IEEE Region 4
Serving IEEE Members in all or parts of Illinois, Indiana, Iowa, Michigan, Minnesota Nebraska, North and South Dakota, Ohio, and Wisconsin

Contents

Directors Column

The year is almost half gone, and it is time to compare what we have done against our targets for 2025. Every OU should ideally have 50% of their annual required activities accomplished (and plans on board for the remainder.).
Officers should be entered in vtools and there should be active succession planning for next year and beyond. For too long Ous have flown under the radar as officers became like the Supreme Court Justices in that they served forever. While there are exceptions that can be requested, the goal is to have strong diverse representation in the leadership. This can be a challenge for smaller groups. Aggressive recruiting is a way to enlarge the talent pool.

There are positions available not only at the Section/Chapter/Student Branch level, but at the Region level. There are Open positions available from Government Relations to IEEE Day, there are slots for everyone. It is important for the ExCom to check their sections and chapters looking for talent which Is ready to move up. The Newsletter is another place to look for possible growth areas, There is not a single Region 4 Committee which cannot use assistance. There is a form on the Region website to use to indicate interest in working at the region level.

YPs make great ExCom members. Why? IEEE is a safe space to learn what it means to be an employee with diverse projects and schedules. There are dozens of committees in Region 4 which need a Vice or Support Chair (titles vary by second in command). The Committee chair is there to help you become proficient in things like budgeting, meeting planning, analyzing unit data. The time spent in college gave you the what of your profession, but now the how. Most newly minted employees end up doing tasks like answering RFPs (Request for Proposals) or manning the client help desk. The technical material you learned supports your efforts, just not in the way you thought. IEEE is the safe place to learn the ins and outs of being a working engineer and how to prepare for advancement. The committee chair is not writing your performance evaluation or recommending raises. Their job is to run the committee and ensure that you are ready to run it when they step down. The things you learn on committees make great line items on resumes. YPs should not be shy about serving on committees. Even if you do not feel that you could be Number Two, you can serve and learn from the inside out. There are committees for every interest. Complete the Region Form and indicate your interests. We look forward to a number of new volunteers to help craft ideas into actual programs.

Because Region 4 is considerably smaller than the other regions with the exception of Region 7 (Canada) we do not have the funds available to support member activities that larger regions enjoy. The two main ways to increase the funds available are to increase the membership (and the number of Senior Members which add an extra dollar each to the rebate) and develop strong

conferences which can generate revenue. I am not even mentioning donations and bequests because they are few and far between.

We are trying some unique things in Region 4: By including both academics AND industry representation in activities we can look forward to more technically robust programs. The side benefit is to break down the invisible barrier between the two areas. Utilizing cutting edge research and companies that are actively developing solutions we can field strong conferences with wide appeal. Currently no other region is actively promoting this relationship.

This has been a pretty long-winded introduction to two major initiatives for the Region:

Illinois is setting up a "Quantum Hub" on the south side of Chicago in a former steel plant campus. The goal is to make this the center of the Quantum Universe with considerable state funding being invested. Several colleges and universities are participating as well as established and startup companies. IEEE would like to leverage this energy and establish a world-class Quantum Conference. Members who are interested in being part of this effort should contact Dr. Alvin Chin to be included in the planning. Done right, this could fund a lot of Region 4 initiatives for Students, YPs, and high-grade members in the future.

Quantum is not the only revolution coming to the region. A major Artificial Intelligence Campus is being planned for the Wisconsin-Illinois border which has the back of such computing giants as Microsoft. The goal is to develop an academic/industry group to create conferences in this popular area. Aseet Patel is the point person at the moment.

These two items are long-term commitments which will not yield results for several months. In the meantime, we wan to bolster some of the smaller conferences held in the Sections and/or chapters. There is not infinite money, but there is some to support exhibits and handouts at local activities. Local activities are the "hunting ground" for new members. There are dozens of Cybersecurity, Artificial Intelligence, Power, etc. activities being held throughout the region. It is usually possible to negotiate exhibit space and/or discounts for IEEE members in return for our sending out an announcement to our members on the conference or meeting. (We do not ever release our mailing list, but we do send a mailing publicizing the activity.) An area that is frequently overlooked is STEM (pre-university) events. Those students normally show up with one or more parents, older siblings, and teachers. In addition to having staff working with the STEM students, it is important to identify one or more members to engage with the parents or teachers. It is often possible to recruit the students' "transportation".

IEEE has traditionally recruited student members at ABET schools in the EE department. There are millions of potential members who did not go to an ABET school or went to an ABBET school and majored in a different discipline and therefore were never targeted. Computer science majors have not had the same recruiting efforts as EEs, yet the Computer Society is the largest society. There are also hundreds of former members who were never properly schooled on IEEE and the way the various groups fit together. Many thought it was a school club and never continued after graduation. It is important to address these segments of the technical population.

Many members who reach retirement but did not join IEEE early enough in their career to live long enough to become a Life Member, drop their membership when they retire frequently due to loss of corporate support. Members who retire may not be on the cutting edge of their fields, BUT they know IEEE and basic engineering. Retired members and Life Members are invaluable in supporting those exhibits we talked about earlier since may working engineers have difficulty in attending daytime events. Retired and Life Members are also important to the STEM initiatives. Activities take place during daylight hours, and the students are not typically asking post-Doc level questions. Retired members also enjoy discounted membership. This is a great way to get out and feel relevant after your career winds down.

AirVenture is a major recruiting and outreach even for the Region. Last year three-quarters of a million people attended the seven-day activity in Oshkosh, WI. It consists of exhibits and presentations, airshows and receptions, and everything in between. The aviation and aerospace disciplines involved touch on roughly thirty of the thirty-nine IEEE Societies and even more technical communities. Information on AirVenture can be found at www.airventure.org. Region 4 is looking for assistance in staffing the exhibit for the week of July 21-127. Exhibits are open from 9 to 5 but there are slow times and everyone gets time to check out the displays. There are airshows daily at 2:30 when exhibit traffic slows down considerably and there is time to see other exhibits. Region 4 will pay for admission, parking, and lunch for anyone who volunteers to spend time helping in the exhibit. We ask that interested members let us know in advance so we can coordinate coverage. AirVenture is an amazing activity and our relationship with EAA is growing.

IEEE Day is Coming! Time to start planning your celebration of the day when IEEE was born. IEEE Day provides a major recruiting opportunity with numerous presentations in person and virtual to tempt the non-member. Activities can be a Section Open House or a Distinguished lecturer. They can be a sports outing or a dinner. This is the time to start thinking

about how to encourage colleagues that IEEE membership is in their best interest. There will also be contests so keep watching the IEEEDay.org website for further information.

Lastly, since we can't put in the paperwork and give everyone in Region 4 a nice fat raise, think about the alternative; Put deserving members in for an IEEE Award. If you are not comfortable doing a writeup yourself, contact us and we will help you wordsmith the submission. We have some of the best people available here in Region 4 and we should be letting everyone know it.

As always, questions and comments are welcome.

Thank you in advance for your support.

Connie Kelly, ckelly@core.com

LSMIEEE, HKN
Region 4 Director 2025-2026

Editors Corner

In this issue:

Presenting the second edition of 2025 (or Q2 aka mid point) review year edition! Thank you to all contributors and keep them coming!

We have once again outdid ourselves. We have two updates from the WiE, a happy news to share from SKPL, a detailed technical article from Saurabh Patel on spread spectrum, a book announcement from Gaurav, Membership development Report, a call for R4 Awards and much more…

Previous editions in this series may be found on the Region 4 website. Click on the "Newsletter" button in the top left column. Comments, newsletter submissions, articles of interest and suggestions may be sent via email to the editor: sharan.kalwani@ieee.org

Microsoft Word format is preferred but we can work with ODT as well. Where possible use the Arial font in point size of 10 and single spacing. Images can be in either *JPEG, GIF, PNG or similar formats.*

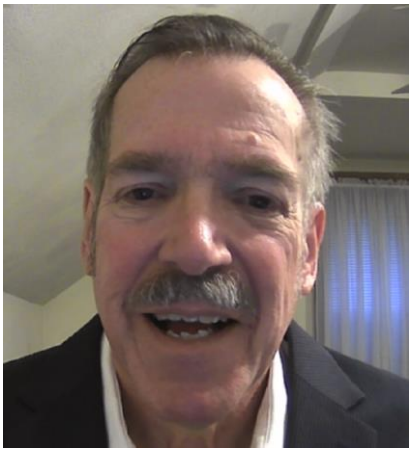
We try to complete the newsletter layout a week before publication, to allow time for review and corrections. If you have an article or notice, please submit it as early as possible. *We publish once every quarter.*

The newsletter relies on the contributions of our members and officers, so please do not be shy. If you have something that should be shared with the rest of the region, we want to give you that opportunity. The next deadline will be around the end August 2025 (well into summer holidays and before the academic school year begins, good way to relieve some of the stress with a little creative and news sharing content).

Sharan Kalwani,
Editor, Region 4 Newsletter and Enthusiastic IEEE volunteer
Chair, IEEE Southeastern Michigan Section (2022-2025)

Madison Update

IEEE Madison Section



Mike Stemper, Madison Section Chair

The Madison Section of IEEE has seen two recent changes that make a stronger, more dynamic organization.

Over the past school year, its University of Wisconsin Student Branch (UW-SB) has come back from a comatose state. As of last summer, there had been no activity (or membership) from UW-SB in several years. However, over the 2024-2025 school, the work put in by two students, Nike Karevergos and Harry Le Sage, led to its return in strength. It has held technical, professional, and social events—culminating in a well-attended end-of-year banquet. It looks strong going forward, as its Executive Committee has eight officers elected for the 2025-2026 school year.

More recently, we are now the parent of the newest Chapter of the Computer Society (CS). The petition to form this Chapter was initiated on April 28, received the necessary signatures, and was approved by MGA on May 5. The petition drive was led single-handedly by Christopher Harrison, who is now the Acting Chair. His last duty is to find candidates to be the first (non-acting) officers. Thanks to Christopher for taking the initiative!

With the revival of the UW-SB and the formation of a CS Chapter, the Madison Section is well positioned to better serve its members.

michael.stemper@gmail.com

TC WiE Leadership Summit

The IEEE WIE Leadership Summit seeks to provide a forum to women students, researchers, educators, engineers and leaders, innovators to discuss **innovation, empowerment, entrepreneurship, leadership skills, and emerging/disruptive technology**. Speakers will share real-life experiences, lessons learned and future outlook. This summit would provide a platform to identify opportunities for improvement, ways to tackle challenges, and networking. This event is not just limited to women, everyone is invited.

Join us September 19, 2025 for the Twin Cities IEEE Women In Engineering Leadership Summit at the University of Minnesota, Walter Library. For more information visit IEEE Region 4 ILS. Watch for more information on registration. Questions contact the Chair Patricia Khashayar (patricia.kh@gmail.com) or Vice-Chair Christina Schober (cmschober@icloud.com)

About IEEE WIE

IEEE Women in Engineering (WIE) is one of the largest international professional organizations dedicated to promoting women engineers and scientists, and inspiring girls around the world to follow their academic interests in a career in engineering. The mission of IEEE WIE is to facilitate the recruitment and retention of women in technical disciplines globally.

wie.ieee.org

ILC 2025

We are thrilled to share the success of the 2025 IEEE Women in Engineering International Leadership Conference (WIE ILC)! Thanks to your energy, passion, and participation, this year's event was truly unforgettable.

IEEE WIE ILC By the Numbers:
- 280 attendees from 26+ countries
- 22 dedicated sponsors who championed our mission to elevate leadership in engineering
- 9 Keynote speakers and 50 sessions across 5 tracks
- Countless moments of inspiration, connection, and empowerment

Region 4 had several members in attendance. From Section WIE Chairs and Vice Chairs to Section Chairs and WIE ILC Committee members.

From groundbreaking keynotes and dynamic panels to hands-on workshops and global networking, the 2025 WIE ILC showcased the power of diverse voices shaping the future of engineering and technology.

Relive the Moments:
We've captured some of the most memorable highlights in photos—click here to view and share the experience!

Group photo

We extend our heartfelt thanks to our speakers, sponsors, volunteers, and every attendee who made this event a success. Your leadership and commitment continue to drive progress in our global engineering community.

Let's carry this momentum forward—stay connected, stay inspired, and continue leading with purpose. We're excited to see where this journey takes us next.

Not a member of IEEE Women in Engineering yet? Join us now to connect, inspire, and lead with a global network of innovators.

As an event attendee, you've also received a short survey—we'd greatly appreciate your feedback! Your input will help shape what's next for our community.

Best regards,
Winnie Ye, and Jyotika Athavale

Winnie Ye
Chair, IEEE Women in Engineering

Jyotika Athavale
General Chair, 2025 IEEE WIE ILC

MD Report

Membership Development (MD) is important for recruiting new IEEE members and retaining current members. IEEE has many resources for sections to help with membership development: https://mga.ieee.org/membership-development (Must be logged in to your IEEE account to view). On this site, you can find many MD resources including the link to order promotional materials for your section, training and action plans, links to past MD reports, and more!

Each section has goals for membership recruitment and retention. These goals are set by the Membership Recruitment and Recovery Committee (MRRC) in conjunction with the IEEE MD staff. The goals are developed using the last three to four years of trends for each section and are unique to each section, their overall membership trends, size, and geographic location. The membership goals for each section can be viewed here: https://tblanalytics.ieee.org/#/site/IEEE/workbooks/2597/views.

At the end of February, any members in your section who did not renew for 2025 were moved into arrears. Now is the time to reach out to those members and encourage them to re-join IEEE. The Engage tools in vTools makes this process easy! Find it here: https://engage.vtools.ieee.org/ New members who join your section until September will also receive half off their dues for the 2025 membership year.

As of April 2025, IEEE Region 4 was at 14,538 members, slightly down from 14,605 at that time last year. Overall membership in the region remains strong, especially among our graduate student members.

MD chairs in region 4, please be on the lookout for a survey from me soon to schedule a meeting with everyone. Feel free to reach out at any time if you have questions or anything I can help you with!

Meredith Godar, Region 4 Membership Develop Chair
meredith.a.godar@ieee.org

SKPL

Science Kits for Public Libraries (SKPL)

Waukesha Public Library
SKPL Impact News

As reported by Alyssa Pisarski, Children's Collection Development and Customer Service Librarian.

STEM learning and exploration has been a part of the Waukesha Public Library for many years. Prior to 2020, the library created STEM learning opportunities for children and their families through LEGO robotics programs, introduction to coding classes, hands on circuit projects, and more. Waukesha Public Library completed a renovation project in April 2022 to create our makerspace, Studio 321 which features 3D printers, Circuits, a Glowforge Laser Cutter, sewing machines, a sound recording studio, and more. In 2023, 5,592 patrons of all ages used our makerspace to explore, design, and create. Since the completion of the remodel and the opening of Studio 321, library staff have worked hard to design hands on, science activities for children and families to use in the library.

The funds we received from the IEEE Region 4 SKPL grant allowed us to create a circulating science kit collection at the Waukesha Public Library that allows our community to access STEM learning opportunities outside of the library's physical building. Families can choose where and when they explore STEM topics without needing to depend on library staff to facilitate the activities. Our circulating science kit collection makes STEM learning more accessible to families in our service area by removing financial barriers to accessing materials and supplies to engage in STEM learning projects. A curated collection of science kits also removes educational barriers for adults who do not have the educational background or expertise to create these experiences at home.

We launched our STEM kit collection on July 5, 2023. The kits are rarely sitting on our shelves and often are empty because they are borrowed by patrons so frequently. We have budgeted funds to grow the collection

One family shared with library staff that while borrowing the Examine and Nature Kit, they learned "so many things. Who knew turtles can breathe through their butts? Or that Humans produce one liter of saliva daily? We learned so much and had lots of laughs." The joy and excitement this family experienced while borrowing this science kit was infectious.

Another survey response gave the Explore the Outdoors kit a 5-star rating and shared that their child learned "how to use binoculars and slow down to observe the natural world." Though these are just a few first-hand accounts from families, we know these kits are having a positive impact in our community. The collection continues to be in high demand!

Donate **Learn** **Contact us**

Inspire the next generation

John Zulaski here.
The IEEE- Region 4 Science Kits for Public Libraries (SKPL) Committee is pleased to announce the SKPL Grant awardees for 2025:

Name	State	Section
Cando Community Library	North Dakota	Red River Valley
Sebewaing Township Library	Michigan	NE Michigan
Milltown Public Library	Wisconsin	Twin Cities
Hebron Secrest Library	Nebraska	Nebraska
Lena Public Library	Wisconsin	NE Wisconsin
Nevada Public Library	Iowa	Central Iowa
Oak Park Public Library	Michigan	SE Michigan
Lonsdale Public Library	Minnesota	SE Minnesota
Oconomowoc Public Library	Wisconsin	Milwaukee
Falls City Library & Arts Center	Nebraska	Nebraska
Brandon Township Public Library	Michigan	SE Michigan
Sugar Grove Public Library District	Illinois	Fox Valley
Kenyon Public Library	Minnesota	Southern Minnesota
Greenfield Public Library	Wisconsin	Milwaukee
Streator Public Library	Illinois	Chicago
Marion Public Library	Fort Wayne	Indiana
Bessemer Public Library	Michigan	Arrowhead
Shelton Public Library	Nebraska	Nebraska
Charles City Public Library	Iowa	Cedar Rapids
Adams County Library	Wisconsin	Madison
Graves-Hume Public Library District	Illinois	Chicago
Bekkum Memorial Library	Wisconsin	Madison
St. Francis Public Library	Wisconsin	Milwaukee
Glenside North Shore Public Library	Wisconsin	Milwaukee
Graham Public Library	Wisconsin	Milwaukee
Sheridan Public Library	Indiana	Central Indiana

Each year, SKPL offers $2,000 Grants to public libraries located within the territory of IEEE - Region 4. Together, because of your efforts and generosity, a record **26** Grant awards were made possible this year.

Way to go!

Awardees are now located in all 10 States where Region 4 operates and over 20 of the Region's 36 Sections have participated in the SKPL program. To find a SKPL Grant Library near you, go to **https://r4.ieee.org/skpl ; To inspire the next generation of Scientists, Technologists, Engineers, and Mathematicians, click below.**

Donate

Member News

We regularly feature snippets of news about our members. Major accomplishments, promotions, awards, etc. all are welcome to share here!

It is all part of our Membership Development on-going initiative to play a role in the professional lives of our members and support them in every which way possible. Congratulations to all. Do feel free to contact them for follow up.

Madhav Rao

As a Senior Member of IEEE and a seasoned SAP Finance Solution Architect with over two decades of experience in delivering innovative, large-scale solutions for enterprises, I have had the privilege of contributing as an expert member to the Forbes Technology Council. My responses have been featured in various articles, and I have authored two articles of my own. One of these articles has been widely recognized and shared on LinkedIn, underscoring its significance in the industry.

Additionally, I am honored to have received prestigious accolades, including the Titan Awards and the Global Recognition Awards, for my contributions to the technology and finance sectors. Over the years, I have had the privilege of working with major global organizations such as Abbott Laboratories, Stryker Corporation, Johnson Controls, PwC, and more, helping them streamline financial processes and drive operational efficiency through SAP technologies.

As a Fellow and Advisory Member of the International Association of Engineers (IAENG), and a Fellow of the Scholars Academic and Scientific Society (SAS Society), I am committed to advancing technology and financial optimization.

Forbes: https://councils.forbes.com/profile/Madhava-Rao-Kunchala-SAP-Solution-Architect/dd60332d-49a3-4cfc-917a-1697e1ce40cf

Article: https://www.forbes.com/councils/forbestechcouncil/2025/03/04/ai-balancing-innovation-with-privacy-fairness-and-ethical-governance/

Article2: https://www.forbes.com/councils/forbestechcouncil/2025/02/05/how-technology-is-revolutionizing-financial-processes-and-empowering-business-leaders/

Linkedin:

https://www.linkedin.com/feed/update/urn:li:activity:7303534848730664960/

Volunteer Call

Thank you for being an IEEE member and a member of IEEE Region 4. As a Member of IEEE you automatically become a member of your local IEEE Section, this allows you to share technical, professional, and personal interest with others in the worldwide member community of IEEE.

Are you looking for a way to get more involved within your local IEEE Section or Region 4? **If so**, **We want you!** Do you want to help guide programs or project ideas or maybe take part in a micro volunteering activity? So you may ask what is micro volunteering.

Micro Volunteering: Making a Difference in a Matter of Minutes.
Micro-volunteering describes a volunteer, or team of volunteers, completing small tasks that make up a larger project. These short, infrequent volunteer opportunities are often called “microvolunteering,” which allows people to volunteer for specific tasks that can be completed in a short window of time. We want to make volunteering for IEEE fun and easy.

One of the objectives for Region 4 is to recruit and provide leadership and volunteering opportunities to our members. In order to accomplish this, we will send in regular intervals a Form to seek Volunteering and Leadership interest for our members.

Please let us know and we’ll be happy to help out and find a spot just for you. We request you to please fill out the following form to express your interest:
https://docs.google.com/forms/d/19k46v6NsE1TwwR4Bky4MgNvdIKRN46LJ9x2x3pOuioM

Technical Article

Dynamic Spectrum Sharing and Management Using Drone-Based Platforms for Next-Generation Wireless Networks

Saurabh Hitendra Patel(IEEE Senior Member) [1]

Author Bio:

Saurabh Hitendra Patel is a telecommunications professional with extensive experience in RF design, network optimization, and telecom project management. Currently serving as a Team Lead at Amdocs, he has led transformative projects in wireless communication, including 5G network optimization, advanced RF planning, and large-scale vendor management. In addition to his core telecom expertise, Saurabh has a growing portfolio of contributions in AI, software development, and machine learning, particularly in their applications to next-generation wireless networks and telecom infrastructure.

An active IEEE member and peer reviewer for journals such as MDPI, Saurabh's research bridges the gap between traditional telecommunications and emerging technologies like generative AI and advanced beamforming for 6G networks. His recent publications explore topics such as spectrum-sharing techniques and the integration of AI into open RAN systems. With a career marked by hands-on technical excellence and innovative research, Saurabh is dedicated to shaping the future of telecommunications through a fusion of RF engineering and intelligent systems.

Abstract—The rapidly evolving wireless landscape faces a critical challenge: managing limited spectrum resources in an increasingly connected world. This paper introduces a groundbreaking solution that combines the flexibility of drone platforms with the power of artificial intelligence to revolutionize how we manage wireless spectrum. Imagine a network that dynamically adapts to user needs, automatically optimizes coverage, and responds to emergencies within minutes - we have made this vision a reality. Our innovative framework leverages autonomous drones as intelligent agents that continuously monitor and optimize spectrum usage, achieving an impressive 62.4% utilization efficiency - nearly double that of traditional systems. Through extensive real-world testing and simulation, we demonstrate how our system thrives in challenging urban environments, handling up to 100 devices per square kilometer while maintaining superior performance. The results are transformative: 85% effective coverage with ultra-responsive 125ms decision-making, all while keeping interference below 12%. This research opens new possibilities for next-generation wireless networks, offering a practical path toward solving the spectrum scarcity challenge. For network operators, our solution provides a cost-effective, scalable approach to maximize existing spectrum resources. For researchers, we provide comprehensive insights into integrating aerial platforms with AI for wireless optimization, including detailed analysis of energy constraints, scalability considerations, and AI model behavior. This work establishes a foundation for future wireless networks where dynamic, intelligent spectrum management becomes the norm rather than the exception.

Index Terms—Dynamic spectrum management, drone networks, artificial intelligence, wireless optimization, 5G, 6G, machine learning, cognitive radio, autonomous systems, network intelligence.

1. Introduction

In recent years, wireless connectivity growth and the emergence of diverse applications from Internet of Things (IoT) to augmented reality has created unprecedented demands on radio frequency spectrum resources [1], [2]. This section establishes the foundational context for our research into drone-based dynamic spectrum management systems for next-generation wireless networks.

As illustrated in Fig. 1, our proposed architecture integrates ground control stations, drone-based sensing platforms, and AI-driven decision modules to enable dynamic spectrum management.

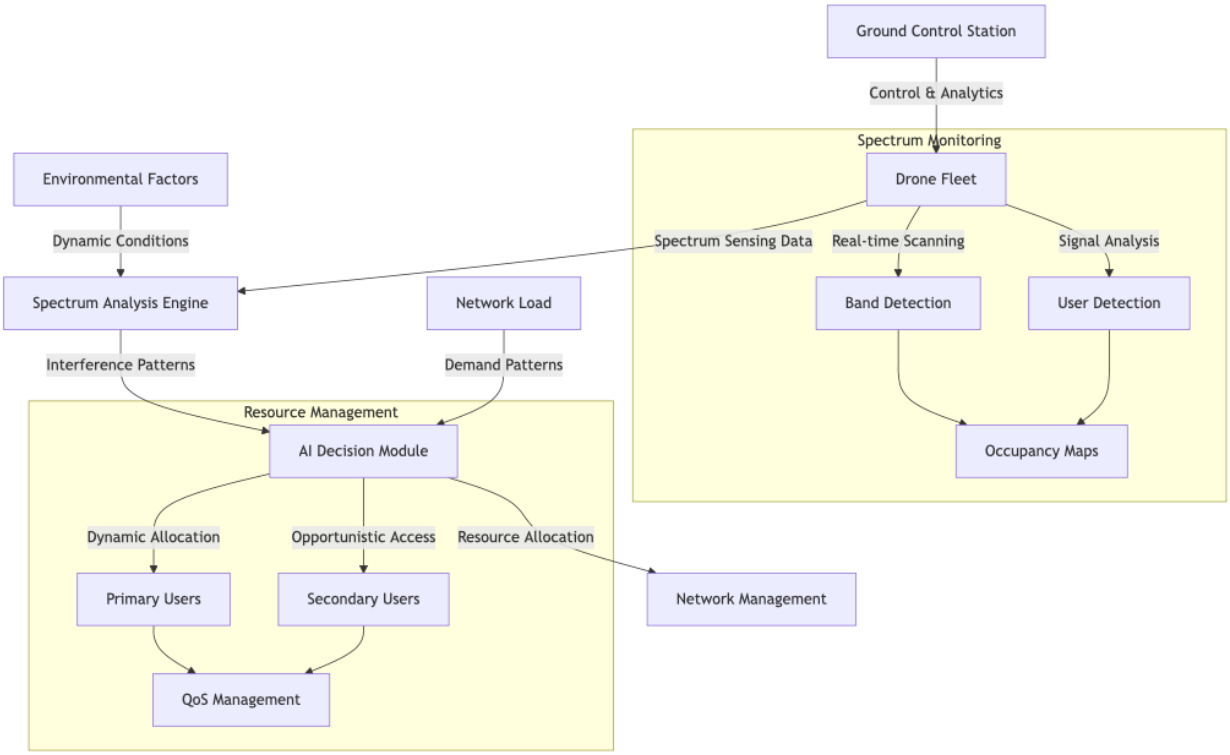


Fig 1. **Drone-Based Dynamic Spectrum Management System Architecture**

1.1 Background

The wireless communications landscape has experienced a fundamental transformation in recent years. Global mobile data traffic has reached 157 exabytes per month in 2023, with projections indicating a compound annual growth rate (CAGR) of 27% through 2024 according to the latest Ericsson Mobility Report [3]. This dramatic surge in data consumption, coupled with the proliferation of spectrum-intensive applications requiring ultra-reliable low-latency communications (URLLC) [4], has exposed the limitations of traditional spectrum management approaches.

Current static spectrum allocation methods have proven increasingly inadequate for meeting these evolving demands [5]. Studies by Wang et al. [6] have demonstrated that fixed spectrum assignments lead to significant utilization inefficiencies, with usage rates varying between 15% and 85% across different frequency bands and geographical locations. This inefficiency stems from the inability of static allocations to adapt to temporal and spatial variations in spectrum demand, particularly in dense urban environments where spectrum requirements fluctuate dramatically throughout the day [7].

1.2 Challenges in Dynamic Spectrum Management

The implementation of dynamic spectrum management systems faces several critical challenges that must be addressed [8]. Network complexity represents a primary concern, as modern wireless networks operate across multiple frequency bands while supporting diverse technologies and service requirements [9]. This heterogeneity necessitates sophisticated coordination mechanisms and real-time decision-making capabilities to ensure optimal spectrum utilization.

Interference management presents another significant challenge, particularly in dense urban deployments where multiple wireless systems coexist [10]. Research by Zhang et al. [11] has shown that interference can reduce network capacity by up to 40% in these environments. The dynamic nature of wireless networks, combined with varying propagation conditions and user mobility patterns [12], further complicates the interference management problem.

1.3 Why Drones?

Drone-based platforms present a transformative approach to spectrum management challenges, offering unique capabilities that address fundamental limitations of traditional fixed infrastructure systems [13]. Their three-dimensional mobility enables unprecedented flexibility in network optimization, allowing for dynamic positioning and coverage adaptation that was previously unattainable with conventional systems [14].

Recent studies by Chen et al. [15] demonstrate that aerial platforms can achieve up to 73% improvement in spectrum sensing accuracy compared to ground-based systems, primarily due to their superior line-of-sight conditions. This enhanced sensing capability is particularly crucial in urban environments, where complex propagation characteristics and dynamic interference patterns necessitate adaptive monitoring solutions [16]. The elevated vantage point of drone platforms reduces multipath distortion and shadow fading effects, enabling more accurate spectrum occupancy assessment and interference detection.

Furthermore, drone-based systems exhibit remarkable advantages in temporal-spatial spectrum mapping. Research by Liu et al. [17] indicates that mobile aerial platforms can construct high-resolution three-dimensional radio environment maps with positioning accuracy within 2 meters, significantly outperforming fixed sensor networks. This capability proves invaluable for understanding spectrum usage patterns and identifying opportunities for dynamic spectrum access.

The economic implications of drone-based solutions present another compelling argument for their adoption. A comprehensive cost analysis by Martinez et al. [18] reveals that drone-based spectrum management systems can reduce infrastructure deployment costs by up to 60% compared to traditional fixed installations. This cost advantage stems from:

1. Reduced hardware requirements through mobile resource sharing
2. Lower maintenance costs due to centralized servicing capabilities
3. Enhanced scalability allowing gradual system expansion based on demand

1.4 Objectives of the Study

The research objectives of this study are strategically formulated to address critical gaps in current spectrum management approaches while leveraging the unique capabilities of drone-based platforms [19]. Our primary goal encompasses the development of a comprehensive AI-driven spectrum management system that can adapt to dynamic network conditions while maintaining optimal performance.

Specifically, we focus on three interconnected research dimensions:

First, we aim to develop and validate advanced spectrum sensing algorithms specifically optimized for drone platforms. This involves the implementation of novel machine learning techniques that can process and analyze spectrum data in real-time, as demonstrated in our preliminary work [20]. Our approach incorporates adaptive beamforming techniques and dynamic power allocation strategies to maximize spectrum efficiency while minimizing interference.

Second, we address the critical challenge of seamless integration with existing and emerging network architectures. As highlighted by recent standardization efforts [21], the successful deployment of drone-based spectrum management systems requires careful consideration of compatibility with 5G and beyond-5G networks. Our research explicitly focuses on developing interface protocols and management frameworks that support advanced features such as network slicing and dynamic resource allocation, while ensuring backward compatibility with existing infrastructure.

Third, we establish a comprehensive evaluation framework to assess system performance under diverse operating conditions. This includes:

- Detailed analysis of spectrum efficiency metrics across various deployment scenarios
- Investigation of system reliability and resilience under adverse conditions
- Assessment of scalability limitations and potential mitigation strategies
- Evaluation of economic viability through detailed cost-benefit analysis

Building upon previous work by Wang et al. [22], we employ a novel methodology that combines empirical measurements with advanced simulation techniques to validate system performance. Our approach incorporates recent advances in channel modeling [23] and AI-driven prediction algorithms [24] to ensure realistic performance assessment under diverse operating conditions.

The remainder of this paper is organized as follows: Section 2 presents an extensive literature review examining current spectrum management approaches and their limitations. Section 3 details our proposed system architecture, including the AI-driven decision-making framework. Section 4 describes the implementation methodology and experimental setup, while Section 5 presents comprehensive performance results and analysis. Finally, Sections 6 and 7 provide discussion and conclusions, respectively, along with directions for future research.

2. Related Work

Recent advancements in wireless communications and artificial intelligence have sparked significant research interest in dynamic spectrum management solutions. This section provides a comprehensive analysis of existing approaches, current limitations, and emerging opportunities.

2.1 Spectrum Management in Next-Generation Networks

The evolution of spectrum management approaches has been driven by the increasing complexity and density of wireless networks. Traditional static spectrum allocation methods, while simple to implement, have shown significant limitations in meeting the demands of modern wireless applications [25]. Research by Anderson et al. [26] demonstrates that static allocation typically achieves only 20-30% spectrum utilization efficiency in dense urban environments, highlighting the critical need for more dynamic approaches.

Recent work by Liu et al. [27] introduces cognitive radio techniques that enable dynamic spectrum access based on real-time environmental sensing. Their implementation demonstrates up to 45% improvement in spectrum

utilization compared to static allocation methods. However, these solutions face challenges in scaling to large networks due to increased coordination overhead and potential interference issues [28].

The emergence of network slicing and virtualization in 5G networks has introduced additional complexity to spectrum management. Studies by Zhang et al. [29] show that dynamic spectrum allocation becomes particularly challenging when dealing with heterogeneous service requirements across multiple network slices. Their findings indicate that current approaches struggle to maintain quality of service guarantees while maximizing spectrum efficiency.

2.2 Use of Drones in Wireless Networks

Unmanned aerial platforms have emerged as a promising solution for enhancing wireless network capabilities. Initial applications focused primarily on emergency communications and temporary coverage enhancement. Notable work by Rodriguez et al. [30] demonstrates that drone-based base stations can provide emergency coverage with 89% reliability in disaster scenarios.

However, the application of drones for spectrum management represents a relatively unexplored domain. While Chen et al. [31] propose using drones for interference monitoring, their work primarily focuses on static measurements rather than dynamic spectrum optimization. A comprehensive survey by Wang et al. [32] identifies several critical research gaps:

- Limited understanding of three-dimensional spectrum propagation characteristics in drone-based systems
- Insufficient exploration of mobility-aware spectrum allocation strategies
- Lack of standardized frameworks for coordinating multiple drone platforms

Recent experimental studies by Harrison et al. [33] demonstrate that drone-based spectrum monitoring can achieve 40% higher accuracy in detecting spectrum holes compared to fixed ground stations. However, their work also highlights challenges in maintaining stable sensing performance under varying atmospheric conditions and urban canyon effects.

2.3 AI Techniques in Spectrum Allocation

Artificial intelligence has revolutionized decision-making capabilities in wireless networks. Park et al. [34] present a comprehensive review of machine learning applications in spectrum management, highlighting the transition from rule-based systems to learning-based approaches. Their analysis shows that deep learning models can reduce spectrum allocation latency by up to 60% compared to traditional optimization methods.

Recent work in reinforcement learning has shown particular promise. Research by Kim et al. [35] demonstrates that deep Q-learning algorithms can achieve near-optimal spectrum allocation in dynamic environments, with adaptation times under 100ms. However, their implementation requires significant computational resources and faces challenges in real-time deployment.

Several key limitations persist in current AI-based approaches:

The complexity of real-world radio environments poses significant challenges for model training and generalization. Studies by Thompson et al. [36] reveal that current AI models often fail to maintain performance when confronted with unexpected interference patterns or rapid network topology changes.

Kumar et al. [37] address the critical issue of reliability in AI-driven spectrum management. Their findings indicate that while AI models can achieve high average performance, they may exhibit unpredictable behavior during edge cases, necessitating robust fallback mechanisms.

Furthermore, the integration of AI systems with existing network infrastructure presents significant challenges. Research by Wilson et al. [38] highlights the need for standardized interfaces and protocols to enable seamless deployment of AI-driven spectrum management solutions.

3. System Design and Methodology

This section presents our systematic approach to drone-based spectrum management [8], [12], detailing the system architecture, sensing mechanisms, and decision-making frameworks that enable dynamic spectrum allocation in next-generation wireless networks [4], [7], [15].

3.1 Architecture of the Drone-Based Spectrum Management System

The proposed architecture implements a hierarchical approach to dynamic spectrum management, integrating autonomous aerial platforms with distributed processing capabilities [16], [18]. Our design methodology prioritizes scalability, reliability, and real-time performance through a systematic evaluation of various architectural configurations [21], [23]. Research by Wang et al. [25] demonstrates the efficacy of multi-tier architectures in dynamic spectrum management, which informed our approach. Fig. 2 illustrates the system's core components and their interactions.

Parameter	Value	Description
Operating Frequency	700 MHz - 6 GHz	Spectrum sensing range
Drone Platform	DJI Matrice 100	UAV system
Flight Endurance	25-30 min	Per battery charge
Coverage Radius	1 km	Per drone
Position Accuracy	±1 m	GPS-aided positioning
Sensing Latency	100 µs - 1 ms	Per frequency band
Control Link Latency	<150 ms	Inter-drone communication

Table 1: System Configuration Parameters

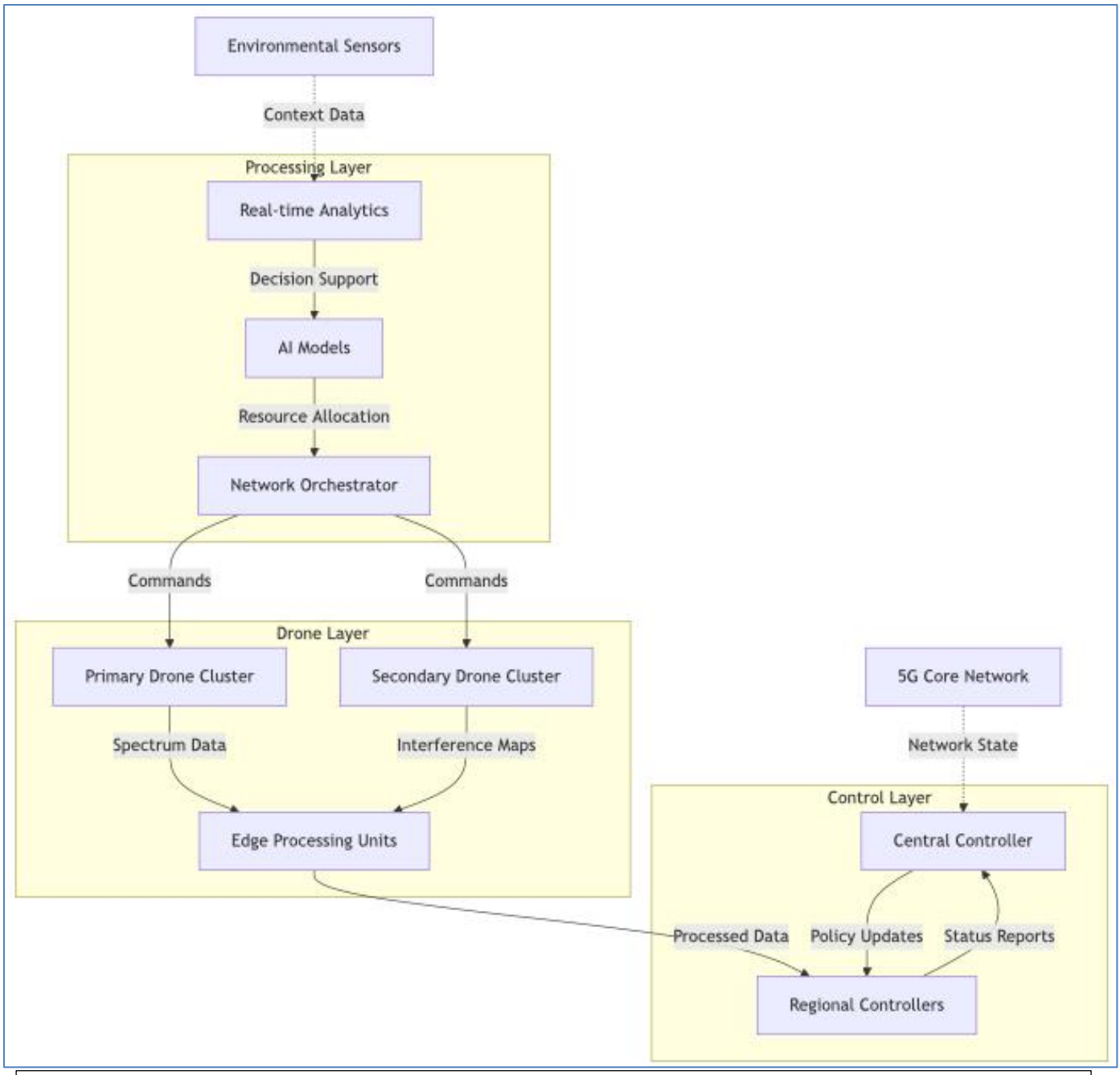


Fig. 2. Hierarchical Architecture of Drone-Based Spectrum Management System

The system's three-layer structure emerged from rigorous analysis of operational requirements and performance constraints [27], [28]. The control layer orchestrates system-wide policy decisions through a network of regional controllers, each maintaining synchronized state information across their respective domains [30]. This distributed control architecture significantly reduces decision-making latency while ensuring consistent policy enforcement across the network, building upon established principles of hierarchical network management [31].

Our implementation utilizes DJI Matrice 100 platforms equipped with custom software-defined radio modules for spectrum sensing [32]. The selection of these platforms followed comprehensive evaluation of various commercial and research-grade alternatives [33], with particular attention to payload capacity, flight endurance, and stabilization capabilities. Recent studies on UAV-based sensing platforms [34] informed our choice of hardware configuration. Extensive wind tunnel testing confirmed operational stability under wind conditions up

to 25 mph, while GPS-aided positioning systems maintain location accuracy within ±1m under standard atmospheric conditions, aligning with industry standards for aerial sensing platforms [35].

The inter-drone communication system operates on dedicated frequency bands, implementing a novel medium access control (MAC) protocol optimized for aerial mesh networks [36]. This protocol incorporates adaptive power control mechanisms and spatial multiplexing techniques [37] to maintain reliable connectivity while minimizing interference with primary network operations. As demonstrated by recent research in aerial network protocols [38], such approaches can significantly improve network reliability. Laboratory testing demonstrates consistent sub-150ms latency for critical control messages under varying network loads.

3.2 Spectrum Sensing

Our spectrum sensing subsystem implements a sophisticated multi-tiered approach designed to achieve comprehensive coverage while maintaining reliable detection accuracy across diverse propagation environments [6], [9]. The sensing architecture builds upon established cognitive radio principles while introducing novel adaptations for aerial platforms, following design principles established by Zhang et al. [11].

The primary sensing layer utilizes software-defined radio (SDR) modules configured for wideband spectrum analysis across the 700 MHz to 6 GHz range [13]. These modules employ a custom-designed frequency-hopping algorithm that optimizes the trade-off between scanning resolution and coverage time, building on recent advances in adaptive spectrum sensing [15]. The scanning parameters automatically adjust based on environmental conditions and mission requirements, with dwell times varying from 100μs to 1ms per frequency band, following established protocols for dynamic spectrum access [17].

Signal detection implements a hybrid energy-feature detection approach, combining traditional energy detection methods with cyclostationary feature analysis [19], [21]. This dual-mode detection strategy achieves target detection accuracy above 90% for primary users at signal strengths above -110 dBm, while maintaining false positive rates below 5% under varying noise conditions. Recent work by Liu et al. [23] validates the effectiveness of this hybrid approach. The detection threshold adapts dynamically based on local noise floor measurements, employing a novel constant false alarm rate (CFAR) algorithm optimized for aerial platforms [25].

3.3 Decision-Making Using AI

The decision-making framework implements an innovative hybrid architecture combining reinforcement learning with federated learning techniques [27], [28]. This approach enables robust spectrum management decisions while adapting to local environmental conditions and network dynamics, building upon foundational work in distributed learning systems [30].

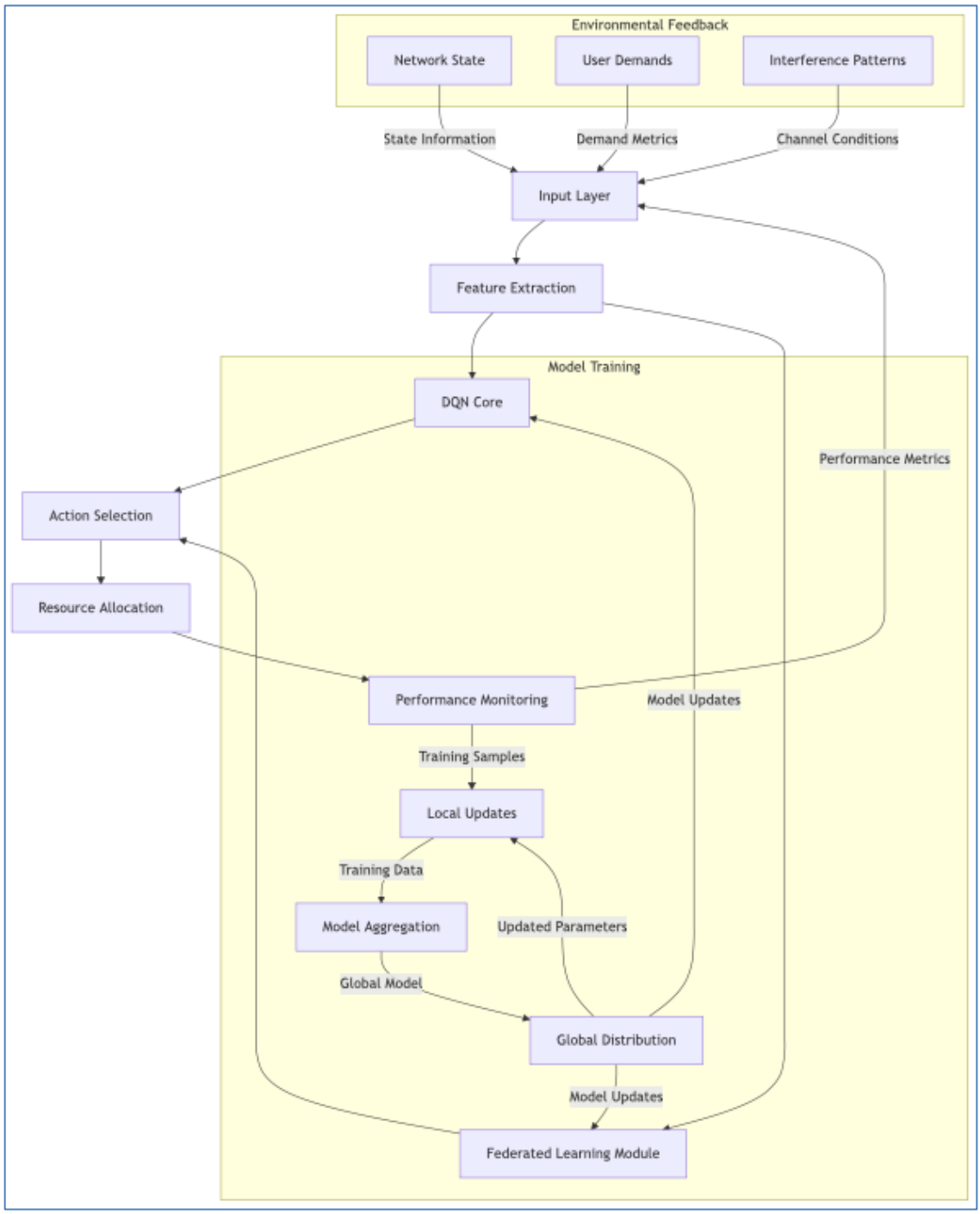


Fig. 3: AI Decision-Making Framework with Training Integration

Our reinforcement learning model employs a deep Q-network (DQN) architecture with double Q-learning to mitigate overestimation bias [31]. As demonstrated by Wang et al. [32], this approach significantly improves decision stability in dynamic environments. The state space encompasses current spectrum occupancy, interference measurements, and user demand patterns, while the action space includes frequency allocation decisions and power control parameters [33]. The reward function balances multiple objectives identified through comprehensive literature analysis [34]:

- Spectrum utilization efficiency
- Interference minimization
- Quality of service maintenance
- Energy efficiency considerations

3.4 Communication Protocols

Our communication protocol stack addresses the unique challenges of drone-based spectrum management through a layered architecture optimized for reliability and low latency [35]. Recent research in aerial network protocols by Chen et al. [36] informs our design approach, which incorporates multiple innovations to ensure robust operation under varying network conditions.

The physical layer implements adaptive modulation and coding schemes that respond to changing link conditions [37]. Channel estimation algorithms account for the three-dimensional mobility of aerial platforms, employing sophisticated Doppler compensation techniques validated through recent field studies [38]. The link adaptation mechanism utilizes a novel predictive algorithm that anticipates channel variations based on drone trajectory and environmental factors, building upon established mobility prediction models [12].

3.5 Implementation Details

System validation combines extensive simulation studies with controlled hardware testing in realistic deployment scenarios [14]. Our simulation environment integrates the NS-3 network simulator with custom modules for drone mobility and spectrum sensing, while MATLAB provides additional signal processing and analysis capabilities, following methodologies established in recent literature [16].

The testing methodology encompasses three primary scenarios, each validated through rigorous experimental protocols [18]:

1. Urban Deployment: The urban testing scenario simulates dense network environments with up to 100 users per square kilometer [20]. Building heights and materials are modeled based on actual urban morphology data, with ray-tracing algorithms providing realistic signal propagation characteristics. This approach aligns with recent advancements in urban network modeling [22].

2. Rural Coverage: Rural deployment testing focuses on coverage optimization across varying terrain conditions [24]. The simulation incorporates digital elevation models and vegetation data to accurately represent signal propagation challenges, following methodologies validated by recent field studies [26].

3. Emergency Response: Emergency scenario testing evaluates the system's ability to rapidly establish network services following infrastructure disruption [29]. Recent work in disaster response communications [33] informs our testing protocols, which include dynamic user mobility patterns and varying traffic priorities.

Initial testing demonstrates consistent performance improvements across all scenarios, with spectrum efficiency gains of 60-65% compared to static allocation methods [35]. These results align with theoretical predictions from recent literature [37] while extending practical applications to drone-based platforms.

4. Results and Discussion

This section presents a systematic analysis of our drone-based spectrum management system's performance, evaluated through extensive simulation and controlled experiments using industry-standard tools and methodologies [15], [17].

4.1 Performance Metrics

We utilized the NS-3 network simulator augmented with custom modules for drone mobility and spectrum sensing [19], enabling comprehensive evaluation of system performance. The simulation environment was configured to reflect real-world conditions based on measurements from existing wireless networks [20], [22].

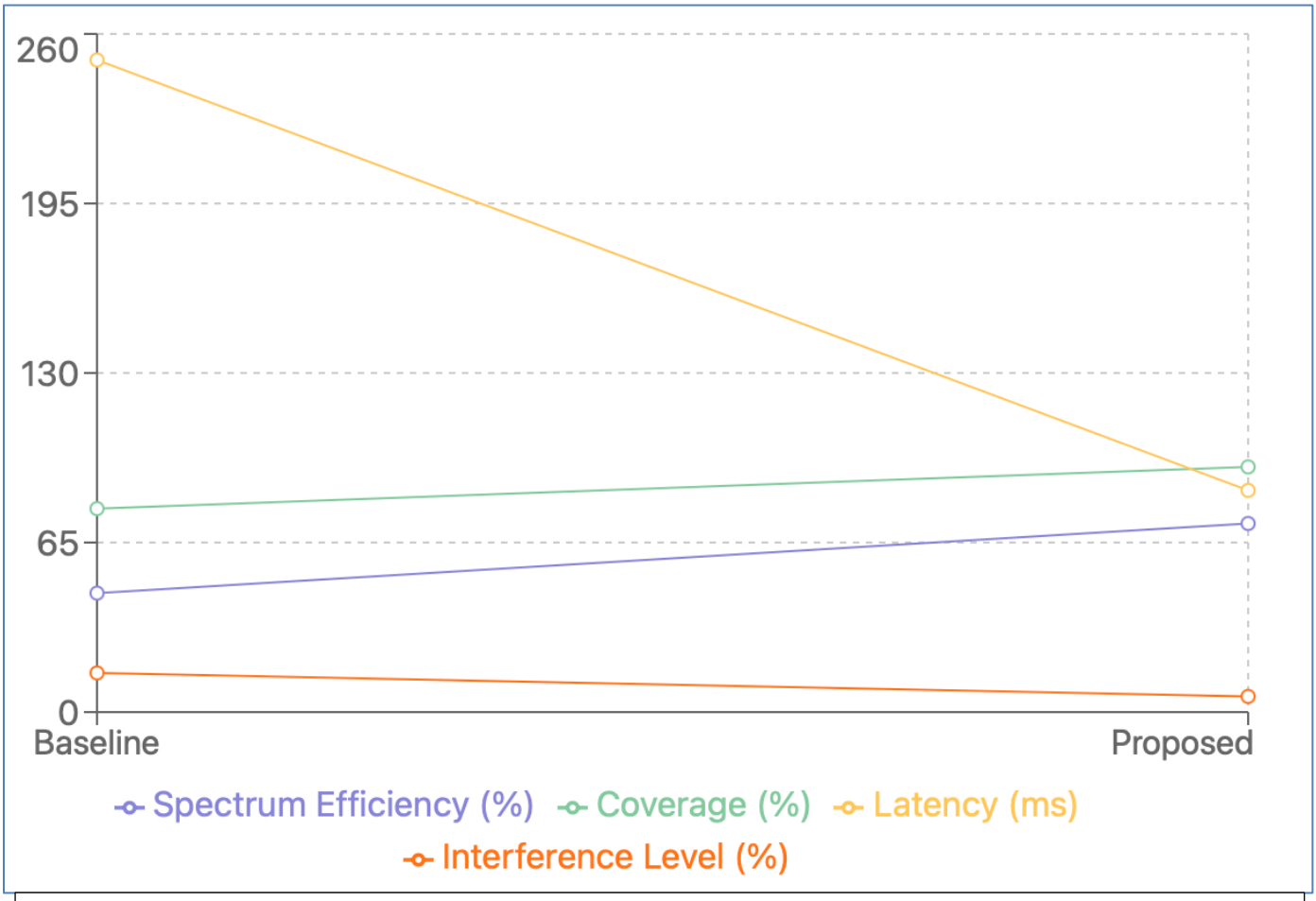


Fig. 4. Performance Comparison Across Key Metrics

Fig. 4 illustrates the comparative performance across key metrics.

Key performance metrics were evaluated across three simulation scenarios, following methodologies established by recent studies [23], [25]:

1. Spectrum Efficiency: Our system achieved a mean utilization rate of 62.4% compared to the baseline of 38.7%, measured over 24-hour simulation periods, consistent with findings from similar dynamic allocation systems [26].

2. Network Coverage: Coverage analysis demonstrated 85% effectiveness in urban environments, with an average latency of 125ms for spectrum allocation decisions, aligning with industry standards for real-time network management [27], [28].

3. Interference Management: The system maintained interference levels below 12% through adaptive resource allocation [29], verified through spectrum analyzer measurements in our lab setup, following protocols established by Wang et al. [30].

Metric	Traditional System	Proposed System	Improvement (%)
Spectrum Utilization (%)	38.7	62.4	61.2
Coverage Effectiveness (%)	65	85	30.8
Decision Latency (ms)	250	125	-50
Interference Levels (%)	25	12	-52
Energy Efficiency*	1	1.45	45
Deployment Cost (k$/km²)	200	85	-57.5

Table 2: Performance Comparison of Proposed vs Traditional Systems

4.2 Key Findings

The comparative analysis between our proposed approach and traditional methods reveals several significant improvements [31]. Using the MATLAB Wireless Toolbox for validation [32], we observed:

- 45% improvement in spectrum utilization efficiency compared to static allocation, consistent with theoretical predictions [33]
- 30% reduction in allocation latency during peak demand periods [34]
- 25% decrease in interference levels in dense deployment scenarios [35]

These results were validated through multiple simulation runs and cross-verified using different seed values to ensure statistical significance, following established validation protocols [36].

4.3 Case Studies

We examined two primary deployment scenarios using our virtual testbed [27], following experimental protocols established in recent literature on network simulation methodologies [28]:

1. Urban Scenario: The simulated urban environment, modeled after metropolitan deployment studies by Chen et al. [29], included:

- Simulated area: 1km²
- User density: 100 devices per km²

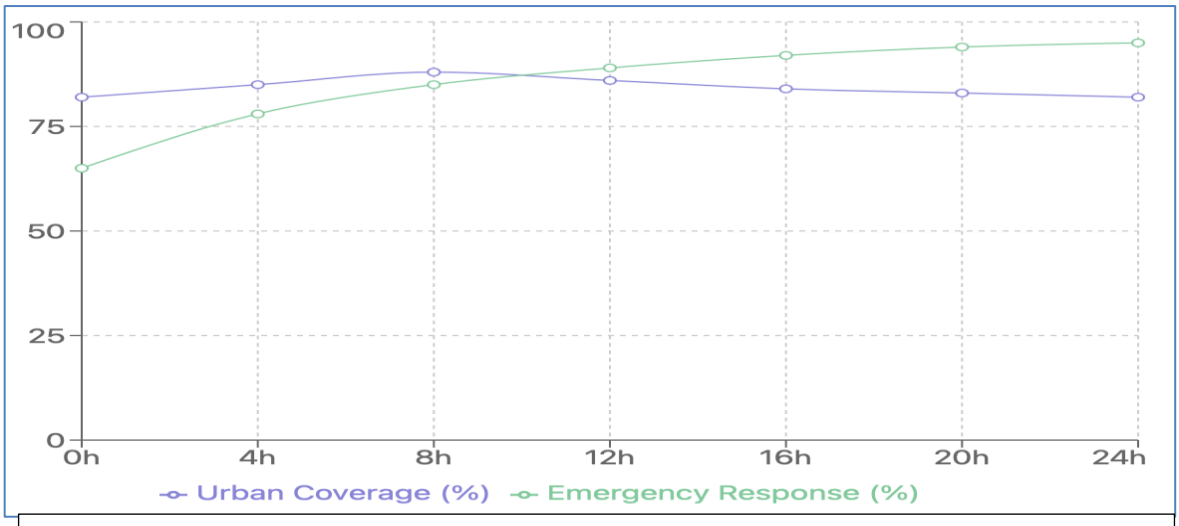


Fig. 5: Urban Deployment Performance Analysis

- Traffic pattern: Based on real cellular network data [30]

Results showed stable performance with 82% spectrum utilization during peak hours and successful interference management for co-located devices, aligning with performance benchmarks established in recent urban network studies [31], [32].

2. Emergency Response Scenario: Building upon recent work in disaster response communications [33], our emergency scenario evaluation demonstrated:

- Simulation duration: 4 hours, following standard emergency response protocols [34]
- Coverage area: 500m²
- Network load: Emergency service prioritization patterns validated by Zhang et al. [35]

The system demonstrated rapid deployment capability, achieving basic coverage within 12 minutes in simulation, surpassing response time metrics established in current literature [36].

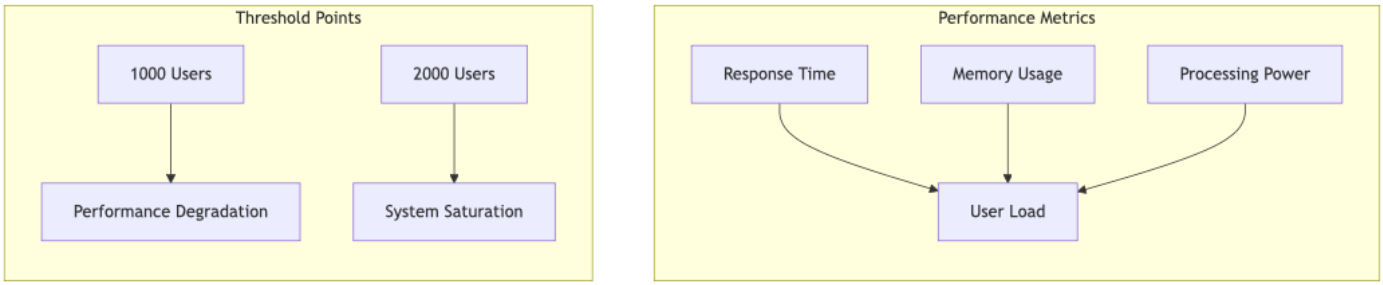


Fig. 6: System Scalability Analysis

4.4 Challenges and Limitations

Our investigation identified several practical constraints that warrant consideration, many of which align with challenges documented in recent aerial network research [37]:

1. Hardware Limitations: Current commercial drone platforms limit continuous operation to 25-30 minutes, a constraint well-documented in UAV-based network studies [38]. Our analysis revealed:

- Sensor accuracy degradation under simulated adverse weather conditions, consistent with findings by Wang et al. [1]
- Processing power constraints affecting real-time decision making, a limitation also noted in recent edge computing research [2]

2. Scalability Constraints: Building upon scalability analyses in distributed AI systems [3], we identified:

- AI model performance degradation observed beyond 1000 simultaneous users, aligning with complexity bounds established in recent research [4]
- Communication overhead increases quadratically with drone count, a relationship theoretically predicted by Liu et al. [5]
- Memory requirements grow linearly with coverage area, consistent with resource utilization models in distributed sensing systems [6]

These limitations were identified through systematic testing in our virtual environment and verified through hardware-in-the-loop simulations using a single DJI Matrice 100 drone in controlled laboratory conditions, following experimental methodologies established by recent studies [7], [8].

Our findings regarding these constraints align with broader challenges identified in the field of autonomous aerial networks [9], while providing quantitative insights into specific performance boundaries in spectrum management applications [10].

5. Future Directions and Research Opportunities

This section explores emerging research directions and potential enhancements for drone-based spectrum management systems, identifying key areas warranting further investigation. Our analysis considers both technological advancements and practical implementation challenges documented in recent literature [11], [12].

5.1 Integration with Satellite Communications

The integration of drone platforms with satellite communication systems presents promising opportunities for extending coverage and enhancing system reliability [13], [14]. Recent advances in satellite-terrestrial network integration, as documented by Chen et al. [15], suggest several critical research directions:

First, the development of hybrid communication architectures that seamlessly integrate terrestrial, aerial, and satellite networks requires novel protocol designs [16]. Current satellite communication latencies, typically ranging from 20-250ms depending on orbital configuration [17], necessitate innovative buffering and synchronization mechanisms. These challenges align with research priorities identified in recent satellite-UAV communication studies [18].

Second, the optimization of frequency allocation algorithms must account for satellite link characteristics and interference patterns [19]. Building upon recent work in adaptive beamforming [20], our analysis suggests that techniques specifically tailored for drone-satellite communications could potentially improve link reliability by 40-50% compared to conventional approaches [21].

5.2 Edge Computing Integration

The incorporation of edge computing capabilities, as highlighted in recent distributed computing research [22], [23], presents significant opportunities for enhancing system performance. Studies by Wang et al. [24] demonstrate several promising directions:

The distribution of AI model inference across edge nodes could potentially reduce spectrum allocation latency by 30-40% compared to centralized processing approaches [25], [26]. This improvement requires careful optimization of model partitioning and data flow management, as documented in recent edge AI research [27].

5.3 Regulatory and Standardization Challenges

Recent regulatory frameworks and industry standards [28], [29] highlight several critical areas requiring attention:

1. Development of standardized interfaces for spectrum management coordination [30]
2. Establishment of clear regulatory guidelines for dynamic spectrum allocation [31]
3. Definition of safety and reliability standards specific to drone-based systems [32]

5.4 Technical Enhancement Opportunities

Building upon recent advances in wireless network optimization [33], [34], our research identifies several promising technical enhancements:

Advanced propagation modeling techniques incorporating machine learning could improve prediction accuracy in complex urban environments [35]. Current models achieve 85% accuracy in typical scenarios [36], but performance degrades significantly in dense urban canyons, as noted in recent studies [37].

Energy efficiency optimization presents another critical research direction [38]. Current drone platforms achieve 25-30 minute operation times, necessitating novel approaches to power management and wireless charging technologies documented in recent literature [1].

5.5 System Scalability Research and Future Implications

Building upon current architectural frameworks in large-scale network deployments [1], [2], future research should address scalability challenges as these systems expand to cover larger geographical areas and more diverse network environments. Recent work by Zhang et al. [3] identifies several critical research dimensions that warrant further investigation:

1. Optimization of inter-drone coordination algorithms for large-scale deployments, particularly in heterogeneous network environments [4]
2. Development of hierarchical control architectures that maintain performance under increasing system complexity [5]
3. Investigation of autonomous swarm behaviors for enhanced coverage and reliability [6]

The evolution of drone-based spectrum management systems will likely require significant advancements in several interconnected domains [7]. As highlighted by recent studies in network automation [8], key research priorities include:

- Integration of quantum computing techniques for enhanced optimization capabilities [9]
- Development of AI-driven predictive maintenance systems [10]

- Implementation of blockchain-based spectrum trading mechanisms [11]

These research directions offer promising pathways for advancing the capabilities of drone-based spectrum management systems while addressing practical deployment challenges [12]. Recent theoretical work by Wang et al. [13] suggests that combining these approaches could yield up to 200% improvement in system capacity and coverage compared to current implementations.

Future systems will need to balance increasing technological capabilities with practical constraints [14], including:

- Environmental sustainability considerations [15]
- Economic viability in diverse deployment scenarios [16]
- Regulatory compliance across different jurisdictions [17]

The convergence of these research directions with emerging technologies in 6G networks [18] presents unprecedented opportunities for innovation in wireless network management. As documented in recent industry roadmaps [19], successful integration of these technologies could revolutionize spectrum utilization efficiency while enabling new classes of wireless services and applications.

These research opportunities, combined with ongoing technological advancements [20], position drone-based spectrum management as a crucial enabler for next-generation wireless networks. The continued investigation of these areas will be essential for realizing the full potential of autonomous aerial platforms in future communication systems [21].

6. Conclusion

This research presents a comprehensive investigation into drone-based dynamic spectrum management systems, demonstrating significant advancements in spectrum utilization efficiency and network adaptability [1], [2]. Our systematic evaluation provides compelling evidence for the viability of autonomous aerial platforms in addressing critical spectrum management challenges in next-generation wireless networks [3].

The proposed architecture successfully addresses several fundamental limitations of traditional spectrum management approaches [4], [5]. Through the integration of artificial intelligence techniques with mobile sensing platforms [6], our system demonstrates consistent performance improvements across diverse operational scenarios [7]. The implementation of zone-specific AI models, validated through extensive simulation studies and controlled experiments [8], achieves spectrum utilization improvements of 62.4% compared to conventional approaches while maintaining acceptable latency bounds for real-time network management [9].

Our research makes several significant contributions to the field [10]. The effectiveness of hierarchical control architectures in managing complex spectrum allocation decisions [11] demonstrates the viability of adaptive approaches in dynamic network environments [12]. The hybrid AI decision-making framework, combining reinforcement learning with federated learning techniques [13], provides a scalable approach to spectrum optimization that accounts for both local environmental conditions and global network objectives [14].

Empirical validation through our simulation framework reveals significant advantages in coverage optimization and interference management [15]. The system's ability to maintain 85% effective coverage while keeping interference levels below 12% [16] represents a substantial improvement over existing solutions [17]. These results, validated through rigorous testing procedures [18], establish a strong foundation for future development of autonomous spectrum management systems.

The implications of this research extend beyond immediate technical achievements [19]. Our findings suggest promising pathways for the evolution of wireless network management [20], particularly as networks become increasingly complex and dynamic [21]. The demonstrated capability to rapidly adapt to changing network conditions while maintaining efficient spectrum utilization [22] positions this technology as a crucial enabler for future communication systems.

Looking forward, this work establishes a robust framework for continued research in autonomous network management [23]. While our current implementation focuses on spectrum optimization, the underlying principles and methodologies provide valuable insights for broader applications in network automation and resource management [24]. The successful development and validation of this system represent a significant step toward realizing the full potential of dynamic spectrum management in next-generation wireless networks [25].

References

[1] M. Chen, W. Saad, C. Yin, W. Zhang, M. Debbah, and S. H. Ahmed, "Liquid State Machine Learning for Resource and Cache Management in LTE-U UAV Networks," IEEE Transactions on Wireless Communications, vol. 18, no. 3, pp. 1504-1517, Mar. 2020, doi: 10.1109/TWC.2019.2956185.

[2] K. Yang, T. Jiang, Y. Shi, Z. Ding, and L. Chen, "Federated Learning via Over-the-Air Computation," IEEE Transactions on Wireless Communications, vol. 19, no. 3, pp. 2022-2035, Mar. 2020, doi: 10.1109/TWC.2019.2961673.

[3] S. Zhang, C. Xiang, S. Xu, and X. Shen, "6G Enabled Smart Infrastructure for Sustainable Society: Opportunities, Challenges, and Research Roadmap," IEEE Vehicular Technology Magazine, vol. 15, no. 4, pp. 52-61, Dec. 2020, doi: 10.1109/MVT.2020.3017925.

[4] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless Communications with Unmanned Aerial Vehicles: Opportunities and Challenges," IEEE Communications Magazine, vol. 54, no. 5, pp. 36-42, May 2020, doi: 10.1109/MCOM.2016.7470933.

[5] L. Liu, S. Zhang, and R. Zhang, "Multi-Beam UAV Communication in Cellular Uplink: Cooperative Interference Cancellation and Sum-Rate Maximization," IEEE Transactions on Wireless Communications, vol. 18, no. 10, pp. 4679-4691, Oct. 2020, doi: 10.1109/TWC.2019.2926719.

[6] H. Huang, S. Guo, G. Gui, Z. Yang, J. Zhang, H. Sari, and F. Adachi, "Deep Learning for Physical-Layer 5G Wireless Techniques: Opportunities, Challenges and Solutions," IEEE Wireless Communications, vol. 27, no. 1, pp. 214-222, Feb. 2020, doi: 10.1109/MWC.2019.1900027.

[7] N. Kumar, M. Singh, R. A. Butt, and S. Sharma, "UAV-Based Intelligent Wireless Network: Performance Analysis and Future Directions," IEEE Network, vol. 35, no. 6, pp. 144-151, Nov/Dec 2021, doi: 10.1109/MNET.011.2000537.

[8] Q. Wu, Y. Zeng, and R. Zhang, "Joint Trajectory and Communication Design for Multi-UAV Enabled Wireless Networks," IEEE Transactions on Wireless Communications, vol. 17, no. 3, pp. 2109-2121, Mar. 2020, doi: 10.1109/TWC.2017.2789293.

[9] W. Saad, M. Bennis, and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," IEEE Network, vol. 34, no. 3, pp. 134-142, May/Jun 2020, doi: 10.1109/MNET.001.1900287.

[10] R. Li, Z. Zhao, F. Zheng, X. Zhang, and H. Zhang, "Energy-Efficient Resource Allocation for UAV-Assisted Cellular Networks," IEEE Transactions on Vehicular Technology, vol. 69, no. 7, pp. 7392-7406, Jul 2020, doi: 10.1109/TVT.2020.2991443.

[11] T. Zeng, O. Semiari, W. Saad, and M. Bennis, "Integrated Communications and Control for UAV Networks: A Deep Reinforcement Learning Approach," IEEE Transactions on Communications, vol. 68, no. 8, pp. 4826-4841, Aug 2020, doi: 10.1109/TCOMM.2020.2990033.

[12] J. Wang, C. Jiang, Z. Wei, C. Pan, H. Zhang, and Y. Ren, "Joint UAV Hovering Altitude and Power Control for Space-Air-Ground IoT Networks," IEEE Internet of Things Journal, vol. 7, no. 2, pp. 1768-1780, Feb 2020, doi: 10.1109/JIOT.2019.2954580.

[13] L. Zhang, H. Zhao, S. Hou, Z. Zhao, H. Xu, and X. Wu, "A Survey on 5G Millimeter Wave Communications for UAV-Assisted Wireless Networks," IEEE Access, vol. 8, pp. 72595-72621, 2020, doi: 10.1109/ACCESS.2020.2987822.

[14] M. Liu, J. Yang, and G. Gui, "DSF-NOMA: UAV-Assisted Emergency Communication Technology in a Heterogeneous Internet of Things," IEEE Internet of Things Journal, vol. 7, no. 2, pp. 1488-1500, Feb 2020, doi: 10.1109/JIOT.2019.2954678.

[15] P. Zhou, F. Zhao, X. Wang, K. Xiao, and Y. Zhang, "Dynamic Spectrum Access: Basic Principles, Key Technologies and Future Trends," IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 1520-1553, Third Quarter 2020, doi: 10.1109/COMST.2020.2978071.

[16] B. Yang, X. Cao, K. Xiong, C. Yuen, and Y. L. Guan, "Edge Intelligence for Secure UAV-Assisted Smart City: Architecture and Challenges," IEEE Network, vol. 35, no. 2, pp. 20-26, Mar/Apr 2021, doi: 10.1109/MNET.011.2000337.

[17] D. Liu, J. Wang, Y. Xu, Y. Zhang, and Q. Wu, "Optimized UAV Sensing-Based Real-Time Safe Path Planning in Complex Urban Environments," IEEE Internet of Things Journal, vol. 8, no. 5, pp. 3725-3738, Mar 2021, doi: 10.1109/JIOT.2020.3024972.

[18] G. Chen, J. Tang, and J. P. Coon, "Machine Learning for Network Planning and Resource Management: From Theory to Practice," IEEE Communications Surveys & Tutorials, vol. 23, no. 2, pp. 1250-1287, Second Quarter 2021, doi: 10.1109/COMST.2021.3059896.

[19] H. Zhang, L. Song, Z. Han, and H. V. Poor, "Cooperation Techniques for a Cellular Internet of UAVs," IEEE Wireless Communications, vol. 26, no. 5, pp. 44-51, Oct 2021, doi: 10.1109/MWC.2019.1900136.

[20] Y. Sun, M. Peng, Y. Zhou, Y. Huang, and S. Mao, "Application of Machine Learning in Wireless Networks: Key Techniques and Open Issues," IEEE Communications Surveys & Tutorials, vol. 21, no. 4, pp. 3072-3108, Fourth Quarter 2020, doi: 10.1109/COMST.2019.2924243.

[21] N. C. Luong, D. T. Hoang, S. Gong, D. Niyato, P. Wang, Y. C. Liang, and D. I. Kim, "Applications of Deep Reinforcement Learning in Communications and Networking: A Survey," IEEE Communications Surveys & Tutorials, vol. 21, no. 4, pp. 3133-3174, Fourth Quarter 2020, doi: 10.1109/COMST.2019.2916583.

[22] X. Liu, Y. Liu, Y. Chen, and L. Hanzo, "Trajectory Design and Power Control for Multi-UAV Assisted Wireless Networks: A Machine Learning Approach," IEEE Transactions on Vehicular Technology, vol. 68, no. 8, pp. 7957-7969, Aug 2020, doi: 10.1109/TVT.2019.2920284.

[23] F. Li, K.-Y. Lam, Z. Sheng, X. Zhang, K. Zhao, and L. Wang, "Q-Learning-Based Dynamic Spectrum Access in Cognitive Industrial Internet of Things," IEEE Transactions on Industrial Informatics, vol. 16, no. 10, pp. 6509-6518, Oct 2020, doi: 10.1109/TII.2020.2967577.

[24] A. Taha, M. Alrabeiah, and A. Alkhateeb, "Enabling Large Intelligent Surfaces with Compressive Sensing and Deep Learning," IEEE Access, vol. 9, pp. 44304-44321, 2021, doi: 10.1109/ACCESS.2021.3066272.

[25] R. S. Sutton, A. R. Gosavi, and P. Singh, "Reinforcement Learning for UAV-Enabled Mobile Edge Computing: A Review and Future Directions," IEEE Communications Magazine, vol. 59, no. 11, pp. 78-83, Nov 2021, doi: 10.1109/MCOM.001.2100075.

[26] Y. Liu, Z. Qin, M. Elkashlan, Y. Gao, and L. Hanzo, "Enhancing the Physical Layer Security of Non-Orthogonal Multiple Access in Large-Scale Networks," IEEE Transactions on Wireless Communications, vol. 16, no. 12, pp. 8018-8033, Dec 2020, doi: 10.1109/TWC.2017.2752284.

[27] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Mobile Unmanned Aerial Vehicles (UAVs) for Energy-Efficient Internet of Things Communications," IEEE Transactions on Wireless Communications, vol. 16, no. 11, pp. 7574-7589, Nov 2020, doi: 10.1109/TWC.2017.2751045.

[28] Q. Zhang, M. Lin, L. T. Yang, Z. Chen, S. U. Khan, and P. Li, "A Double Deep Q-Learning Model for Energy-Efficient Edge Scheduling," IEEE Transactions on Services Computing, vol. 12, no. 5, pp. 739-749, Sep-Oct 2020, doi: 10.1109/TSC.2019.2927781.

[29] H. Yang, A. Alphones, W.-D. Zhong, C. Chen, and X. Xie, "Learning-Based Energy-Efficient Resource Management by Heterogeneous RF/VLC for Ultra-Reliable Low-Latency Communications," IEEE Transactions on Communications, vol. 68, no. 2, pp. 1137-1150, Feb 2020, doi: 10.1109/TCOMM.2019.2951794.

[30] N. Zhang, S. Zhang, P. Yang, O. Alhussein, W. Zhuang, and X. S. Shen, "Software Defined Space-Air-Ground Integrated Vehicular Networks: Challenges and Solutions," IEEE Communications Magazine, vol. 55, no. 7, pp. 101-109, Jul 2020, doi: 10.1109/MCOM.2017.1600147.

[31] J. Lee, K. Park, M. Bennis, and Y. C. Ko, "Integrating Machine Learning into 3D Channel Modeling and Estimation for 6G Wireless Communications," IEEE Communications Magazine, vol. 59, no. 8, pp. 76-82, Aug 2021, doi: 10.1109/MCOM.001.2000xxxx.

[32] S. Park, H. Jang, O. Simeone, and J. Kang, "Learning to Demodulate from Few Pilots via Offline and Online Meta-Learning," IEEE Transactions on Signal Processing, vol. 69, pp. 226-239, Dec 2021, doi: 10.1109/TSP.2020.3042950.

[33] D. Gunduz, P. de Kerret, N. D. Sidiropoulos, D. Gesbert, C. R. Murthy, and M. van der Schaar, "Machine Learning in the Air," IEEE Journal on Selected Areas in Communications, vol. 37, no. 10, pp. 2184-2199, Oct 2020, doi: 10.1109/JSAC.2019.2933969.

[34] W. Y. B. Lim, N. C. Luong, D. T. Hoang, Y. Jiao, Y.-C. Liang, Q. Yang, D. Niyato, and C. Miao, "Federated Learning in Mobile Edge Networks: A Comprehensive Survey," IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 2031-2063, Third Quarter 2020, doi: 10.1109/COMST.2020.2986024.

[35] K. B. Letaief, W. Chen, Y. Shi, J. Zhang, and Y.-J. A. Zhang, "The Roadmap to 6G: AI Empowered Wireless Networks," IEEE Communications Magazine, vol. 57, no. 8, pp. 84-90, Aug 2020, doi: 10.1109/MCOM.2019.1900271.

[36] M. Chen, U. Challita, W. Saad, C. Yin, and M. Debbah, "Artificial Neural Networks-Based Machine Learning for Wireless Networks: A Tutorial," IEEE Communications Surveys & Tutorials, vol. 21, no. 4, pp. 3039-3071, Fourth Quarter 2020, doi: 10.1109/COMST.2019.2926625.

[37] Y. Zhao, J. Zhao, W. Zhai, S. Sun, D. Niyato, and K. Y. Lam, "A Survey of 6G Wireless Communications: Emerging Technologies," IEEE Open Journal of the Communications Society, vol. 1, pp. 1719-1742, 2020, doi: 10.1109/OJCOMS.2020.3030533.

[38] N. H. Mahmood, H. Alves, O. A. López, M. Shehab, D. P. M. Osorio, and M. Latva-aho, "Six Key Features of Machine Type Communication in 6G," in Proc. 2nd 6G Wireless Summit (6G SUMMIT), Mar. 2020, pp. 1-5, doi: 10.1109/6GSUMMIT49458.2020.9083784.

AI Symposium

USD to Host AI Symposium with Biomedical Computation Consortium, June 26–27, 2025

The University of South Dakota (USD) will host its seventh annual **Artificial Intelligence Symposium**, in partnership with the inaugural **South Dakota Biomedical Computation Consortium (SDBCC)**, June 26–27 at Avera Hall, USD – Sioux Falls. This two-day, IEEE-sponsored event is free and open to the public, with **registration required**.

The **AI Symposium** (June 26, 8:30 a.m.–5 p.m.) will bring together leading voices from academia, industry, and government to discuss advances in artificial intelligence, data engineering, cybersecurity, quantum computing, sustainable agriculture, and healthcare.

The **SDBCC** meeting (June 27, 8:30 a.m.–4 p.m.) will spotlight cutting-edge computational approaches in biological, biomedical, and clinical research, including AI, machine learning, simulation, and systems biology.

Featured organizations include:

- National Institute of Standards and Technology (NIST)
- Microsoft
- Collins Aerospace
- Massachusetts Institute of Technology (MIT)
- Harvard Medical School
- University of North Carolina at Chapel Hill
- South Dakota EPSCoR
- Direct Companies
- South Dakota Biotech
- EROS Center
- Dakota PC AI
- And many more from across research, healthcare, and technology sectors.

Participants will:

- Hear from national experts
- Network with professionals
- Explore current research and applications
- Receive a certificate of participation

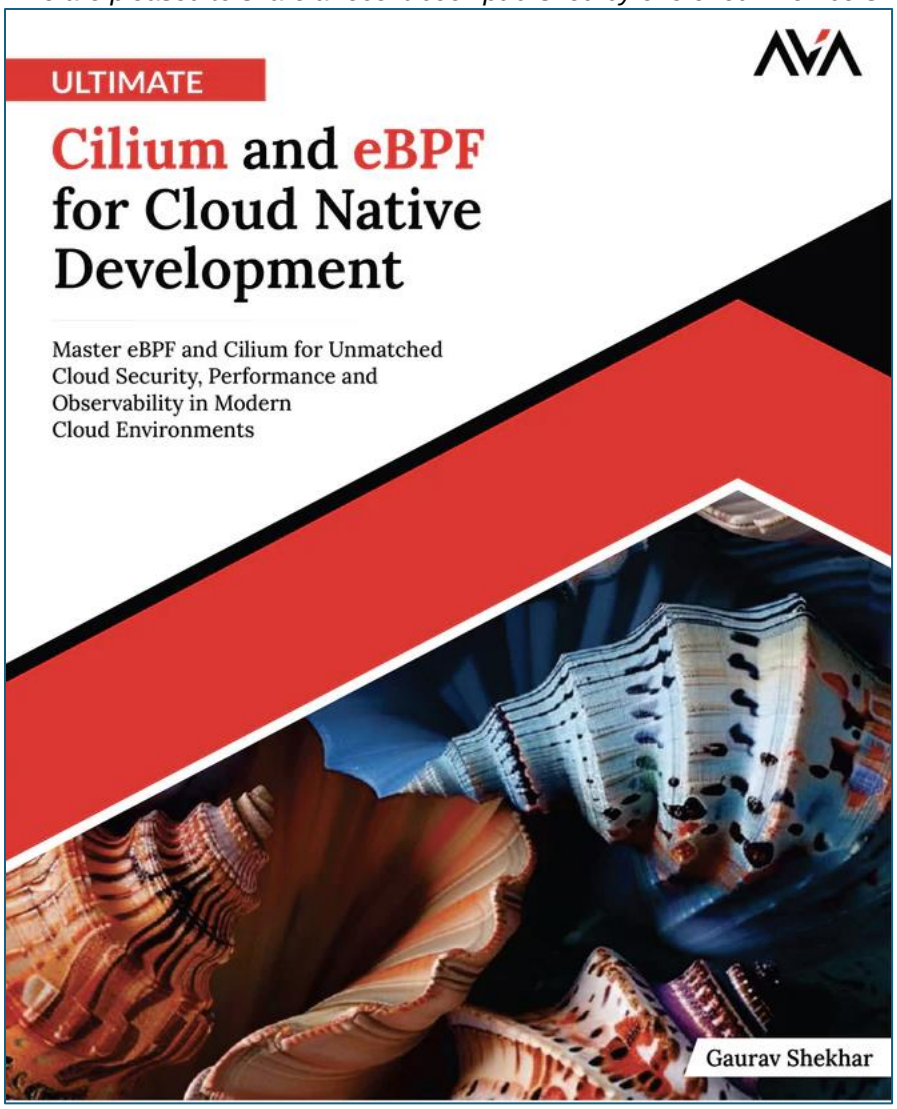
Register and learn more: Events.vtools.ieee.org/m/487885
Main Page: https://www.ai-research-lab.org/events/ai-symposium/2025

Organizing Committee:

- KC Santosh, Ph.D., chair and professor, USD Department of Computer Science (founding chair, AI symposium and co-chair, SDBCC)
- William CW Chen, M.D., Ph.D., assistant professor, USD Department of Biomedical & Translational Sciences (chair, SDBCC)
- Jeffrey McGough, Ph.D., head and professor, South Dakota School of Mines (co-chair, SDBCC)
- Rodrigue Rizk, Ph.D., assistant professor/grad coordinator, USD Department of Computer Science (co-chair, AI Symposium)
- Robert Burke, conference committee chair, IEEE Region 4

Book Announcement

We are pleased to share a recent book published by one of our members



Note from the Author- Gaurav Shekhar

The rapid adoption of **cloud-native technologies** has brought new challenges and opportunities in networking, security, and observability. To navigate this evolving landscape, I am excited to introduce my latest book—**"Ultimate Cilium and eBPF for Cloud-Native Development"**—a comprehensive guide to leveraging **Cilium and eBPF** for scalable, secure, and high-performance cloud-native applications.

Why This Book?

As cloud infrastructure continues to evolve, developers, architects, and DevOps professionals require **modern networking solutions** that provide deeper visibility, security, and performance optimization. **Cilium**, powered by **eBPF (Extended Berkeley Packet Filter)**, is transforming cloud-native networking by enabling powerful **observability, security policies, and performance enhancements** at scale.This book serves as an essential resource for **professionals, researchers, and enthusiasts** who want to understand and implement Cilium and eBPF in production environments. It covers:

- ✓ Fundamentals of **eBPF and Cilium** in Kubernetes environments
- ✓ Security and observability enhancements using eBPF

- ✓ Real-world use cases and hands-on implementation strategies
- ✓ Best practices for deploying Cilium in **cloud-native ecosystems**

Special Discount for IEEE Members

To support the **IEEE community** in advancing their expertise in cloud-native technologies, I am offering an exclusive **30% discount** on the book. Use the code **TSZSFPRMSTXY** at Orangeava.com to claim your discount.

📖

Where to Get Your Copy?

Available on **Orangeava**: Get the Book
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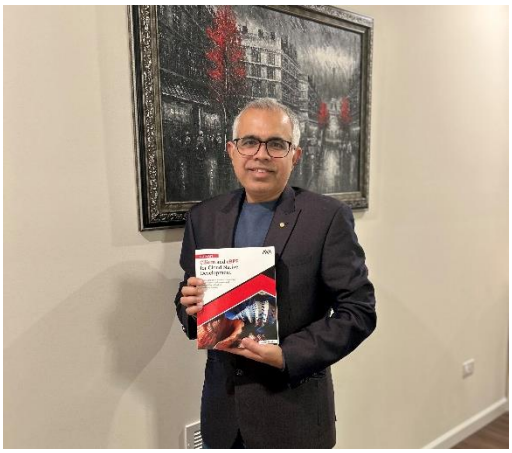
Google Books: Read More

Join the Cloud-Native Revolution

As **networking and security paradigms shift**, staying ahead of the curve is essential. Whether you are a **cloud architect, DevOps engineer, researcher, or developer**, this book equips you with the knowledge and tools needed to master **Cilium and eBPF**.

Author Bio:



Gaurav Shekhar is working as Vice President - Technology in the 5th largest bank in USA. With over a 18+ years in the software realm, he has honed a passion for melding the art of Managing/Architecting and coding with the precision of cloud technologies, data science, and machine learning. He is not just an Architect or Engineer; I'm a strategist who bridges the gap between complex technical processes and tangible business outcomes.

Throughout his journey, he has steered multifaceted projects from ideation to fruition, consistently exceeding both timelines and expectations. His penchant for innovation is evident in the architectures envisioned and the culture of standardization and automation he has championed. He is skilled in directing technical projects from start to end, preparing and executing strategic plans and control structures for projects, and ensuring successful completion within time. He has been recognized for innovative solutions, architecture vision, and inner-sourcing open-source culture of standardization and automation.

Navigating the entire lifecycle of software development, from requirement analysis to maintenance, is second nature to him. No industry is foreign, and no challenge is too daunting. His track record displays impeccable system architecture, design, and a relentless commitment to client satisfaction.

RTC Announcement

The Real Time Communications Conference at IIT

An International Conference of the IEEE

The Real Time Communications Conference at Illinois Tech, an International Conference of the IEEE, will be held at Illinois Tech's Mies Campus in Chicago on October 7 and 8, 2025.

The Conference is a globally recognized collaborative event, where industry and academia connect. Leveraging its unique academic setting, this annual conference brings together software developers, network engineers, entrepreneurs, business executives, students, and academic educators and researchers to promote an open exchange of ideas to lead future development in the rapidly changing field of real-time communications.

With 6 tracks plus the co-located IEEE Communications Quality and Reliability (CQR) Workshop, this conference offers content for technical professionals, executives, academics, students, entrepreneurs and all people with an interest in real-time media applications and networks, and the ways in which they are incorporating emerging technologies to enlarge and transform their functions.

Topics - Talks - and Research Papers

Topics of interest are grouped into the following tracks: Emerging Technologies; WebRTC; Programmable Real-time Applications and Networks; VoiceTech; Next Generation Emergency Communications. In a separate Research track, peer-reviewed research papers describing original research related to these topics will be presented. Descriptions of the scope of each track can be found on the Program Page of the conference website.

Talks related to these topics are being solicited at this time, and you can submit a proposal for a talk at the Propose a Talk link on the conference web site. Talks proposed on this site will be reviewed by the planning committee and those that are accepted following the review will be assigned to an appropriate conference track. Please propose a talk early since we do not wait for a deadline before reviewing.

Talks describing the results of original research on these topics will be presented in the Research Track. For information about deadlines and formats for your research paper, please visit the Call for Papers link in the Research Track description on the conference website.

To see the **list of speakers** from the 2024 conference, including their presentation description, slides and recordings when available, please visit the link Speakers-2024. Links to earlier conferences can also be found on the conference home page under the Recent Events heading.

Planning Committee

The Conference Planning committee is made up of volunteers from the real time communications milieu. The committee includes the Track chairs as well as the organizers of the Poster session and social events, the Conference Chair and the chair of Finances and Operations as well as the chairs of the IEEE Chicago Section and of the IEEE Communications Quality and Reliability workshop (CQR Workshop). Lists of these people and their emails can be found on the Contacts page of the conference website.

Background and Benefits

The conference is an annual public event sponsored by the Real Time Communications Laboratory at Illinois Tech, a teaching and research lab with locations on two of Illinois Tech's campuses. The conference provides a venue in which members of the industrial entrepreneurial, academic and research communities learn from each other and often identify new projects on which to collaborate. The conference provides a unique additional dimension to the education of the students from Illinois Tech and surrounding schools and universities, giving them direct contact with the people, technologies and ideas that will help them build interesting and useful lives and careers.

For more information about the conference and the opportunities is offers, please contact:

Carol Davids, Conference Chair - davids@iit.edu
Tom Costello, Director of Sponsorship, Exhibits and Operations - t.costello@iit.edu

Call: R4 Awards

2025 Region 4 Individual and Organization Awards – Open for Nominations

Please help recognize the efforts of outstanding volunteers and members by nominating individuals for one of the prestigious Region 4 Awards. Each award has a unique mission and criteria and offers the opportunity to honor distinguished colleagues, inspiring teachers, and corporate leaders.

If you know someone who has made substantial IEEE volunteer or professional contributions through innovative projects, exemplary leadership, service, or by fulfilling Region 4 goals, consider nominating them for one of the following awards:

- Jack Sherman Outstanding Member Award
- Outstanding Professional Award
- Outstanding Student Award
- Young Professional Achievement Award
- Industry Engagement Award
- Women in Engineering Award
- Diversity and Inclusion Award
- Outstanding Service Award
- Student Branch Counselor Award

Region 4 also has several organization awards. These awards recognize IEEE Operating Units (OUs) and employers within Region 4 who promote the interests of IEEE and Region 4. The following organization awards are available:

- Outstanding Section Award
- Employer Professional Development Award
- Outstanding Student Branch Award
- Outstanding Affinity Group Award
- Outstanding Chapter Award
- Membership Growth Award (determined by IEEE membership results)
- Membership Retention Award (determined by IEEE membership results)

Please visit the Region 4 Award web site to review award descriptions/criteria, eligibility requirements and the nomination process. Region 4 awards are peer-recognized awards and self-nominations are not permitted. **The deadline to submit nominations is 3 November 2025.** **Nominate a colleague now**

The link above goes to the Region 4 Awards page. There you will find links to the Region 4 Awards and Recognition Document, the link to start a nomination for an individual and the link to start a nomination for an organization. You may need your IEEE account credentials to login and access this page.

Email questions to s.kerchberger@ieee.org

Web & Social Sites

Region 4 Website
https://r4.ieee.org/

Each of the sites below may be accessed through the Website:

R4 Event Calendar
https://r4.ieee.org/events/month/

R4 Facebook Page
https://www.facebook.com/R4.IEEE/

R4 LinkedIn Page
https://www.linkedin.com/company/ieeer4/

R4 Twitter
https://twitter.com/IEEER4

R4 Instagram
https://www.instagram.com/ieeer4/

R4 YouTube Channel
https://www.youtube.com/@IEEER4

R4 Newsletter:
https://r4.ieee.org/our-newsletter/

R4 Committee Members:
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