Innovative Approaches to Interference Protection in Next-Gen Wireless Networks

Colin Brown*, Chaitanya Parekh and Humphrey Rutagemwa
Communications Research Centre Canada
Ottawa, Ontario, K2H 8S2, Canada
Email Contact: *firstname.lastname@ised-isde.gc.ca,

***Abstract*—Technology advancements fueled by 5G and upcoming 6G standards are driving the expansion of wireless services across various industries. However, this growth presents challenges for regulatory bodies tasked with managing harmful interference. Current interference protection criteria (IPC), which rely solely on radio frequency (RF) signal power levels, have limitations as they overlook the inherent robustness and adaptability to interference of the diverse technologies. This article explores how different RF interference threshold values impact communication quality across different layers of the protocol stack. It argues that significant improvements in spectrum usage can be achieved by adopting a data-driven approach and considering information about the services and technologies used by current or anticipated spectrum users when assessing suitable IPC.**

***Index Terms*—Interference Protection, Data-driven**

I. Introduction

Evolving consumer needs are driving the expansion of wireless services into many areas including traditional telecommunications and mobile connectivity. Furthermore, the deployment of advanced standards such as 5G, 5G-Advanced, and the upcoming 6G standardization effort is enhancing speed, capacity, and latency for a variety of diverse use cases.

This expansion is placing increased pressure on the management practices of spectrum regulatory authorities. Specifically, it challenges their ability to effectively coordinate and mitigate the impacts of harmful interference among a diversity of technologies sharing the spectrum in frequency, geography, and time.

To clarify the level of interference protection that is afforded to spectrum users, regulatory authorities often define interference protection criteria (IPC). These criteria typically consist of technical parameters detailing the nature of interference and specifying methods for measuring and quantifying harmful interference. Typically, IPC rely on comparing the power level of the interfering radio frequency (RF) signal with other RF signals, such as noise or carrier power [1].

However, IPC based solely on RF signal power levels have limitations. They often operate under worst-case assumptions, employ a conservative one-size-fits-all approach and overlook the inherent resilience of the impacted technologies when defining harmful interference.

This article examines the effects of harmful interference on the communication quality across various layers of the communication protocol stack. It presents a data-driven analysis of spectrum sharing between existing or incumbent services and new spectrum users accessing the same resources. It is shown that the dependence on an RF-centric IPC with relatively conservative threshold values reduces the effective sharing of spectrum.

Previous research in this field has typically followed one of two paths: either addressing RF interference effects across various layers of the communications protocol stack [2] or refining current IPC models to enhance accuracy [3].

The specific contributions of this article are threefold. Firstly, the article provides evidence of data-driven analysis identifying sharing scenarios whereby the interference between new entrants is a limiting factor in the IPC rather than between new entrants and incumbent systems. Secondly, based on these limitations, a mathematical model is presented to quantify the effects of examining harmful interference in higher-layers of the protocol stack. Lastly, results from the model are presented to examine the trade-offs between quality of service (QoS), number of new spectrum entrants and throughput in the higher layers.

The remainder of the article is as follows. First, current interference protection for spectrum management is discussed. Next, the concept of interference assessment at higher layers in the protocol stack is introduced. This is followed by a description of the data-driven modelling approach including a case study on interference for spectrum sharing. Results and analysis are then presented, followed by concluding remarks.

II. Interference Protection in Spectrum Management

Spectrum authorities typically manage interference by employing various mechanisms to separate systems based on frequency, distance, or time [4] [5]. The primary goal is to minimise the risk of causing harmful interference to the operations of spectrum users. The degree of separation in these dimensions is determined by the acceptable level of performance degradation, or the level of protection required for existing primary users or between new spectrum users.

An IPC is used for maintaining the quality and reliability of radiocommunication services by defining acceptable levels of interference. The IPC typically encompasses definitions of interference metrics, their corresponding threshold levels, the bandwidth over which interference is measured, and the percentage of time that the interfering signal must exceed the threshold level [1].

Two commonly used IPC metrics for quantifying interference are based on either the interference-to-noise ratio (I/N) or the carrier-to-interference-plus-noise ratio (C/(I+N)). The

I/N ratio references the theoretical noise floor, while the C/(I+N) ratio relies on knowledge of the carrier signal power. For instance, in the CBRS system, an I/N ratio of -12dB is employed to safeguard incumbent fixed satellite service (FSS) receiver stations from terrestrial interference [6].

In contrast, IPC metrics for radionavigation-satellite services, such as global navigation satellite systems (GNSS), are often based on the allowable decrease in the receiver C/N ratio, whereby a degradation of the C/N ratio by 1dB, equivalent to an I/N ratio of -6dB, is considered harmful [7].

Lastly, predominantly for terrestrial services, IPC can be combined with additional methods to manage interference, such as exclusion and protection zones or defining minimum separation distances between co-located systems.

Despite their importance in managing interference, current interference metrics have the following limitations:

- **System Capabilities:** Existing metrics often fail to account for the advanced capabilities of modern communication systems to withstand and mitigate interference.
- **Reliance on RF-Level Measurements:** Current metrics primarily focus on RF-level effects, neglecting the end-user experience and broader system-level performance metrics.
- **Generic Thresholds:** Many IPCs implement a one-size-fits-all static threshold for various services, which can lead to technical approximations that either under- or overestimate the real impact of interference.

One approach to overcome the limitations is to consider the effects of interference in the higher layers of the communications protocol stack.

III. IPC Analysis

Moving away from RF-level assessments, higher-layer interference protection considers the impact of interference on different layers of the protocol stack. Analysing interference at the physical, data link, and application layers enables the tailoring of interference management strategies to specific technology needs, particularly in geographically shared environments where the risk of harmful interference is increased. Fig. 1, shows a relatively simple model of a communications protocol stack indicating the key metrics at each layer. From the figure, the impact of RF interference is assessed at the various layers prior to making a determination on whether the interference is harmful to the radiocommunications system. In turn, each layer has protocol-specific methods for handling and adapting to transmission errors. For instance, at the application layer, services such as internet TV streaming adjust media quality or resolution based on factors including transmission link quality. This adaptive approach is similarly implemented across other layers in response to RF interference. The following section reviews the metrics shown on the right-hand side of Fig. 1 and describes the various layer-specific mitigation factors influencing the metrics.

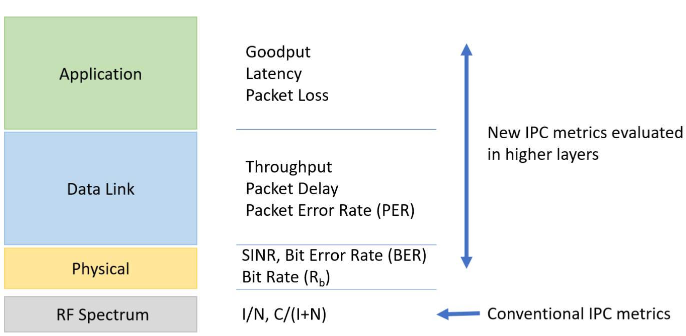


Fig. 1: Communications protocol stack highlighting the different metrics that can be used in an IPC at various layers.

A. Metrics & Mitigation Factors

- **RF Spectrum layer:** The I/N and C/(I+N) are two of the main metrics for assessing whether RF interference is harmful. Generally, IPC set a predefined harmful threshold level for all services within a specific frequency band. Factors influencing the metrics include shifting to a different RF band through techniques such as frequency hopping or dynamic frequency selection, or employing RF interference cancellation methods.
- **Physical layer:** Metrics include the signal-to-interference-and-noise ratio (SINR) at the receiver's input as well as the bit error rate (BER) resulting from the modulation and coding scheme and the resulting bit rate R_b delivered to the upper layers. Power control, beamforming and diversity reception can all be used to enhance the SINR, whereas the BER largely depends on the advanced modulation and coding schemes and the input SINR.
- **Data Link layer:** Key data-link metrics include the throughput or the rate of successfully received bits at the destination, packet delay defined as the time used to transmit a frame and receive acknowledgement and the packet error rate (PER) representing the percent of packets not received successfully. Factors influencing these metrics include packet length and error control protocol e.g. automatic repeat request
- **Application layer:** The main metrics of interest at the application layer are highly correlated with the specific application being used and the number of simultaneous users demanding data. Applications typically have performance targets that contain the requirements for data rate or goodput (the useful data rate accounting for all of the lower layer overheads), latency, and packet loss [8].

IV. Data-Driven Modelling

Irrespective of the mitigation methods used across different layers, the impact of RF interference is reflected in the metrics of each layer. A data-driven approach can model these effects by considering the specific services and technologies in various interference scenarios. This discussion defines a model that maps RF interference to the upper layers of the protocol stack, specifically from the RF spectrum layer to the data-link layer. Although this model focuses on these layers, it can be generalized to all layers of a radiocommunication system with a structured communication processes. The model is then applied to a spectrum sharing scenario to evaluate the impact of integrating IPC with upper layer metrics.

A. Data Link Model

As depicted in Fig. 1, the key metrics at the data link layer are packet delay, packet error rate, and throughput. Packet delay is round-trip time, defined as the time used to transmit a frame and receive acknowledgement. The packet error rate is defined as the number of packets received with errors at the destination node divided by the number of original packets from the source node. Throughput is defined as the number of information bits successfully received at the destination node per unit time and is measured in bits per second.

In the data link model, the delay is independent of interference because it is an arbitrary but fixed round-trip time. For the throughput, however, the average throughput can be defined as:

$$\lambda = (1 - \epsilon_p) R_b, \tag{1}$$

where ϵ_p is the packet error rate. R_b is the maximum bit rate delivered by the physical layer

$$R_b = \frac{L_d}{(L_d + L_h)} \frac{R_s \log_2 M}{C}, \tag{2}$$

where M is the modulation order, C is the coding rate, L_d and L_h are the number of symbols and the number of overhead symbols in a time slot, respectively, and R_s is the symbol rate.

Assuming uncorrelated bit errors across the time slot and substituting Eq. (2) into Eq. (1), the packet error rate and throughput can be expressed as:

$$\epsilon_p = 1 - (1 - \epsilon_b)^{N_p} \tag{3}$$

and

$$\lambda = \frac{L_d}{(L_d + L_h)} \frac{R_s \log_2 M}{C} (1 - \epsilon_b)^{N_p}, \tag{4}$$

where ϵ_b is bit error rate and N_p is number of bits in a packet. In general, the symbol rate is technology dependent and can be derived once the physical layer waveform has been identified. The values of independent variables in Eqs. (3) and (4) are computed or derived by accounting for factors such as signaling and framing overheads, modulation and coding schemes, and the received SINR at the physical layer. Assuming typical characteristics of radio receivers, the BER (ϵ_b) can be estimated for various values of the received SINR. However, to enhance computational efficiency and processing speed, the mapping from SINR to BER are typically tabulated in a look-up table. Note, this relationship assumes that the interference signal is wideband and Gaussian. However, other forms of interference can be considered with the corresponding SINR mapping for different modulation and coding schemes.

B. Spectrum Sharing Scenario

A case study is presented below, in order to assess the impact on the upper layer metrics in an interference environment. The case study considers spectrum sharing between an incumbent FSS earth station and secondary IMT (International Mobile Telecommunications) systems in the upper mid-band spectrum (approximately between 7 GHz and 24 GHz) in Canada. Specifically, the case study examines and analyses the aggregate interference received at the incumbent receiver from secondary systems and between the secondary systems themselves. From a data perspective, information on the incumbent system including its location and technical parameters are extracted from the Canadian licensing database [9]. Of particular interest in this band, especially from a spectrum sharing perspective, are incumbent services operating close to urban and suburban areas where the potential for secondary broadband demand is greater than, say, rural areas. Fig. 2 shows the location of an incumbent satellite receiver station operating at 12450 MHz situated in Calgary, Canada. The technical parameters for the incumbent system are listed in Table I.

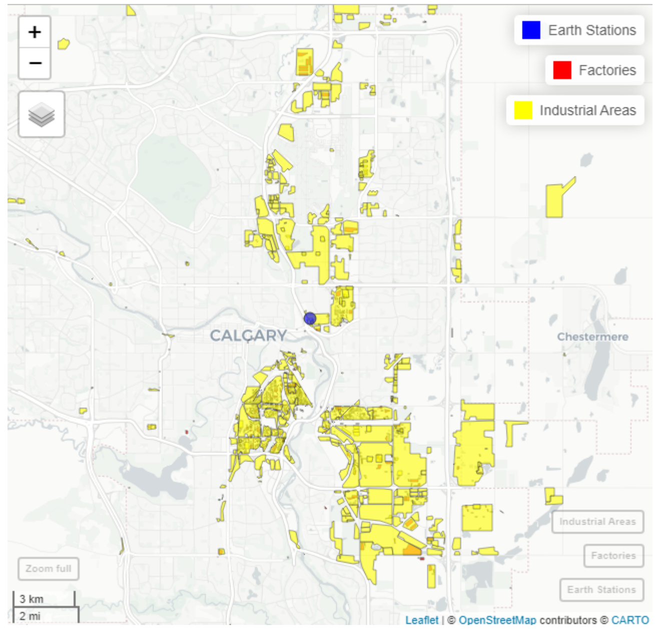


Fig. 2: Scenario of an incumbent FSS earth station with surrounding data polygons indicating potential secondary service demand areas sharing the band.

TABLE I: Parameters for Incumbent and Secondary Systems

Parameter	**Incumbent Value**	**Secondary Value**
Antenna Height	6 m	10 m
Antenna Elevation Angle	27.65°	-
Antenna Azimuth Angle	151.4°	-
Antenna Pattern	ITU REC-465	-
Bandwidth	300 kHz	10 MHz
Frequency	12450 MHz	-
Latitude	51.05278°	-
Longitude	−114.0156°	-
Satellite Name	Nimiq-6, Telesat	-
Receiver Traffic Profile	80%/20% Duty Cycle	-
Transmitter EIRP[1]	-	24 dBm
Antenna Directionality	-	Omni
Antenna Gain	-	0 dBi
Downlink Traffic Profile	-	50% Duty Cycle
Antenna Location	-	Outdoor

In terms of the secondary systems, following the recent trends in spectrum sharing towards more localised access, it is assumed that the locations demanding secondary access to spectrum correspond to different vertical markets. In the scenario shown in Fig. 2, the locations of potential secondary transmitters are represented by coloured polygons visualizing geospatial-footprint data, available from OpenStreetMap [10], associated with industrial areas and factories. The use of polygon data serves as a more realistic representation of possible sources of interference and differs from the conventional method, which assumes a random distribution [11]. In this case, using the locations of the polygons is more representative of spectrum demand from specific vertical markets.

For the case study, a finite set of data polygons, $N_c = 633$, are generated using the data from OpenStreetMap. Next, the centroids of the data polygons are determined and used to represent the transmission location (latitude and longitude) of a single base-station for a secondary system. The parameters for the secondary systems are listed in Table I. and were selected to mimic the coverage from a local broadband network. Additionally, the secondary systems are assumed to be operating co-channel with the incumbent system with both incumbent and secondary systems implementing a random traffic profile as defined in Table I.

C. Interference Calculation

The aggregate interference is calculated from interactions between secondary systems and incumbents, and among the secondary systems themselves. Define the interference power at receiver j from transmitter i as $I_{i,j}$. The formula for calculating this interference in dBm is given by:

$$I_{i,j} = P_i + G_i + G_{c,i}(\theta_i) - L_p(i,j) + G_j + G_{c,j}(\theta_j) \quad (5)$$

where:

- P_i: Power in dBm from the i-th transmitter.
- G_i, G_j: Antenna gain in dBi for the i-th transmitter and j-th receiver respectively.
- $G_{c,i}(\theta_i)$, $G_{c,j}(\theta_j)$: Correction gain in dB based on the antenna gain pattern at an angle θ_x for the i-th transmitter and j-th receiver respectively.
- $L_p(i,j)$: Path loss in dB between the i-th transmitter and j-th receiver.

Assuming N_a active secondary systems with duty cycle dc, where $N_a \leq N_c$, and J incumbent systems, the aggregate interference at the incumbent, calculated using $I_{i,j}^{mW} = 10^{\frac{I_{i,j}}{10}}$ to convert from dBm to milliwatts (mW), is:

$$I_{SI,j} = \sum_{i=1}^{N_a} I_{i,j}^{mW} dc_i \quad (6)$$

where dc_i is the duty cycle of the i^{th} transmitter. Similarly, the aggregate interference received at each secondary system is given by:

$$I_{SS,n} = \sum_{i=1}^{N_a} I_{i,n}^{mW} dc_i \qquad i \neq n \quad (7)$$

where $n = 1, 2, \ldots, N_a$. Note, the path loss is calculated using the irregular terrain model.

D. Assignment Model

Following the interference calculation, the case study uses Monte Carlo modeling to simulate the introduction of secondary IMT systems into the environment. For both incumbent and secondary systems, an interference threshold is used to moderate the aggregate interference. For each simulation trial, the following steps are implemented:

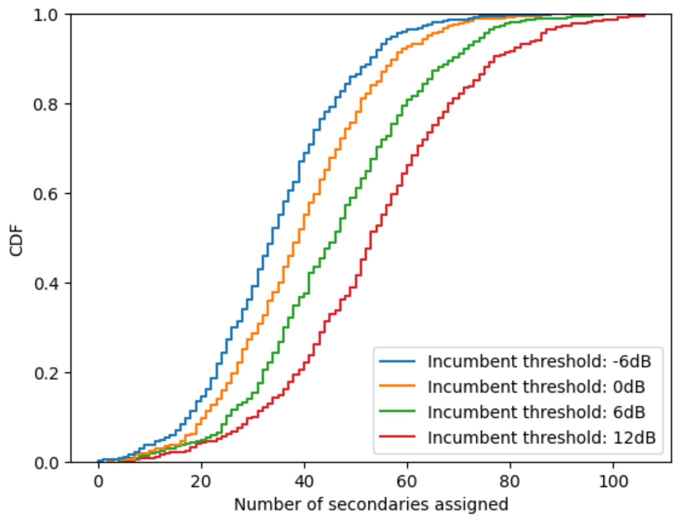
1) Randomly select a candidate secondary location from the set of N_c geospatial-footprints. The selection is implemented using a uniform random distribution, where each location has an equal probability of being chosen.
2) Update the aggregate interference calculation, (6), between the candidate secondary location and the incumbent location.
3) Update the aggregate interference calculation, (7), between the candidate secondary location to any other secondary locations that have already been assigned a channel.
4) If the aggregate interference is below the interference threshold at both the incumbent and other secondary systems, assign a channel to the candidate secondary location. Otherwise, remove the candidate location from the simulation.
5) Repeat steps 1-4 until either the interference threshold is exceeded or until all N_c of the possible candidate secondary locations are exhausted.

Note a similar methodology as described above has been previously published by the authors [12], [13]. However, earlier contributions did not include the temporal aspect in the model and focused on augmenting the analysis with more precise propagation models and climate effects on conventional RF-centric metrics.

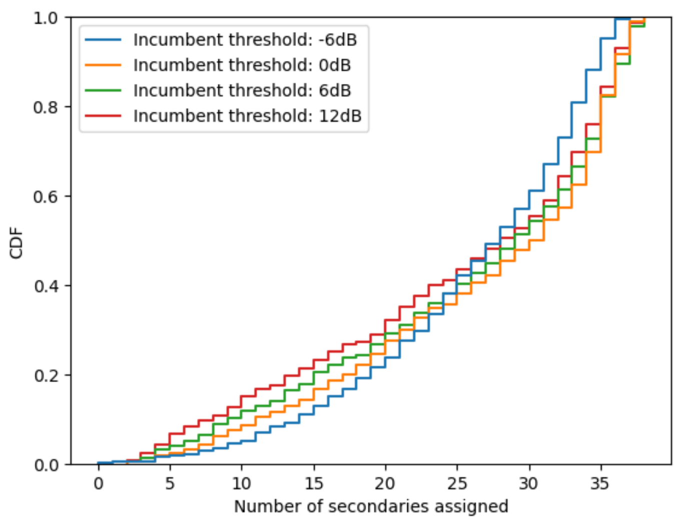
V. Results and Analysis

One metric of interest when considering spectrum sharing with an incumbent system is the number of secondary systems that are able to co-exist with the incumbent. Fig. 3 displays cumulative distribution functions (CDFs) comparing the number of secondary systems assigned for different I/N threshold values. In Fig. 3a, these threshold values are used to protect the incumbent system only. That is, the secondary systems are afforded no protection from harmful interference in this particular case. The results show that as the incumbent's interference threshold rises, more secondary systems can operate simultaneously. However, because secondary systems are not shielded from harmful interference, the average SINR at their locations decreases, significantly impacting their communications quality. Fig. 3b on the other hand, shows the number of assigned secondaries when a certain QoS is defined. In this case, due to the temporal nature of the interference a mean SINR of 10dB is used as the interference threshold at the secondary locations to ensure that sufficient signal quality exists for the secondary systems to operate. As a result, the CDF curves show an increase in the number of assigned

[1]Effective Isotropic Radiated Power - the combination of transmit power, antenna gain and line loss



(a) CDF for assigned secondary systems without interference protection across varying incumbent threshold levels.



(b) CDF for assigned secondary systems with interference protection to ensure minimum QoS across varying incumbent threshold levels.

Fig. 3: Comparative CDFs of the number of assigned secondary systems under different interference thresholds.

secondary systems as the incumbent interference threshold is increased for approximately 50% of the simulation scenarios and greater. The results in Fig. 3 are somewhat counter-intuitive as typically interference threshold values are used to protect the incumbent service rather than to protect new entrants sharing the spectrum. However, in this data-driven scenario, the dominant factor is the interference between secondary systems.

Analysis of the SINR at the secondary locations when a QoS threshold of SINR = 10dB is used, results in the curves shown in Fig. 4. Note, due to the different duty cycle of the secondary transmissions, not all of the secondary systems transmit simultaneously, leading to a probabilistic distribution of interference and SINR values at the secondary locations.

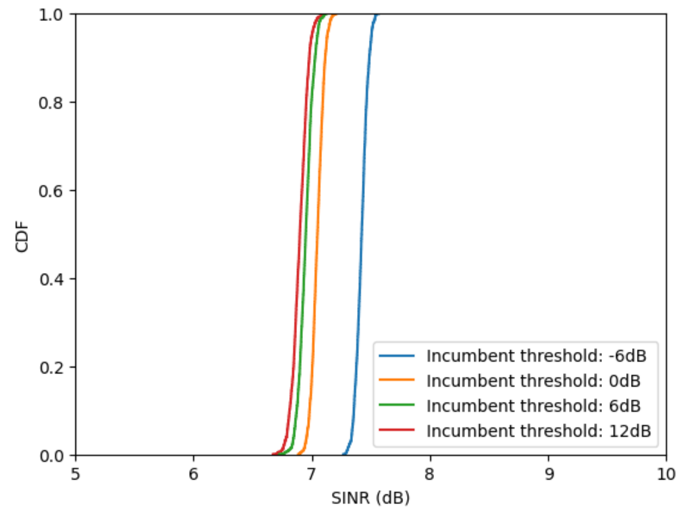


Fig. 4: Average SINR values at secondary locations, illustrating signal quality and interference levels.

Irrespective of the distribution of SINR values, the SINR shows relatively tight clustering with values within 1dB for all of the incumbent threshold values.

The SINR is one metric used to assess the effects of interference at the physical layer. Another valuable metric at this layer is the Bit Error Rate (BER), which is derived by mapping the SINR to an error rate curve using values from a look-up table. Fig. 5 illustrates the mean BER for various modulation and coding schemes, predominantly quadrature phase shift keying (QPSK) and quadrature amplitude modulation (QAM), along with incumbent threshold values.

Note that these example modulation and coding schemes represent a subset of those available to 5G systems. Without loss of generality, they provide a representative analysis of 5G systems [14].

In this figure, it is observed that the error rate increases as the order of the modulation scheme increases and for increasing coding rates within a specific modulation family. In terms of the interference effects at this layer, the impact of increasing the allowable interference to the incumbent system has a relatively small impact on the BER for the majority of the modulation and coding schemes. This is due to the fact that the dominant interference is between secondary systems only such that the aggregate interference at the secondary locations is moderated by the interference threshold levels at the secondaries and not at the incumbent. Of note for the results in Fig. 5, the flattening observed for the first modulation and coding group, QPSK rate 1/3 is due to the relatively small BER values and the quantisation of values in the corresponding look-up table.

Given the BER values at the physical layer and using the model as described in Section IV-A, the interference impact can be determined at the data link layer. Although showing the results of the mapping to PER is insightful, it is more useful to analyse the impact on the throughput. Using 4, Table II lists the throughput values in the data link layer for

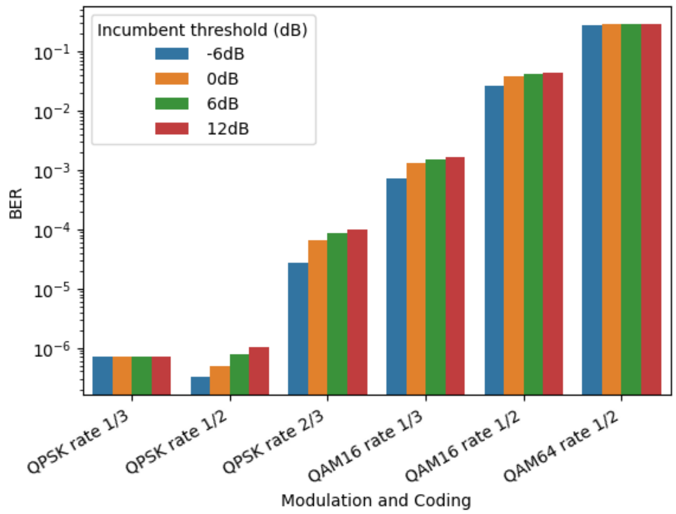


Fig. 5: Average BER at secondary locations, for different modulation and coding schemes.

TABLE II: Mean throughputs (Mbps) for a packet duration of 1ms.

Modulation and Coding	QPSK rate 1/3	QPSK rate 1/2	QPSK rate 2/3	QAM16 rate 1/3
I/N Threshold (dB)				
-6	5.02	7.54	7.69	0.01
0	5.02	7.53	5.22	0.00
6	5.02	7.51	4.32	0.00
12	5.02	7.50	3.85	0.00

a packet duration of 1ms. In this case, it is observed that there exists a trade-off in the achievable throughput values, the QoS that is afforded to the secondary systems and the incumbent interference threshold value. The results show that defining the IPC based on I/N values at the RF spectrum level does not account for the inherent resilience to interference at the various layers in the protocol stack. For example, a relatively conservative I/N value of -6dB precludes the access opportunities for new spectrum users as evidenced in Fig. 3b, without unduly limiting the achievable throughput, for the lower order modulation schemes, at the data link layer. Indeed, relatively robust throughput levels can be achieved for QPSK with code rates less than $1/2$ at the link level.

VI. Concluding Remarks

Current interference protection criteria (IPC) based solely on RF signal power levels are inadequate for managing the complex spectrum landscape of next-generation wireless networks. This article demonstrates that a data-driven approach, considering service-specific technologies and their inherent interference resilience, can significantly enhance spectrum utilisation. Analysing interference effects across multiple protocol layers enables regulatory authorities to strike a balance between quality of service for secondary users and interference thresholds at the RF layer. This refined IPC methodology maximises spectrum efficiency and facilitates more dynamic and adaptive spectrum management practices to better support the diverse needs of emerging wireless technologies and services.

References

[1] Alakananda, Paul, et al., "Interference Protection Criteria Phase 1 - Compilation from Existing Sources.." [Online]. Available: https://www.ntia.doc.gov/files/ntia/publications/ipc_phase_1_report.pdf, 2005. Last accessed July 2024.

[2] R. C. D. Paiva, P. Papadimitriou, and S. Choudhury, "A Physical Layer Framework for Interference Analysis of LTE and Wi-Fi Operating in the Same Band," in *2013 Asilomar Conference on Signals, Systems and Computers*, pp. 1204–1209, 2013.

[3] K. Po and J. i. Takada, "Conservative Protection Criteria for TV Broadcasting Services from IEEE 802.22 WRAN," in *2008 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008)*, pp. 1–4, 2008.

[4] Innovation Science and Economic Development (ISED), "Decision on the Technical and Policy Framework for the 3650-4200 MHz Band and Changes to the Frequency Allocation of the 3500-3650 MHz Band." [Online]. Available: https://ised-isde.canada.ca/site/spectrum-management-telecommunications/en/spectrum-allocation/3650-4200-mhz/decision-technical-and-policy-framework-3650-4200-mhz-band-and-changes-frequency-allocation-3500, 2021. Last accessed July 2024.

[5] 47 CFR 73.207, "Minimum Distance Separation Between Stations." [Online]. Available: https://www.ecfr.gov/current/title-47/section-73.207. Last accessed July 2024.

[6] 47 CFR 96.17, "Protection of Existing Fixed Satellite Service (FSS) Earth Stations in the 3600-3700 MHz Band and 3700-4200 MHz Band.." [Online]. Available: https://www.ecfr.gov/current/title-47/section-96.17. Last accessed July 2024.

[7] International Telecommunication Union Radiocommunications Sector (ITU-R) Recommendations, "Characteristics and Protection Criteria for Receiving Earth Stations in the Radionavigation-Satellite Service (Space-to-Earth) and Receivers in the Aeronautical Radionavigation Service Operating in the Band 1 559-1 610 MHz." [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1903-1-201909-I!!PDF-E.pdf, 2019. Recommendation ITU-R M.1903-1.

[8] International Telecommunication Union - Telecommunication Standardisation Sector (ITU-T), "Series G: Transmission Systems and Media, Digital Systems and Networks Quality of Service and Performance: End-user Multimedia QoS Categories." [Online]. Available: https://www.itu.int/rec/dologin_pub.asp?lang=s&id=T-REC-G.1010-200111-I!!PDF-E&type=items, 2001. ITU-T G.1010.

[9] Government of Canada: Innovation Science and Economic Development, "Spectrum Management System Data." [Online]. Available: https://www.ic.gc.ca/engineering/SMS_TAFL_Files/TAFL_LTAF_Satellite.zip, March 2019.

[10] OpenStreetMap Contributors, "Planet Dump Retrieved from https://planet.osm.org." [Online]. Available: https://www.openstreetmap.org, 2017. Last accessed July 2024.

[11] De Vries, Jean Pierre and Livnat, Uri and Tonkin, Susan, "A Risk-Informed Interference Assessment of MetSat/LTE Coexistence," *IEEE Access*, vol. 5, pp. 6290–6313, 2017.

[12] C. Brown and A. Ghasemi, "Leveraging geospatial data to improve spectrum sharing in mid-band," in *2023 IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 1–5, 2023.

[13] C. Brown and A. Ghasemi, "Evolution toward data-driven spectrum sharing: Opportunities and challenges," *IEEE Access*, vol. 11, pp. 99680–99692, 2023.

[14] ETSI TS 138 214 V16.2.0 (2020-07), "Technical Specification: 5G;NR;Physical layer procedures for data." [Online]. Available: https://www.etsi.org/deliver/etsi_ts/138200_138299/138214/16.02.00_60/ts_138214v160200p.pdf, 2020. Last accessed July 2024.