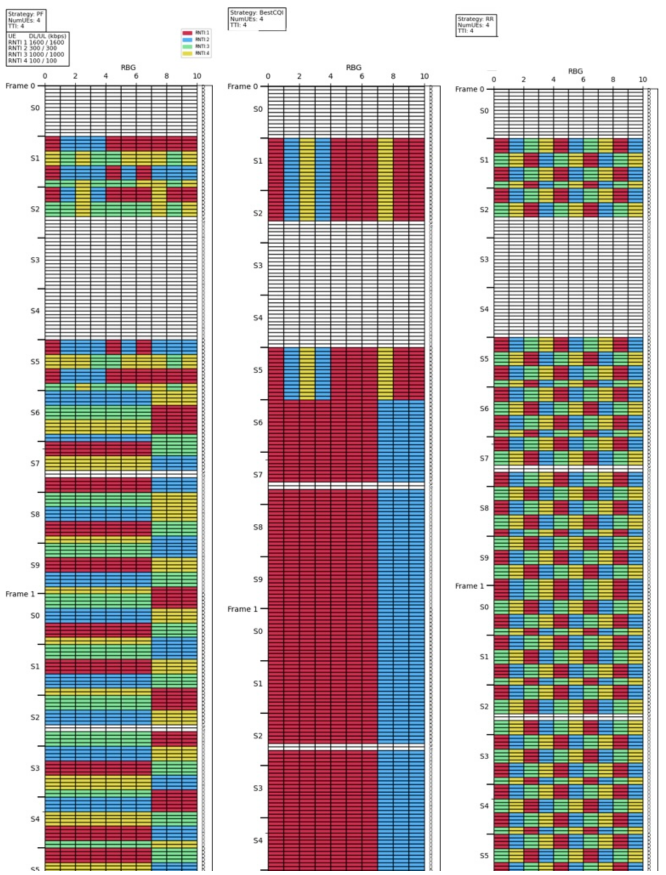

Fig. 4: Scheduler Comparisons: Proportional Fair, Best CQI, and Round Robbin (From left the right). Time is in the Y AXIS.

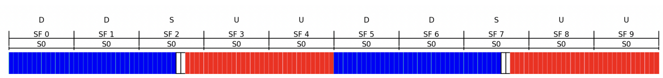

Fig. 5: DDSUUDDSUU Slot Pattern for 15KHz SCS (Generated from [20])

a) Pulse Widths:

b) Pulse Repetition Intervals:

2) 5G Parameters:

a) Scheduler Type: The simulation support Round Robbin, Proportional Fair, and BestCQI. From initial assessments in visualizing [19] the various schedulers as seen in figure 4 round robbin produced the most dense and evenly distributed resources. This was selected such that any given pulse would likely effect multiple UEs at the same time, as in comparisons that Proportional fair would likely only interfere with one user.

b) Slot Patterns:

c) TTI (Transmission Time Interval): The TTI (Transmission Time Interval) is a configurable setting in the experiment. This dictates the number of symbol allocated to each user during a transmission. For example if the TTI = 4 then the user will be allocated 4 symbols at 0, 4, 8 and at 12 will be allocated 2 because there are only 14 symbols per slot.

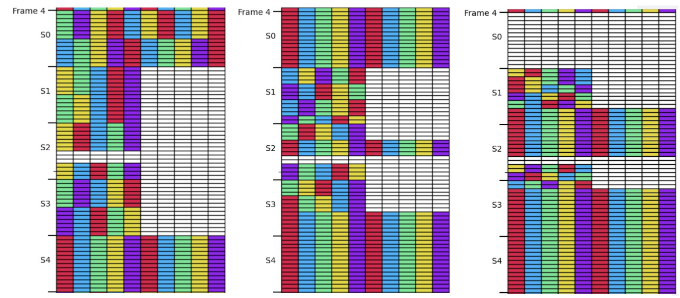

Fig. 6: Round Robbin Scheduler for TTI: 7, 4, 2 with 5 UEs

MCS = 5, Table = 256, TTI = 2,4,7, Scheduler RR,

d) RGB (Resource Block Group) Assignments:

e) Number of UEs:

f) UE Distance & PathlossModel:

g) UE Datarates:

h) UE MCS:

i) MCS Table Selection:

VIII. Experimentation and Results

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

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

- Scheudler: 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.

IX. Conclusion

The box plot results from Figure 7 show that our simulated radar interference was close to our mathematical predictions. We can see that as the TTI grow larger and occupy more of the symbols in a slot, the percentage of retransmissions grows. We can also see that for smaller TTIs the average re transmission is quite low in comparison. The results found here show that reducing the number of allocated symbols in our scheduler directly relates to less retransmissions in the system overall.

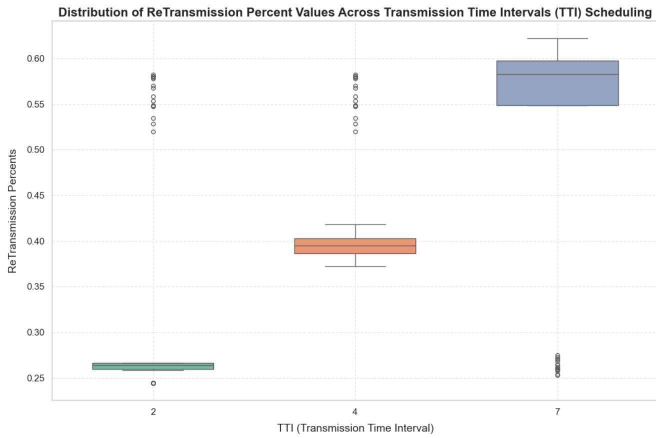

Fig. 7: Box Plot showing Re-Transmissions percentages per TTI

We can also see that the interference is larger than what was predicted. This is due to the scheduling fact that some retransmissions can be retransmitted more than once. This a feature of HARQ (Hybrid Auto Repeat Request). A Re Transmission may occur in the same spot interference spot, causing additional retransmissions to be sent again.

Large bit rates for the actual bandwidth were chosen to maximize the resource scheduling. However we can see from Fig. 6 that not all symbols were allocated. However we can see from this figure that the resources scheduled are uniform in distribution. This uniform distribution despite full utilization in symbol allocation would still allow for symbol interference without bias.

A. Comments on TTI Implementations and Trade off

From the results in 7 we can see the utuility of smaller TTI as a interference mitigation strategy. However there are trade offs that should be considered. For example smaller TTIs would inevitably require more total transmissions than a larger TTI for the same amount of data. More messages requires more overhead control. We can see that this may be useful in URLLC conditions, however for more consistent expected traffic larger TTIs would be more efficient. Although untested, dynamic scheduler changes to the TTI could be a potential mitigation strategy for uniform bursty interference.

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