

SIGNALS OF RESILIENCE: THE CONTINUING ROLE OF AMATEUR RADIO AND ITS
MODERNIZATION IN GLOBAL COMMUNICATIONS

by

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Bachelor of Science in Information Technology, Middle Georgia State University, 2018

Master of Science in Information Technology, Middle Georgia State University, 2020

A Research Paper Submitted to the School of Computing Faculty of

Middle Georgia State University in

Partial Fulfillment for the Requirements for the Degree

DOCTOR OF SCIENCE IN INFORMATION TECHNOLOGY

MACON, GEORGIA

2026

Signals of resilience: The continuing role of amateur radio and its modernization in global communications

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Abstract

Amateur radio is evolving to meet the demands of a digital, interconnected, and security-conscious communication environment. This study presents a conceptual model framing amateur radio within a resilient digital communication system highlighting the intersection of technological relevance, operational application, and regulatory governance. Drawing on a narrative review, it examines how amateur radio contributes to society through emergency communications, public service, and emerging governance, while serving as a platform for innovation in wireless communication technologies.

When centralized infrastructure fails due to natural disasters, technical disruptions, or cyberattacks, amateur radio provides an infrastructure-independent communication lifeline, enabling local and long-distance connectivity. These capabilities support disaster response, foster global cooperation, strengthen community engagement, and facilitate knowledge sharing.

Regulatory restrictions on encryption under FCC Part 97 and international guidelines create tension between traditional openness and modern security needs. The study identifies gaps in empirical research on secure, regulation-compliant communication and emphasizes ethical considerations and public perceptions. Overall, amateur radio is positioned as resilient, innovative, and socially impactful by shaping future emergency preparedness, public service, and evolving communication systems.

Keywords: Amateur radio, Emergency communication, Digital communication, Wireless innovation, FCC regulation

Introduction

Amateur radio, commonly known as ham radio, serves as a vital tool for personal communication, emergency response, and technological advancement and has been used for decades. In addition, amateur radio contributes to emergencies, underscoring its significance in disaster response and recovery operations (Gill, 2019, p. 112).

From its origins in the early 20th century to the advanced technologies used today, amateur radio is continually evolving to keep pace with emerging innovations. In an age where communication depends heavily on internet-connected devices like smartphones, tablets, and computers; natural disasters such as hurricanes, tornadoes, floods, earthquakes, and volcanic eruptions can quickly disrupt these systems. In such situations, “amateur radio is still the most reliable way to get communications up and running with the people on the ground” (Brown, 2023, para 25; Cid et al., 2017, p. 257).

In today's digitally connected world, communication methods are heavily dependent on centralized infrastructure such as cellular networks and the internet. When these systems become disrupted, amateur radio operators play a crucial role in maintaining the flow of information. Whether supporting emergency response efforts, relaying information globally, or stepping in when smartphones and internet access become unavailable, amateur radio operators possess the knowledge and equipment to bridge

communication gaps. When centralized infrastructure fails, amateur radio becomes essential, enabling both regional and long-distance communication without reliance on network-based systems or external power sources. (Gill, 2019, pp. 109 & 112).

Moreover, amateur radio fosters global connectivity and community engagement, used to link individuals across nations through shared technical knowledge, public service, and humanitarian collaboration. International networks of operators regularly coordinate to assist in disaster relief efforts, support scientific expeditions, and provide communication to remote or underserved areas. This global cooperation highlights amateur radio's continued relevance not only as a technological artifact but also as a cornerstone of civic and cultural exchange in an increasingly interconnected world (Laster, 2000, p. 13).

Despite its historical importance and continued contributions to emergency response and community service, amateur radio faces growing challenges in the digital age. In an era dominated by internet and mobile communication technologies, the relevance of amateur radio, a legacy communication system, is experiencing increasing marginalization. Although its past reliability during crises remains well documented (Brown, 2023, para 12), amateur radio continues to struggle with issues of modernization, declining public awareness, and restrictive regulatory policies. Among the most pressing challenges is the Federal Communications Commission's (FCC) prohibition of encrypted transmissions, which limits experimentation with secure communication methods and has created tensions between innovation and compliance (Rose, 2022, p. 67). These restrictions raise critical questions about how amateur radio can continue to serve as a secure and adaptable communication platform within a rapidly evolving technological and regulatory landscape.

Given these challenges, there is limited academic research examining how amateur radio can modernize while remaining a viable and secure communication solution in an increasingly security-conscious and technologically advanced environment. This gap highlights the need to better understand how legacy communication systems can coexist with and complement modern digital infrastructure. The conceptual model for this study is grounded in the relationship between legacy communication technologies, modern digital infrastructure, and regulatory influence. Addressing this issue requires analyzing the interplay between these constructs, particularly in balancing operational transparency with data protection. In an age defined by digital security and interconnectedness, there is limited understanding of amateur radio's continued importance in modern communication systems and the regulatory implications of maintaining legacy restrictions (King, 2017, p. 30).

The study therefore aims to analyze historical, regulatory, and technological developments influencing the modernization and relevance of amateur radio. Through document and literature analysis, the study explores how FCC policies, encryption restrictions, and emerging digital technologies shape the service's role in communication resilience and public engagement. Accordingly, this study is guided by the following research question.

Research Question

RQ1: How do the major themes in the literature reflect adaptation, effectiveness, and visibility of amateur radio in today's communication environment?

Review of Literature

Introduction

The goal of this literature review is to provide information and insight into existing literature related to amateur radio and its critical role in communications, emergency response, and future technological innovation. Maier (2013) suggests the purpose of research is to discover something new and useful. In order to accomplish this, we need to determine what is the current state of understanding which requires identification of knowledge gaps in the topic domain (p. 3). Snyder (2019) states a literature review can be broadly be described as a systematic way of collecting and synthesizing previous research (p. 333). This literature review encompasses research across amateur radio technologies, public service, and emergency response communications. It provides background on amateur radio and its continued relevance in modern society. Building on this foundation, the review explores technologies which support global connectivity through communication, public service, and emergency response, encryption technology, and governance. Conducted an in-depth review of these areas to assess the current state of knowledge and to highlight areas for future research.

Amateur Radio Technologies-Background

Amateur radio operators, commonly known as “Hams” are essential contributors to global communication, particularly when modern systems fail. Historically, Hams provide reliable communication during emergencies because radio transmissions rely on natural atmospheric conditions rather than infrastructure-dependent systems such as fiber optics or cellular towers (Brown, 2023, para, 22-23; Morris, 1981, p. 34). Beyond emergency response, amateur radio serves as a platform for technical experimentation and entertainment, fostering innovation and public engagement (Blyth, 2016, p. 20).

Amateur radio operates on frequencies above the AM broadcast band of 540-1660 kHz at 1800 kHz on both digital and analog signal sources (Laster, 2000, pp. 23-24). An analog signal source produces messages defined on a continuum whereas a digital signal produces a finite set of messages. For example, a touchtone pad delivers signals in short bursts in a finite number of characters. In contrast, a microphone operates on output voltage on a continuous range of values (Couch II, 2012, p. 27). The ability to transmit wirelessly often uses the atmosphere as the transmission channel at any frequency. Each frequency band is assigned frequencies by the International Telecommunications Union (ITU). These assignments are designed to provide order and minimize interference over frequency bands (Couch II, 2012, p. 32).

Contemporary research also emphasizes amateur radio’s scientific value, illustrated by global networks like the Reverse Beacon Network (RBN) and WSPRNet, which collect HF propagation data used for ionospheric research and space weather monitoring (Frissell et al., 2022, p. 2). Collectively, literature highlights amateur radio as a technologically rich, scientifically relevant, and resilient communication system which remains important in both practical and research contexts.

Public Service and Emergency Communications

The FCC (Federal Communications Commission) regulates and licenses radio systems for the general public, state and local governments (Couch II, 2012, p. 11). The FCC is extremely specific as to the ability of radio operations under emergency conditions. This regulatory context shapes the social system within which amateur radio operates, particularly under emergency conditions. As stated in FCC Part 97.1(1), one justification for the Amateur Service is its ability to provide communication during emergencies and public service events (Laster, 2000, p. 52). To give back to communities, amateur radio enthusiasts participate in public service and disaster recovery operations when needed. Because of this interest, organizations such as ARES (Amateur Radio Emergency Service), RACES (Radio Amateur Civil Emergency Service) and SKYWARN were developed to enhance communications during a crisis. Volunteers to these organizations are appointed as emergency coordinators and encouraged to undergo training to obtain certification for an emergency coordinator designation (Gill, 2019, p. 112).

Within this regulatory and organizational framework, amateur radio demonstrates its practical value during emergencies. It provides a reliable method of communication during medical crises and natural disasters, especially when conventional systems such as telephone and cellular networks fail. Because it operates independently of centralized infrastructure, amateur radio can remain functional even when those systems are compromised. Furthermore, the widespread distribution of licensed operators often extends beyond the geographic limitations of cellular networks, which depend on fixed tower locations, thereby enhancing communication reach during critical situations (Poornashree et al., 2014, p. 32).

A practical example of this is the BMERS system. According to Cid et al. (2017), BMERS helps healthcare facilities maintain communication during major emergencies by providing a dependable channel for emergency managers and staff. It integrates Wi-Fi, amateur radio, and custom software to enable email services, even during complete communication blackouts. This system ensures critical information can still be exchanged when standard communication channels are unavailable (pp. 2, 6-7).

Amateur radio faces certain limitations which hinder its broader adoption, particularly in systems like BMERS. Its limited bandwidth and slow data rates make it unsuitable for data-heavy applications, and the requirement for operators to hold an FCC license adds regulatory complexity (Cid et al., 2017, p. 4). These factors reduce both trialability, the ease with which a new technology can be tested and observability, the visibility of its benefits to others (Sahin, 2006, pp. 17-18). According to Rogers' Diffusion of Innovation Theory, trialability and observability are key drivers of adoption. Technologies which are easier to test (trialability) and whose benefits are visible (observability) are more likely to be quickly adopted (Sahin, 2006, p. 14). Because amateur radio systems are difficult to assess and their benefits are often not readily seen by outsiders, their adoption remains relatively low, especially among institutions which lack strong incentives or resources to support redundant communication systems (Cid et al., 2017, p. 3).

In contrast, Terrestrial Trunked Radio (TETRA), and APCO Project 25 are protocols used for public safety and security communications. TETRA standards are used globally, whereas P25 are used by agencies in North America and the Pacific. A study by Dansarie (2024), highlights many security issues such as encryption and vulnerability to attacks (pp. 91110-91111). Similarly, Meijer et al. (2023) analyzes TETRA protocols and vulnerabilities concluding its security posture is significantly weaker than commonly perceived. The authors recommend end-to-end encryption solutions as a necessary mitigation strategy (pp. 7464 & 7478).

Despite their status as institutional standards, recent research challenges their perceived security advantages. Dansarie (2024) emphasizes encryption weaknesses and susceptibility to attacks, while Meijer et al. (2023) demonstrates TETRA's security posture is worse than widely assumed, reinforcing the need for stronger encryption measures (p. 7478). These findings illustrate how emerging evidence reshapes perceptions of established systems, potentially influencing future adoption or rejection cycles.

The table below compares both the benefits and constraints of each technology.

Table 1
Cross-domain Matrix

Technology	Encryption Capabilities	Legal Constraints	Resilience During Disaster	Public Trust
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Table 1 – continued

Technology	Encryption Capabilities	Legal Constraints	Resilience During Disaster	Public Trust
Amateur Radio	Not permitted by FCC on amateur bands; all transmissions must be open and intelligible (FCC Part 97.113)	Strictly regulated; requires FCC license; no commercial use or encryption permitted	High resilience; independent of infrastructure; ideal in total communication failures	Trusted by emergency volunteers, but less known to the public
Cellular Resilience	Strong encryption (e.g., LTE, 5G AES-based protocols)	Heavily regulated; commercial carriers governed by federal and telecom laws	Moderate; dependent on tower infrastructure and power grid; vulnerable in total outages	High among general population; perceived as dependable for daily communication
TETRA	End-to-end encryption possible (though recent vulnerabilities exposed flaws)	Restricted to government/public safety agencies; licensing and approved vendor use only	Very high; designed for mission-critical services (fire, police, EMS); built-in redundancy	High among emergency services; trusted for critical ops, but not public facing
BMERS	Encrypted mesh networking via Wi-Fi and amateur radio integration	Hybrid model; depends on local, hospital, and amateur radio regulations; encryption limited on ham bands	High; decentralized mesh reduces dependence on central infrastructure	Growing awareness; trusted within healthcare during disasters; still emerging

Note: The above cross-domain matrix compiled concepts from within the review of literature.

The key insights from this information are amateur radio is resilient and community-driven but remains limited by legal prohibitions on encryption, which reduces its suitability for transmitting sensitive data (Collins et al., 2017, p. 144). In contrast, cellular systems provide strong encryption and benefit from widespread public trust, but they are vulnerable to disruption during major disasters (Brown, 2023, para. 25). TETRA is generally considered highly resilient and secure; however, recent research identifies vulnerabilities which challenge its assumed robustness (Meijer et al., 2023, p. 7467). BMERS integrates multiple communication systems in a flexible way, using encryption where permitted, but it must navigate legal constraints, particularly when incorporating amateur radio (Cid et al., 2017, p. 7).

Encryption Technology and Governance

Encryption technology converts data into a secret code that only those with the key to the code can access the information when received (Widjaja, 2025, p. 265). Modern day data encryption is the cornerstone of any information security program (Pratomo et al., 2023, p. 3). As described on the Code of Federal Regulations website, a prohibited transmission is “messages encoded for the purpose of obscuring their meaning” (“Code of Federal Regulations,” 2024, sub-section 97.113(a)(3)(iv)). “Encryption for obfuscation

of messages is not permitted in amateur radio, although new modes of communication may be devised and used by operators as long as the mode's standard is published" (Collins et al., 2017, p. 144). Encryption converts information into a coded form accessible only to authorized users, offering protection against cyberthreats, data breaches, and unauthorized access, risks amplified in the digital age (Pratomo et al., 2023, pp. 1-2; Widjaja, 2025, pp. 268-269). In sectors such as healthcare, encryption is essential for safeguarding sensitive records and ensuring compliance with privacy regulations like HIPAA (Pratomo et al., 2023, p. 3).

Studies on wireless and RF systems demonstrate that without encryption, signals can be intercepted, altered, or disrupted, underscoring the vulnerability of unprotected transmissions. In a 2022 project by DATAworks, researchers find "anyone with the proper equipment can capture, alter or disrupt signal from your RF devices" (Mancini et al., 2022, p.5). These technical vulnerabilities underscore why encryption is standard in high-stakes communication environments. Research on military and public safety communication further illustrates the operational necessity of encrypted radio systems, as seen in efforts to develop secure HF/VHF encryption for the Philippine Navy (Tigcal & Paglinawan, 2024, p. 415). However, amateur radio remains constrained by FCC Part 97 regulations, which prohibit encrypted transmissions to preserve transparency and the civic nature of the service ("Code of Federal Regulations," 2024, sub-section 97.113(a)(3)(iv)). This emphasis on security contrasts sharply with amateur radio, where regulatory frameworks prioritize transparency over confidentiality.

Amateur radio in the United States operates under regulations established by the Federal Communications Commission (FCC), which licenses and governs all radio transmitters, including those on U.S.-registered ships and aircraft (Laster, 2000, p. 23). In addition to FCC oversight, the sector is guided by international governance through the ITU (International Telecommunication Union), as well as by local amateur radio clubs and voluntary self-monitoring practices, creating a multilayered system of regulation (Bustamante et al., 2024, p. 10). Part 97 rules for amateur radio operators serve as a "constitution" for the community in which it establishes the terms for clubs and societies. These rules establish broad parameters in which amateur radio use is to take place and help to legitimize the allocation of public resources for activities (Bustamante et al., 2024, p. 12). FCC section 97.113 delineates prohibited transmission types from amateur radio systems. Section 97.113 (4) stated in part "messages encoded for the purpose of obscuring their meaning, except as otherwise provided herein" ("Code of Federal Regulations," 2024, sub-section 97.113(a)(3)(iv)).

Bridging this divide, governance scholars are exploring alternative regulatory approaches. Bustamante et al. (2024) suggest because amateur radio is a societal service and is open-ended in nature, polycentric governance is necessary for resource management. The key feature of polycentric governance is it operates with more autonomy for local units and shares system to resolve disputes over spectrum. This allows for these polycentric systems of governance to respond better to local challenges. The stakeholders develop their own rules in response to local demands and conditions in ways which rigid property-rights regimes cannot (p. 4). Emerging frameworks like polycentric governance may offer a middle path, enabling context-specific rules which balance transparency with security, especially in cases where amateur systems overlap with public safety functions. However, as Bustamante et al. (2024) note, this approach requires trust in localized self-regulation and ongoing dialogue between operators, institutions, and regulators (p. 5).

The tension between encryption and openness reflects a broader policy and ethical dilemma. On one hand, the escalating risks of unprotected wireless data in sectors such as healthcare, defense, and disaster response suggest encryption should be normalized across all forms of radio communication (Poornashree et al., 2014, p. 2). On the other hand, amateur radio's legacy as a civic, transparent, and collaborative space resists the logic of secrecy, privileging openness as a public virtue (Dansarie, 2024, p. 91102). The dilemma is not easily resolved. Attempts to mandate encryption across all

wireless systems could threaten the participatory nature of amateur radio and the legal status of educational programs. Conversely, maintaining open frequencies in an increasingly hostile digital environment could leave vital infrastructure exposed (Pratomo et al., 2023, p. 3).

Practical experimentation further illustrates this tension. A project conducted by students of Visvesvaraya Technological University in 2014 used Amateur Radio technology to digitally transmit encrypted GPS based location data to police or help centers using Amateur Radio emergency frequencies (Poornashree et al., 2014, pp. iv & 1). This data used encryption technology to obscure the GPS coordinates of the accident.

Overall, the literature reveals an unresolved challenge in modern communication governance, how to balance the security advantages of encryption with the longstanding principles of openness which define amateur radio. The themes identified in the literature review, spanning historical developments, emergency communication practices, and evolving governance concerns, help shape the focus and direction of this study. These insights inform decisions about how to structure the investigation and approach the data in a systematic yet interpretive manner. To provide clarity and transparency in how the study was conducted, the following section outlines the methodology, including the research design, data sources, and analytical procedures used to develop the findings.

Methodology

This study employed qualitative research methodology centered on a narrative literature review. The purpose of the review was to analyze existing scholarships on amateur radio, with particular attention to their roles in communication, emergency response, and technological innovation. Following Snyder's (2019) description of a narrative literature review as a semi-systematic method for collecting and synthesizing prior research, the review sought to identify and understand all research traditions relevant to the topic (p. 335).

The review examined how modernization through digital technologies influences the relevance, visibility, and functional effectiveness of amateur radio in contemporary communication systems. It also explored how legacy innovations and Federal Communications Commission (FCC) regulations, including encryption restrictions, shape the evolution and modernization of amateur radio. To address these questions, the analysis considered patterns in the literature related to technological innovation, communication practices, emergency response roles, and regulatory constraints.

The search was conducted using Google Scholar, employing keywords such as "amateur radio," "digital communication," "emergency communication," and "FCC regulation." Sources were included if they addressed amateur radio technology, regulatory policy, or communication practices and were published between 2015 and 2025. Sources were excluded if they were not relevant to the research questions or were published before 1980, unless needed for historical context. Initial selection of articles encompassed over 200 articles. The selection process involved screening titles and abstracts, followed by full-text review, resulting in the final set of sources.

Data was analyzed using a narrative synthesis approach. Themes were identified through an iterative approach based on recurring patterns and conceptual relevance, and keyword frequency, across the selected literature. Initial codes were developed during the data familiarization stage, where key terms and ideas related to amateur radio technologies, emergency communications, and encryption were noted. These codes were then compared and refined to identify broader patterns, which informed the development of preliminary thematic categories. To finalize the themes, sources were systematically grouped according to

their primary focus, methodology, and contribution to the research question. Articles which addressed foundational knowledge and historical development were categorized under amateur radio technologies and background; those emphasizing applied use in disaster response and public service were grouped under public service and emergency communications; and studies examining security, regulation, and policy issues were classified under encryption technology and governance. Overlapping sources were evaluated based on their dominant emphasis to ensure consistency in classification.

As a narrative review, the analysis was interpretive and may reflect subjective emphasis. Additionally, the search was limited by the availability of open-access materials. The overall methodological structure was informed by Bouchrika’s (2026) guidance on research design (section 6).

Data Analysis and Results

In applying a narrative review methodology, the synthesis was shaped by the researcher’s judgment in determining thematic boundaries and emphasizing particular insights. While this allows for a rich, context-sensitive understanding of the field, it also introduces potential subjectivity. The findings therefore represented an informed interpretation rather than a purely quantitative or systematically coded output.

The review was also shaped by practical limitations, particularly those related to the availability of open-access materials. Because the search strategy prioritized sources which were accessible without subscription barriers, but paywalled studies may not be included, which could influence the scope of the discussion. Despite this limitation, the selected literature provided sufficient depth to construct meaningful thematic conclusions.

Table 2 categorized the reviewed literature across three thematic areas related to amateur radio technologies: amateur radio technologies and background; public service and emergency communications; and encryption technology and governance.

Table 2
Summary Data Analysis

Theme	Technical Bulletins	Literature Reviews	Textbooks or Handbooks	Empirical Studies	Total Number of Articles	Contribution
Amateur Radio Technologies-Background	0	5	2	2	9	Historical, importance, impact, ionospheric, governance, emergency, frequencies, FCC
Public Service and Emergency Communications	1	5	2	2	10	Impact, medical, community, analog, digital, security, disaster, licensing, privacy, emergency, visibility

Table 2 - continued

Theme	Technical Bulletins	Literature Reviews	Textbooks or Handbooks	Empirical Studies	Total Number of Articles	Contribution
Encryption Technology and Governance	1	6	1	3	11	Self-governance, permissible, standard, openness, operations, hackability, protection, analysis, encryption, data transfer, legality

For each theme, literature was distributed across four publication types, technical bulletins, literature reviews, textbooks/handbooks, and empirical studies, allowing a comparative evaluation of scholarly contributions. The final column synthesized the dominant contributions emerging from each category.

The amateur radio technology-background theme was dominated by literature reviews, showing the scholarship is conceptual and historical. Textbooks and empirical studies contributed minimally, suggesting foundational knowledge of amateur radio technologies is well established but not frequently updated through technical bulletins or new field data.

The public service and emergency communications theme was made up of literature reviews. The presence of two empirical studies and one technical bulletin indicate modest engagement with practical case analyses and operational guidance, consistent with the applied nature of emergency communications.

The encryption technology and governance theme showed the highest total volume with eleven articles, indicating significant scholarly interest. It stands out to have more empirical studies compared to the other themes, reflecting an increased need to analyze operational, legal, and governance issues through real-world data.

Snyder (2019) states “a thematic or content analysis is a commonly used technique and can be broadly defined as a method for identifying, analyzing, and reporting patterns in the form of themes within a text” (p. 335). The results presented in Table 2 outline the themes with key patterns, thematic distributions, and trends which emerged from the analysis. The thematic analysis process was used where a six-step approach was implemented, “data familiarization; keyword identification; code selection; theme development; conceptualization through interpretation of keywords, codes, and themes” (Naeem et al., 2023).

While these findings described what the data revealed, their broader meaning and implications required further interpretation. The following discussion section expanded on these results by situating them within the existing literature, examining their relevance to the study’s guiding inquiry, and exploring the theoretical and practical insights they offer. In doing so, it addressed the central research question of how modernization through digital technologies influences the relevance, visibility, and functional effectiveness of amateur radio in contemporary communication systems, as well as how legacy innovations and FCC regulations, particularly encryption restrictions, shape their ongoing evolution and modernization.

Discussion and Implications of Findings

Amateur radio is undergoing a significant transformation as it adapts to the demands of an increasingly digital, interconnected, and security-conscious world. Once primarily regarded as a hobby centered on analog voice communication, it now occupies a more complex role at the intersection of technological innovation, public service, and regulatory governance. This study designs a conceptual model which frames amateur radio within a resilient digital communication system. By situating amateur radio within broader discussions of innovation and evolution, practical use and deployment, and governance challenges, this analysis seeks to evaluate both the enduring value and evolving limitations. Figure 1 presents a framework for how amateur radio is evolving into a resilient digital communication system by integrating three core dimensions: technological relevance, operational implications, and regulatory environment. The model emphasizes resilience is achieved not by any single factor, but by the interaction and balance of all three where technology is practical, compliant, and adaptable.



Figure 1
Conceptual Model for Modern Amateur Radio Resilience

Building on this framework, the following discussion explores the research question by examining how technological advances reshape capabilities and operator skills (technological relevance), how these changes influence deployment, interoperability, and resilience in practice (operational implications), and how FCC rules, particularly prohibitions on encrypted or obscured transmissions and non-commercial mandates, both constrain and guide modernization efforts (regulatory environment). Together, these dimensions structure the analysis of amateur radio's evolving role as a resilient, digitally enabled

communications resource and highlight the trade-offs and policy gaps which emerge when aligning technological innovation with operational needs and legal constraints.

Technological Relevance

Today's amateur radio operators require skills in analog and digital signal processing. "The FCC defines Amateur Radio Service as one of self-training, intercommunication, and technical investigation carried on by amateur radio operators" (Laster, 2000, p. 11). "Operation of an amateur station requires an amateur operator license grant from the FCC. For individuals entering the amateur service, or upgrading their license operator class, there are three classes of license, each authorizing privileges corresponding to the qualifications required. The classes of license, from highest to lowest are: Amateur Extra Class, General Class, and Technician Class" (Rose, 2022, pp. 66-67). According to ARRL, there are currently over 742,000 active, licensed Ham operators in the United States ("FCC License Counts," 2025). Radio communications rely on what nature provides rather than fiber optic cables or cell phone towers, therefore, Hams are usually more likely to be able to communicate when modern communications cannot (Brown, 2023, para. 25). In addition to their role in more "serious" communications, Hams have acquired skills and expertise which excited audiences into creating an entertaining medium to transmit voice and music (Blyth, 2016, p. 13).

The valuable social capital the amateur radio community affords is difficult to quantify. The "technical culture" and skill provided by these operators reaches far beyond the simple number of operators in a club. These skills are increasingly in demand in an "ever-more digital economy and labor markets" (Bustamante et al., 2023, p. 2). Quantifying the economic value of amateur radio operators' contributions to society is challenging, particularly because they provide critical public services such as disseminating information during emergencies and disasters, as well as raising awareness of community events not covered by other media channels. (Bustamante et al., 2023, p. 2).

The formation of human capital is done by learning through doing. The technical skills developed by radio operators are skills which are independent and portable investments in individuals. Skills shared by a small percentage of the population in which all consumers will benefit overall. Human capital formation spurs long-term innovation through an advanced work force. The capabilities of this skilled labor force allow for a range of innovations, not specific to any discipline, and have possibilities for "potentially unforeseeable innovations" (Bustamante et al., 2023, p.10).

Operational Implications

The use of amateur radio communications in medical and public safety contexts illustrates both the strengths and limitations of its deployment. Simultaneously, initiatives such as BMERS show the potential of integrating amateur radio with digital communication tools to maintain operations in critical sectors like healthcare. Amateur radio, operating independently of traditional infrastructure, becomes especially crucial when mainstream systems fail during natural disasters, power outages, or emergencies (Cid et al., 2017, p. 2). Organizations like ARES and RACES exemplify the organized volunteerism which sustains amateur radio's public service mission (Gill, 2019, p. 112).

While amateur radio continues to serve as a critical tool for communication during emergencies, public service events, and in educational contexts, its integration with modern security practices remains limited. One of the most pressing challenges is the inability to use encryption within amateur radio transmissions due to regulatory restrictions. Most notably, FCC Part 97 and ITU guidelines prohibit the use of encrypted communications on amateur frequencies ("Code of Federal Regulations," 2024). This creates a significant vulnerability in an era where secure, private communication is paramount, especially in sensitive scenarios

such as disaster response, medical communications, and satellite-based operations (Dansarie, 2024, p. 91120).

Regulatory Environment

The governance structures surrounding amateur radio, particularly FCC regulations and ITU guidelines, play a crucial role in shaping the operational boundaries and ethical use of these technologies. However, these same regulations may restrict innovation in areas like encrypted communications, suggesting a tension between openness and security (Widjaja, 2025, p. 263). Despite the growing importance of cybersecurity in wireless systems, there remains an obvious lack of scholarly research exploring alternative approaches to secure data exchange within the constraints of amateur radio regulations (Widjaja, 2025, p. 269).

In addition, there is limited quantitative research examining how the absence of encryption affects communication reliability, privacy, and operational effectiveness during emergencies or public service events. Similarly, practical experimentation on how amateur radio can securely interface with other technologies, such as TETRA, cellular networks, or software-defined radio platforms using automated or context-aware switching mechanisms, remains underexplored. By contrast, discussions on adapting FCC, ITU, and other international regulatory frameworks to modern encryption needs are based on policy analyses, legal reviews, and white papers rather than empirical evidence.

This research gap hinders the advancement of amateur radio as a viable communication solution in increasingly security-conscious environments and raises critical questions about the balance between operational transparency and data protection in public-spectrum technologies.

The research through scholarly articles included viewpoints of amateur radio operators and the related communities and little from the FCC and journalistic writings. However, since 2000, there has been more work calling for the FCC to use light-touch regulation in its regulatory grip so as not to stifle innovation and market competition (Rose, 2022, p. 36). There is an apparent gap in research related to encryption of communications via amateur radio transmission. This also highlights the contradictory points of the FCC regulation and amateur radio operators with respect to the use of encryption technology of radio transmissions.

Conclusion

The evolution of amateur radio into a digital-hybrid communication system reflects both its adaptability and its continued societal relevance. The integration of advanced technical skills, combined with its proven role in emergency and public service communications, underscores its importance as a resilient and decentralized communication resource. At the same time, regulatory constraints, particularly those surrounding encryption, present significant challenges in aligning amateur radio with contemporary expectations of security and privacy.

The tension between transparency and security represents a central challenge for the future of amateur radio. The absence of robust empirical research on legally compliant security mechanisms, interoperability with modern communication systems, and the real-world impact of unencrypted transmissions further constrains its evolution. Addressing these gaps will require a shift toward experimental, interdisciplinary, and quantitatively grounded research approaches.

The sustainability and relevance of amateur radio will depend on its ability to balance openness with security, innovation with regulation, and tradition with technological progress. By addressing these

challenges, amateur radio can continue to serve as a resilient, secure, and socially valuable component of the broader communication ecosystem in the years ahead.

Limitations of the Study

A key limitation of this study is its reliance on a narrative literature review rather than a systematic approach. The selection of sources, which includes scholarly articles, operator perspectives, and policy discussions, was guided by relevance to the evolving role of amateur radio within a digital-hybrid communication framework. However, the absence of a standardized search strategy, explicit inclusion and exclusion criteria, and formal quality assessment introduces the potential for selection bias and incomplete coverage of the literature.

This limitation is particularly significant given the interdisciplinary nature of the topic, which spans telecommunications, cybersecurity, public policy, and emergency management. As a result, relevant studies, especially empirical research on encryption, interoperability, and security within amateur radio systems, may have been limited due to federal regulation limitations. Additionally, the interpretive nature of the review may reflect an emphasis on emerging concerns, such as regulatory constraints on encryption, rather than providing a fully balanced representation of all perspectives within the field.

Consequently, the findings of this study should be understood as exploration and conceptual, intended to identify key themes, gaps, and future research directions rather than to provide a comprehensive or definitive synthesis of the existing body of literature.

Recommendation for Future Research

The evolving landscape of wireless communication, coupled with increasing cyber-security demands, underscores a pressing need to develop innovative, legally compliant models to enhance security within amateur radio systems. Future research should prioritize the design of layered security architectures which allow encryption to occur either before data enters or after it exits the amateur radio transmission pathway, thus maintaining strict adherence to FCC Part 97 and ITU regulations which prohibit encrypted over-the-air transmissions (“FCC License Counts,” 2025). Additionally, hybrid communication systems, such as the BMERS mode, which integrate encrypted networks like Wi-Fi or cellular infrastructure with amateur radio should be further explored for their potential to provide robust, redundant communication channels in emergency and healthcare contexts. Store-and-forward data transfer methods, which separate encryption processes from live transmissions to enable legally secure communication through delayed delivery (Cid et al., 2017), also warrant pilot studies.

The introduction of encryption into a domain traditionally grounded in openness and transparency raises significant ethical and societal questions. Future studies should investigate public perceptions regarding encrypted versus open communications, particularly in disaster, medical, and public service contexts. Moreover, examining the intersection of core amateur radio value, such as civic engagement, technical openness, and public accessibility, with modern privacy and security expectations is critical to understanding potential tensions or synergies (Cid et al., 2017).

Finally, the governance of spectrum use must evolve to accommodate technological innovation while preserving foundational amateur radio values. Future inquiry should explore polycentric governance frameworks which involve community-based organization, such as ARES, RACES, and local emergency management agencies, in piloting conditional encryption policies under localized oversight. Evaluating the feasibility of adaptive, local rule-making approaches which balance innovation with adherence to national and international standards will be crucial in this regard.

Collectively, these research directions offer a comprehensive roadmap to advance amateur radio as a secure, resilient, and ethically grounded communication platform. Addressing these challenges not only promises to enhance technical scholarship but also to inform policy development in the broader context of public-spectrum technologies amid a rapidly evolving digital and security-conscious world.

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