Solving the 5G Crisis: Enabling Coexistence with Crucial Safety Systems through Adaptivity and Reconfigurability

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***Abstract*—The deployment of fifth-generation (5G) wireless technology has created difficulties in coexistence with multiple types of wireless systems, including passive weather radiometers, military radars, and commercial aircraft radar altimeters. The continued addition of more bands for spectrum sharing to compensate for technical limitations of 5G continues to affect more systems. An approach is presented whereby potential interference victims can be enabled, via adaptivity and reconfigurability, to share spectrum actively with 5G and future-generation transmitters. This approach could re-innovate how the spectrum is shared, and should be used with the rollout of sixth-generation (6G) and future technologies, rather than as a reaction to unplanned interference. A forward-thinking outlook involves parallel development of technology and policy to enable incumbent safety systems to use spectrum in an adaptive and reconfigurable manner.**

***Index Terms*— radio spectrum management, reconfigurable circuits**

I. Introduction

The deployment of fifth-generation (5G) wireless systems has created a multi-faceted spectrum crisis with multiple scientific, military, and public-safety users of the spectrum. In 2015, the pre-rollout forecast for 5G was that it would provide larger bandwidths and corresponding high data rates by transmitting at millimeter-wave frequencies. Even so, challenges with using the millimeter-wave bands effectively began to be discussed in the literature. Niu discusses the limitations of mm-wave communication due to propagation attenuation, suggesting that a cell size of 200 meters or less is best for attempting communications at these frequencies [1]. Wang mentions that millimeter-wave (mm-wave) technology is difficult to deploy outdoors due to the high attenuation over distance and potential absorption of transmissions by the atmosphere, but suggests that indoor and outdoor scenarios be separated [2]. Eze overviews the benefits of 5G and includes increased throughput as a significant benefit, stating that spectrum assigned in the mm-wave range, as well as the use of multiple-input, multiple-output technologies, will support this benefit [3].

The problem is that mm-wave transmission is fraught with challenges. Busari describes millimeter-wave and terahertz transmission as one of three critical enabling technologies of future wireless systems, but admits the performance is affected by increasing path loss at higher frequencies [4]. Narayanan presents an overview of early 5G rollouts at both mm-wave and midband, with a study that shows the significant impact of rain on 5G throughput, and also examines the effects of different protocols [5]. Lopez discusses how America's Mid-Band Initiative Team (AMBIT) recently allocated 3.45 – 3.55 GHz for sharing between 5G mid-band systems and Department of Defense (DoD) radars, and discussed how low-, mid-, and high-band spectrum are all needed for the success of 5G [6].

The present paper examines the challenges created by the multi-frequency 5G deployment, and discusses a long-term paradigm shift that will provide a solution to the problems caused by 5G sharing with critical public safety and military wireless applications.

II. The 5G Crisis

Several potential interference victims have been created by the multi-band 5G deployment. Three safety-oriented applications subject to interference are briefly discussed as examples.

A. 24 GHz: Weather Radiometers

In attempting to produce the greater bandwidths initially promised by 5G, the Federal Communications Commission (FCC) made the 24 GHz band available for commercial wireless occupation in 2016. Unfortunately, the 5G 24 GHz allocation is immediately adjacent to a band critical for weather forecasting use. Weather-sensing ground stations and satellites measure the signature emission of water vapor at 23.8 GHz, and this measurement is critical to providing advance weather forecasts. Additionally, the oxygen content of the atmosphere is assessed through sensing a unique signature emission near 50 GHz. 5G systems in the 24 GHz band can interfere with the water vapor measurements through out-of-band emissions and with the oxygen measurements through harmonic emissions. Both of these interference scenarios can result from nonlinearities in the power amplifiers of the 5G transmitter arrays. This critical interference problem must be discussed.

The United States Government has intervened in this issue. In 2019, Thomas discusses how initial coordination of passive device spectrum usage was muddled between the agencies. Despite objections from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), the FCC proceeded with auctions of the 24 GHz band to commercial wireless providers [7]. Follow-on hearings were held in Congress in July 2021, with the Government Accountability Office (GAO) presenting a report on how spectrum conflicts are resolved, and a Congressional witness suggested that improvements to spectrum use are needed [7].

B. 3.45 GHz: Military Radar

Because mm-wave attenuation challenges have not yet been overcome, even with coherent transmission from phased arrays, 5G operators have sought midband frequencies to use for 5G. When AMBIT was assembled to develop a strategy by which the 3.45-3.55 GHz radar band could be shared with 5G, it involved stakeholders from the military in building a solution [6]. However, the 3.45-3.55 GHz cession from solely radar to heavy sharing with 5G was not the first loss of prime radar spectrum from this band, nor will it be the last. The Citizens Broadband Radio Service (CBRS) was the first sharing institution in the military S-band radar allocation. Radars began sharing 3.55-3.70 GHz with wireless communication devices with initial trials in 2016 [8]. In 2020, four Spectrum Access System operators, serving as spectrum coordinators, were licensed to allocate sharing for full use of the band by wireless communications [9].

AMBIT operated with the goal to allow significant 5G use of the midband by wireless devices in geographic regions far from radar transmitters. For example, in inland areas, DoD Navy radars are not needed, and DoD land-operated radars are not densely packed. In essence, this is a simple use of spatial diversity to pack more systems into this frequency band.

There is presently additional movement to reallocate the 3.1-3.45 GHz part of the DoD radar band for sharing with wireless communications. This effort is being organized through the National Spectrum Consortium, with the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group launched in 2021. The PATHSS Task Group has recently begun meeting to consider the model and use cases related to potential sharing [10].

The eroding bandwidth in the midband available for sole use by DoD radars could be viewed by some as a threat to successful DoD radar operations with legacy radar systems. Presently, legacy radar systems, not designed for real-time adaptation and reconfiguration, are not designed for spectrum-sharing protocols and may eventually suffer greatly in critical performance. This should be kept in mind as a serious, unforeseen repercussion of the 5G advancement: radar systems are critical to national protection and defense.

B. 4.2-4.4 GHz: Radar Altimeters

The midband rollout of 5G has emerged as a threat to another critical safety-related device: the radar altimeter. Since the mid 2010's, the radar altimeter band has been seriously considered for sharing with wireless communications. The rollout of 5G into the 3.7-3.98 GHz band was initially scheduled for December 5, 2021. However, the Federal Aviation Administration (FAA) released a Special Airworthiness Bulletin (SAIB) in November 2021 detailing potential issues that out-of-band emissions from 5G transmitters could cause [11]. Because the radar altimeter is only functional from 20 feet to 8200 feet [12], interference would impact low-elevation altitude measurements and automatic landing systems. In December 2021, the FAA ordered a halt on the usage of some automatic landing functions out of concern for potential interference. In January 2022, Boeing and Airbus (major aircraft manufacturers), urged a further delay in deployment. The wireless companies agreed to delay for two additional weeks. During this delay, the FAA worked with commercial wireless providers to obtain 5G transmitter locations and power–level values [13]. Additionally, the FAA established an Alternative Method of Compliance (AMOC) process, whereby airlines can demonstrate that the altimeters on their planes are resilient to 5G interference [13]. The 5G systems were enabled in the 3.7-3.98 GHz band on January 19, 2022, but the usage of these systems was limited near airports, with 5G rollouts increasing as more analysis of the altimeter systems is performed [14].

In addition to civilian radar altimeter use, concern exists for interference to military radar altimeters. A Joint Interagency Five G Radar Altimeter Interference (JI-FRAI) Working Group was launched to perform both bench testing and flight testing to examine radar altimeter interference from 5G systems [15]. This study is in progress and may result in findings of how 5G emissions affect military radar altimeters.

III. Potential Solutions

The three aforementioned situations show that 5G has been deployed at risk of several crucial public safety and defense systems. The extensive usage of bandwidth by this technology has overwhelmed several safety systems due to the differing needs of 5G not available in a single bandwidth. Unorganized identification and re-regulation of possible use bands is not a sustainable approach in moving to 6G and beyond. While the three situations above often paint a grim picture, it is possible to construct the development of future generations so that all technologies are better equipped; however a different (proactive) approach is needed, and the supporting research and development efforts must go beyond the wireless communication systems to the potential interference victims. If potential interference victims of wireless communications are designed to be capable of interacting and sharing by using adaptive and reconfigurable circuits and systems, then a thoroughly planned coexistence and sharing approach could be launched from the beginning of development. The present coexistence approach is a (reactive) problem-solving approach that will lead to system ineffectiveness, both of wireless communication and incumbent systems. A forward-thinking, pre-planned (proactive) approach to mutual sharing is needed.

What technologies are critical to facilitating this new adaptive paradigm in which interference is avoided? Technology-based solutions are examined for the different applications in the following subsections.

A. Broker-Coordinated Real-Time Optimization to Avoid Interference with Weather Radiometers

Chong describes the use of manifolds, containing requested time, frequency, and spatial usage, for coordinating spectrum usage between active and passive systems [16]. Marino demonstrates the use of a spectral broker to coordinate between different wireless systems [17]. The broker technology could be a methodology in which passive devices could make requests for resource use, and these requests could be negotiated with wireless communication system requests. The broker could then communicate the decisions back to the systems, along with potential suggested modifications for time, frequency, and spatial usage.

This work is currently being pursued by Baylor, Colorado, and Purdue Universities under funding from the National Science Foundation, and will involve the construction of a 5G transmitter test bed at the University of Colorado near a radiometer system to demonstrate coexistence [18]. A prototype 5G front end will be modified to contain an array of reconfigurable circuits, capable of real-time optimization to maximize output power and efficiency, while meeting interference specifications.

B. Automated Radar Altimeter Avoidance Coordinated with Air Traffic Control

As Singh observes through a study of the Chicago metropolitan area, interference potentials for wireless communications with radar altimeters are mostly near airport flight approach paths, where aircraft are below 8200 feet [12]. Since the flight paths are prescribed by air traffic control (ATC), it is prudent to co-locate an automated frequency coordination system at ATC facilities. After the flight path has been assigned to an aircraft for takeoff or landing, the automated frequency control system would read the flight path and create real-time exclusion zones for the frequencies of the radar altimeters within range of the prescribed flight path. This would minimize the unnecessary protection of the altimeter frequencies, while ensuring that adequate protection is provided based on real-timeflight information. This automated system would report to the 5G controller, and the 5G controller would automate both the frequency and spatial use of its transmitter arrays.

Many additional features of the frequency coordination and the 5G transmitter optimization can be similar to the broker-based 5G optimization for radiometer coexistence.

C. Real-Time Amplifier Impedance Tuning for Reconfigurable Radar

To address the issues with the Department of Defense radar systems in the S-band, real-time reconfiguration of the radar transmitter power amplifier is under examination for increasing output power and range after changing operating frequency or antenna impedance. The load impedance for a transmitter amplifier providing best output power changes with both operating frequency and array scan angle. A tunable matching network, controlled by a software-defined radio (SDR), adjusts to present the optimum impedance to the power-amplifier device when scan angle or operating frequency change, as shown in Fig. 1.

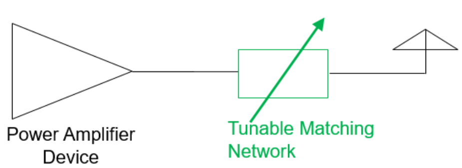

Fig. 1. A tunable matching network, placed between the transmitter power amplifier device and antenna, used to optimize the output power and linearity of the transmitter. Reprinted from [19].

The goal of the radar transmitter is to detect targets as far away as possible, as shown in Fig. 2. By increasing the output power, the range can be maximized. This would be accomplished under constraints based on spectral coexistence with other systems, such as wireless communications.

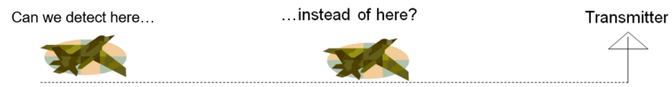

Fig. 2. Maximization of radar range for farther-out detection of targets. Reprinted from [20].

Working toward fast, on-board optimization of a reconfigurable radar circuit, an SDR platform can be used to perform algorithmic control and measurements. Recent collaborative work between Baylor University, Purdue University, and the Army Research Laboratory shows that a high-power, evanescent-mode cavity tuner can be controlled using an SDR, using the setup shown in Fig. 3. The SDR is capable of performing waveform generation, spectrum analysis, and output power measurements. Using the SDR, a real-time search algorithm is shown to optimize impedances in 4-10 seconds the first time an operating frequency is visited, and in less than 2 seconds when a look-up table is used to generate the search starting point on subsequent visits to the frequency. If the look-up table point is used without further optimization, the reconfiguration can be completed in less than 1 second. This has been recently shown by Dockendorf [20]. Fig. 4 shows the time required for optimization at different frequencies revisited as indicated by random choice [20]. Upon re-visits to a frequency, it is seen that the optimization time is significantly reduced [20].

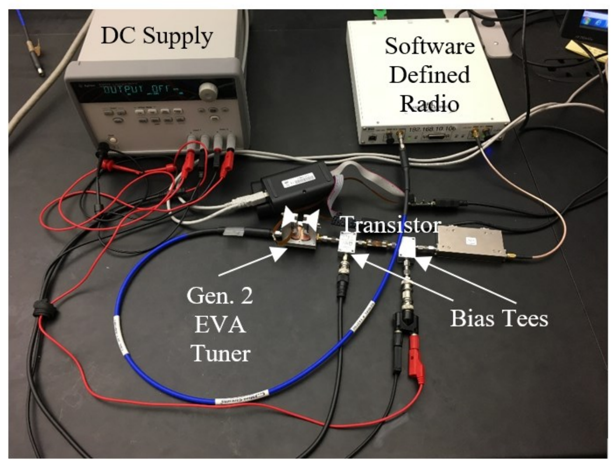

Fig. 3. Software-defined radio controlled optimization using a load impedance tuner terminating a transistor. Reprinted from [20].

The evanescent-mode cavity tuner developed and used in this study requires milliseconds to seconds to optimize. As a result, complete tuning optimizations cannot keep pace with a cognitive radar's center frequency and bandwidth changes. Under funding from the Office of Naval Research, a fast reconfigurable impedance tuner [21] has been designed using semiconductor plasma switches [22]. A recent paper shows that this switched-stub tuner can optimize in about 300 μs, on average [21]. This is a three order-of-magnitude improvement in reconfiguration times over the evanescent-mode cavity tuner. The tuner was demonstrated under SDR control to optimize given changing impedances between 2 GHz and 4 GHz, with a varying emulated antenna impedance.

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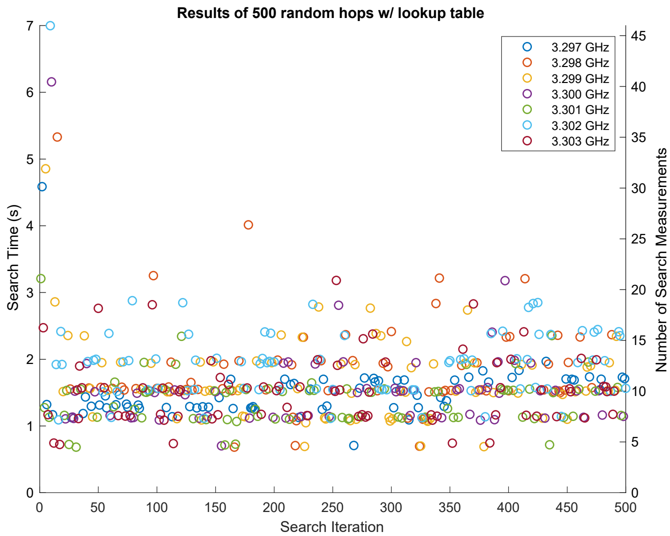

Fig. 4. Complete reconfiguration optimization times for SDR-controlled impedance tuning. Reprinted from [20].

IV. Forward-Thinking Outlook

The scenarios involving coexistence with 5G wireless devices presented herein, and the solutions that are discussed, bring forward some major themes for consideration in moving forward toward solving the 5G crisis, and for setting up future generations of wireless systems. These conclusions are the following:

1. Less spectrum will be owned, and more spectrum will be shared. This will continue to be the case in future generations of wireless communication. The continued development of new wireless applications and connectivity will require adaptive and reconfigurable spectrum sharing techniques.
2. Real-time adaptive and reconfigurable capabilities must be built into incumbent systems affected by wireless communications (such as radar and radiometers) and the wireless communications themselves.
3. Policy alone is not capable of solving spectrum issues. Technology development can provide a paradigm shift that creates new possibilities. The proposed radar altimeter plan is an example of this. Present altimeter protection proposals are mostly regulatory, with slight adaptivity in the flexibility of lowering transmit power or turning off 5G transmitters. The solution proposed in this paper requires more technological innovations to facilitate new levels of reconfigurability in the wireless systems.
4. Policy and technology must be co-developed. Technology innovations must be created to open up new sharing opportunities, and policy must be created that can evolve as reconfigurable and adaptive technologies are developed. If policy is developed before technology, or technology is developed without policy in mind, both the policy and technology development processes and, ultimately, the utility of spectrum usage, become inefficient.

If these guidelines are followed, new opportunities will be presented for future generations of wireless communications, unlocked by the capability to adapt and reconfigure.

V. Conclusions

The 5G rollout has caused challenges for key scientific, aviation, and military systems. While much activity has been observed over the past several years in the regulatory environment surrounding coexistence of wireless communications with passive radiometers, radar altimeters, and Department of Defense radars, technical developments are required that are capable of making all of these wireless systems adaptive and reconfigurable. These technology developments will allow the spectrum to be shared beyond the limitations of the present technologies, and will unlock new capabilities and opportunities for wireless devices. For each of these coexistence scenarios, a brief illustration of planned and accomplished technological developments has been discussed. In looking forward to 6G and beyond, sharing of spectrum should be considered the norm, and real-time adaptive and reconfigurable technology should be created, accompanied by significant policy improvements. This will free more spectrum and allow more potential spectrum-use applications novel capability to optimally function.

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References

[1] Y. Niu, Y. Li, D. Jin, L. Su, and A.V. Vasilakos, "A Survey of Millimeter Wave Communications (mmWave): Opportunities and Challenges," *Wireless Networks*, Vol. 21, 2015, pp. 2657-2676.

[2] C.-X. Wang, F. Haider, X. Gaio, X.-H. You, Y. Yang, D. Yuan, H.M. Aggoune, H. Haas, S. Fletcher, and E. Hepsaydir, "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks," *IEEE Communications Magazine*, Vol. 52, No. 2, pp. 122-130.

[3] K.G. Eze, M.N.O. Sadiku, and S.M. Musa, "5G Wireless Technology: A Primer," *International Journal of Scientific Engineering and Technology*, Vol. 7, No. 7, July 2018, pp. 62-64.

[4] S.A. Busari, S. Mumtaz, S. Al-Rubaye, and J. Rodriguez, "5G Millimeter-Wave Mobile Broadband: Performance and Challenges," *IEEE Communications Magazine*, Vol. 56, No. 6, June 2018, pp. 137-143.

[5] A. Narayanan, E. Ramadan, J. Carpenter, Q. Liu, Y. Liu, F. Qian, and Z.-L. Zhang, "A First Look at Commercial 5G Performance on Smartphones," Proceedings of The Web Conference 2020, April 2020, pp. 894-905.

[6] C.T. Lopez, "AMBIT Gambit Pays Off, Advances U.S. 5G Efforts," U.S. Department of Defense Chief Information Officer, https://dodcio.defense.gov/In-the-News/News-Display/Article/2311483/ambit-gambit-pays-off-advances-us-5g-efforts/

[7] W. Thomas, "Science Committee Explores Roots of Interagency Radio Spectrum Fights," *FYI: Science Policy News from AIP,* No. 68, July 23, 2021, American Institute of Physics, https://www.aip.org/fyi/2021/science-committee-explores-roots-interagency-radio-spectrum-fights.

[8] M. Hamblen, "Multiple U.S. Trials Underway for Shared 3.5 GHz Wireless Spectrum," *Computerworld*, May 26, 2016, https://www.computerworld.com/article/3075748/multiple-u-s-trials-underway-for-shared-3-5ghz-wireless-spectrum.html.

[9] C. Sulhoff, "FCC Authorizes Full Commercial Deployment in 3.5 GHz Band, Advancing American 5G Leadership," *News from the Fedral Communications Commission*, January 27, 2020.

[10] A. Keeney, "National Spectrum Consortium Launches PATHSS Task Group to Explore 5G Spectrum Sharing," *Businesswire*, October 27, 2021.

[11] Federal Aviation Administration: Special Airworthiness Bulletin AIR-21-18: "Risk of Potential Adverse Effects on Radio Altimeters," November 2, 2021.

[12] R. Singh, *Spectrum Sharing Opportunity for LTE and Aircraft Radar in the 4.2-4.4 GHz Band*, Ph.D. Dissertation, Illinois Institute of Technology, 2017.

[13] "5G and Aviation Safety," Federal Aviation Administration, January 2022, https://faa.gov/5g.

[14] FAA Statement on 5G: January 28, 2022, https://www.faa.gov/newsroom/faa-statements-5g.

[15] E. Tegler, "Until Flight Tests Begin, The Air Force Knows Little About 5G Interference and It's Saying Less," *Forbes*, January 21, 2022, https://www.forbes.com/sites/erictegler/2022/01/21/until-flight-tests-begin-the-air-force-knows-little-about-5g-interference-and-its-saying-less/?sh=5614ffc31b80.

[16] J. Marino and A.J. Gasiewski, "A Broker Based Scheme for Spectrum Sharing," 2017 IEEE International Geoscience and Remote Sensing Symposium, Fort Worth, Texas, July 2017.

[17] J. Chong, *Manifold-Based System for Passive-Active Spectrum Sharing*, M.S. Thesis, University of Colorado, Department of ECEE, May 2014.

[18] "SWIFT: LARGE: Broker-Controlled Coexistence of 5G Wireless Artificially Intelligent Power Amplifier Array (AIPAA) with Passive Weather Radiometers," National Science Foundation, Grant No. 2030243, https://www.nsf.gov.

[19] C. Baylis, A. Egbert, J. Alcala-Medel, A. Dockendorf, A. Martone, and R.J. Marks II, "Real-Time Circuit Reconfiguration for a Cognitive Software-Defined Radar Transmission: A New Paradigm in Spectrum Sharing", 2019 IEEE Electromagnetic Compatibility Symposium, New Orleans, Louisiana, July 2019.

[20] A. Dockendorf, A. Egbert, E. Langley, C. Calabrese, J. Alcala-Medel, S. Rezayat, Z. Hays, C. Baylis, A. Martone, E. Viveiros, K. Gallagher, A. Semnani, and D. Peroulis, "Fast Optimization Algorithm for Evanescent-Mode Cavity Tuner Optimization and Timing Reduction in Software-Defined Radar Implementation," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 56, No. 4, August 2020, pp. 2762-2778.

[21] C. Calabrese, J. Roessler, A. Fisher, Z. Vander Missen, C. Baylis, M. Abu Khater, D. Peroulis, and R.J. Marks, "A Plasma-Switch Impedance Tuner for Real-Time, Frequency-Agile, High-Power Radar Transmitter Reconfiguration," 2021 IEEE MTT-S International Microwave Symposium, Atlanta, Georgia, June 2021.

[22] A. Fisher, Z. Vander Missen, A. Semnani, and D. Peroulis, "A Low-Loss 1-4 GHz Optically-Controlled Silicon Plasma Switch," 2021 IEEE 21st Annual Wireless and Microwave Technology Conference, April 2021, Sand Key, Florida.

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