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RESEARCH ARTICLE

India's Quantum Technology Advancements: National Security Implications for Pakistan

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Article Info	Abstract
<p>Keywords: Quantum Technology, National Security, India-Pakistan Relations, Quantum Communication, Strategic Stability</p>	<p><i>Quantum technology has the potential to transform computing, communication, and security, and it holds significant implications for national security. This paper examines the development of quantum technology in India and its national security implications for Pakistan. India's significant investment in quantum technology, primarily through the National Quantum Mission (NQM), is expected to establish India as an influential state in the field. This paper aims to fill a critical gap in the existing body of knowledge by answering important questions: how India is planning to develop quantum technology? How this could be a potential national security issues for Pakistan? These concerns include the weakening of conventional security measures and the necessity to strengthen cyber and defense capabilities. This study employs a qualitative methodology, utilizing primary and secondary data. The results emphasize the need for Pakistan to allocate resources towards quantum research, produce quantum-resistant technology, and bolster its intelligence and surveillance infrastructure to maintain strategic stability.</i></p>

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Introduction

Quantum technology, a rapidly advancing field with the potential to revolutionize computing, communication,¹ and security. It is likely to have profound implications for the national security of states.² As states around the world are competing to harness the power of quantum mechanics,³ the technological and geopolitical scene is set to experience significant transformations.⁴ This study aims to examine the development of quantum technology in India and its national security implications for Pakistan. Through a comprehensive research, this study develops an understanding of the Indian advancement in quantum technology. Furthermore, it evaluates the potential 0 for Pakistan's national security. India has made significant developments in quantum technology, driven by substantial investments and strategic initiatives.⁵ In 2023, the National Quantum Mission (NQM) was launched with a budget of Rs. 6003.65 crore.⁶ This initiative of the Indian Government aims to foster research and development in quantum computing, communication, and sensing, and positioning India as a significant state in the field of quantum technology.⁷ Furthermore, the Indian

¹ Goldner, Philippe, Alban Ferrier, and Olivier Guillot-Noël. "Rare Earth-doped Crystals for Quantum Information Processing," *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 46 (Elsevier, 2015): 1-78.

² James Andrew Lewis and Georgia Wood, "Quantum Technology Applications and Implications," *Centre for Strategic & International Studies* (May 2023).

³ Elizabeth Gibney, "Quantum Computer Race Intensifies as Alternative Technology Gains Steam," *Nature*, Vol. 587, No. 7834 (November, 2020): 342–43.

⁴ Brennen, Gavin, Simon Devitt, Tara Roberson, and Peter Rohde, "An Australian strategy for the quantum revolution," *Australian Strategic Policy Institute* (2021).

⁵ Varun G. Menon and Mainak Adhikari, "Quantum Computing in India: Recent Developments and Future," *IET Quantum Communication*, Vol. 4, No. 2 (June, 2023): 93–95, <https://doi.org/10.1049/qtc2.12056>.

⁶ Sourabh Lele and Shivani Shinde, "Rs 6,000-Crore National Quantum Mission Gets Union Cabinet Approval," *News and Analysis, Business Standard* (April, 2023).

⁷ WAM, "India's National Quantum Mission Announces Four Thematic Technology Hubs," *News Agency, Emirates News Agency - WAM*, April 24, 2024,

governments' quantum initiative's ambitious goals include developing intermediate-scale quantum computers, establishing quantum networks equipped with quantum memory. Moreover, it also aims to enhance quantum sensing capabilities. These advancements are expected to have significant impact on various sectors, including defense.⁸

Previous studies have extensively explored the potential of quantum technology in transforming national security paradigms. For instance, Frank Smith discusses the concept of technology hype and its implications for national security, highlighting how varying levels of familiarity with quantum technologies influence their acceptance and consequential decisions.⁹ Raymer and Monroe provide a comprehensive overview of the US National Quantum Initiative (NQI) and its anticipated impact on national security.¹⁰ Sokolova examines the development of quantum technologies in the context of the US-China technological rivalry, predicting geopolitical tensions and the need for regulatory mechanisms.¹¹ Abuarqoub et al. examines quantum computing's implications for cryptographic techniques and emerging technologies¹². Chowdhury

<https://www.wam.ae/en/article/b2o3pnf-india's-national-quantum-mission-announces-four>.

⁸ Government of India, Department of Science & Technology, "National Quantum Mission (NQM)," *Ministry of Science and Technology*, accessed May 20, 2024.

⁹ Frank L Smith, "Quantum Technology Hype and National Security," *Security Dialogue*, Vol. 51, No. 5 (2020): 499.

¹⁰ Michael G Raymer and Christopher Monroe, "The US National Quantum Initiative," *Quantum Science and Technology*, Vol. 4, No. 2 (February 22, 2019): 02.

¹¹ Marianna Sokolova, "On the Way to the Second Quantum Revolution & Security Risks and the US-China Technological Rivalry," *Russia and America in the 21st Century*, No. 4 (2021).

¹² Abuarqoub, Abdelrahman, Simak Abuarqoub, Ahmad Alzu'bi, and Ammar Muthanna, "The impact of quantum computing on security in emerging technologies," *5th International Conference on Future Networks and Distributed Systems* (2021): 171-176.

et al emphasize the importance of physical security in the era of quantum technology.¹³ Khan, Dalawai, and Nagachandan highlight India's significant investment in quantum computing and examine its expected outcomes.¹⁴ However, research gap exists related to implications of Indian quantum technology development on Pakistan's national security, which this study aims to fill. To fill this research gap, this paper aims to answers two significant questions: first, how is India developing its quantum technology? Secondly, what are the national security implications for Pakistan? By addressing these questions, the study provides a nuanced understanding of the regional security dynamics shaped by advancements in quantum technology.

The significance of this study lies in its investigation of the strategic implications of development of quantum technology in the context of India-Pakistan. This study underlines the importance of preemptive measures, including investments in quantum research, cybersecurity, and advanced defense technologies, to ensure national security of Pakistan in the evolving technological environment. It uses a qualitative methodology and utilizes primary and secondary data sources, including official reports, books, journal papers, and newspaper articles, to provide a comprehensive analysis of India's quantum technology advancements and their national security implications for Pakistan. The concept of the security dilemma provides a broader strategic context through which advancements in India's quantum technology and its implications for Pakistan's national security can be understood. According to this

¹³ Chowdhury, S., Covic, A., Acharya, R.Y., Dupee, S., Ganji, F. and Forte, D., "Physical Security in the Post-Quantum Era: A Survey on Side-Channel Analysis, Random Number Generators, and Physically Unclonable Functions," *Journal of Cryptographic Engineering* (2021): 1-37.

¹⁴ Firoz Khan, Gururaj Dalawai, and Nagachandan P, "Impact of Quantum Computing in India and It's Applications," *International Journal of Engineering Research & Technology*, Vol. 8, No. 15 (2020): <https://doi.org/10.17577/IJERTCONV8IS15011>.

concept, efforts by one state to improve its security can unintentionally decrease the security of others, which creates a cycle of action and reaction. India's advancements in quantum technology, intended to enhance its national security, may create challenges to Pakistan's national security, which can take countermeasures to enhance its security. This article is organized into the following sections. The introduction summarizes the significance of quantum technology and its potential implications on national security. Following introduction, the literature review provides a comprehensive overview of recent research on quantum technology, emphasizing gaps in the current understanding of its security implications for Pakistan. The methodology section details the qualitative approach used in this study. Afterwards, the analysis section examines India's quantum technology initiative and its objectives, and their national security implications for Pakistan. Finally, the conclusion provides a summary of the findings and discusses the effects within the conceptual framework of the security dilemma and provides recommendations.

Conceptual Framework

John Herz introduced the concept of the “security dilemma” in 1950. It described a situation where efforts by states to enhance their own security unintentionally reduce the security of other states.¹⁵ This dilemma leads to a vicious cycle of action and reaction, which can possibly escalate to war.¹⁶ Robert Jervis further elaborated on idea of security dilemma that nations in anarchic and uncertain environments might inadvertently provoke hostility by adopting

¹⁵ John H. Herz, “The Security Dilemma in International Relations: Background and Present Problems,” *International Relations*, Vol. 17, No. 4 (December 2003): 411–16.

¹⁶ John H. Herz, “Idealist Internationalism and the Security Dilemma,” *World Politics*, Vol. 2, No. 2 (1950): 157–80.

defensive measures intended to strengthen their security.¹⁷ The realist paradigm accords that the anarchic international system results in the security dilemma¹⁸. In this anarchic system, states are the primary actors; moreover, they must rely on self-help to ensure their survival. In this environment of anarchy, the relative power of other states becomes important, and a state's actions are evaluated in terms of relative power.¹⁹

As Kenneth Waltz pointed out, anarchy compels states to act independently.²⁰ In such an environment, states often resort to militarization, forming alliances, and adopting defensive postures as means of ensuring their security.²¹ While these measures may appear rational from a governmental perspective, they can be perceived as threatening by other states. The inherent uncertainty in international relations means that no state can be certain of another state's true intentions. Even defensive actions may be misinterpreted as aggressive.²² This uncertainty fosters mistrust, leading to a cycle of insecurity.²³ The primary concern for any state is the preservation of its own security.²⁴ However, in the competitive and anarchic international system, actions taken to enhance the security of one state may inadvertently undermine the security of others,

¹⁷ R. Jervis, "Cooperation Under the Security Dilemma," *World Politics*, Vol. 30 (1978): 167–214, <https://doi.org/10.2307/2009958>.

¹⁸ Kenneth Neal Waltz, *Theory of International Politics*, Reiss (Long Grove, Ill: Waveland Press, 2010).

¹⁹ Ibid.

²⁰ Ibid.

²¹ Nincic, Miroslav, "The Tragedy of Great Power Politics. By John J. Mearsheimer," *Perspectives on Politics*, Ed.1, No. 1 (2003): 232-233.

²² Robert Jervis, "Was the Cold War a Security Dilemma?" *Journal of Cold War Studies*, Vol. 3, No. 1 (2001): 36–60.

²³ Oliver Kessler and Christopher Daase, "From Insecurity to Uncertainty: Risk and the Paradox of Security Politics," *Alternatives: Global, Local, Political*, Vol. 33, No. 2 (2008): 211–32.

²⁴ Georg Sørensen, "Individual Security and National Security: The State Remains the Principal Problem," *Security Dialogue*, Vol. 27, No. 4 (1996): 371–86.

perpetuating a cycle of reactive measures²⁵. The security dilemma idea, first formulated by John Herz and subsequently elaborated by Robert Jervis, offers a convincing framework for comprehending the strategic ramifications of India's progress in quantum technology. India is bolstering its quantum capabilities to improve national security by developing sophisticated communication networks, improved surveillance systems, and strong encryption techniques. However, Pakistan might view these measures as aggressive developments. This perception heightens insecurity in Pakistan, prompting it to respond with its own advancements in military and quantum technologies. Such actions lead to an arms race, where each side's efforts to bolster its own security paradoxically result in increased regional instability and heightened risk of conflict. This cycle exemplifies the security dilemma, where the pursuit of security by one state inadvertently diminishes the security of another, necessitating a careful balance of power and strategic stability in South Asia.

Indian Development of Quantum Technology

In 2021, scientists from Ahmedabad's Physical Research Laboratory (PRL), in collaboration with the Indian Space Research Organization (ISRO), verified the viability of sending encrypted messages 300 meters into space using quantum-key encryption.²⁶ Through this technological advancement, they carried out secure live video conferencing. It was a significant milestone in quantum communication for India. In 2023, researchers from the Indian Institute of Technology Delhi (IIT-Delhi) achieved further progress in the field. They set new records for “the Differential Phase Shift

²⁵ Mehran Kamrava, “The Intractable Security Dilemma,” *Troubled Waters* (Cornell University Press, 2018), 111–44, <https://doi.org/10.7591/cornell/9781501720352.003.0005>.

²⁶ Indian Space & Research Agency, “Quantum Key Distribution (QKD),” Indian Space & Research Agency, 2021, [https://www.isro.gov.in/Quantum%20Key%20Distribution%20\(QKD\).html](https://www.isro.gov.in/Quantum%20Key%20Distribution%20(QKD).html).

(DPS) Quantum Key Distribution (QKD) protocol”.²⁷ By extending the range of secure quantum communication to 380 kilometers using conventional telecommunications lines without relying on trusted nodes, they underlined the potential of quantum communication technology to significantly enhance secure communication infrastructures.²⁸

On April 19, 2023, the Union Cabinet approved the National Quantum Mission (NQM) with a budget of Rs. 6003.65 crore. This program is set to operate from the fiscal year 2023-24 to 2030-31.²⁹ The objective of the mission is to provide a conducive environment for the research and development of quantum technology (QT) by allocating resources to both academic and industry-led projects.³⁰ This strategic investment is expected to drive economic growth through advancements in quantum technology. The program aims to develop intermediate-scale quantum computers, utilizing platforms such as photonic and superconducting technologies, capable of supporting fifty to one thousand physical qubits over the next eight years.³¹ One of the ambitious goals of the NQM is the creation of quantum networks with quantum memory. It has potential to enable long-distance secure communications with foreign countries, multi-node secure quantum communications, and inter-city quantum key distribution across 2000 kilometers.³² Furthermore, they plan to establish two

²⁷ IIT Delhi, “Researchers at IIT Delhi Achieve Trusted-Node-Free Secure Quantum Communication for 380 Km in Standard Telecom Fiber,” *News, Indian Institute of Technology Delhi*, October 6, 2023, https://home.iitd.ac.in/show.php?id=193&in_sections=Press.

²⁸ Ibid.

²⁹ Science & Technology, “National Quantum Mission (NQM),” *Ministry of Science & Technology*.

³⁰ Ibid.

³¹ Prateek Tripathi, “Quantum Computing: Current Scenario and Future Prospects,” *Observer Research Foundation*, May 27, 2024.

³² Bilal Sheik, “India’s National Quantum Mission: A Step Forward,” *News, QNu Labs*, September 14, 2023, <https://www.qnulabs.com/national-quantum-mission-india/>.

ground stations in India, 2000 kilometers apart.³³ In addition, a key purpose of the NQM is the development of highly precise atomic clocks and magnetometers, essential for accurate navigation, communications, and timing.³⁴ Moreover, the mission aims to transform semiconductor architectures, topological materials, and superconductors, crucial for development of quantum devices.³⁵

The NQM's execution plan includes the establishment of four Thematic Hubs (T-Hubs) at leading academic institutions and government laboratories. These thematic hubs likely to focus quantum computing, communication, metrology, sensing, and the development of quantum materials and devices. Furthermore, the Indian government aims to utilize quantum computers across various sectors, including energy, healthcare, finance, space exploration, and security.³⁶ Furthermore, the US and Indian scientists are collaborating on quantum computing initiatives.³⁷ The Joint Report of the US-India Information and Communications Technology (ICT) Working Group signifies the corresponding national efforts of both states to prioritize quantum technology. They plan to strengthen bilateral cooperation that includes expert exchanges, joint workshops, and site visits to key facilities, aligning with existing laws and policies.³⁸

³³ Ajai Chowdhry, "India's Quantum Connects, from 1924," *The Times of India*, April 19, 2024.

³⁴ Matt Swayne, "India Announces \$730 Million-Plus National Quantum Mission," *News and Analysis, The Quantum Insider*, April 20, 2023.

³⁵ Ibid.

³⁶ Science & Technology, "National Quantum Mission (NQM)," Ministry of Science & Technology.

³⁷ John Potter, "US, India Launch Joint Quantum Initiative," *News and Analysis, Quantum Insider*, February 8, 2023, <https://www.iotworldtoday.com/industry/us-india-launch-joint-quantum-initiative>.

³⁸ US Department of State, "Joint Report of the U.S.-India Information and Communications Technology (ICT) Working Group," *United States Department of State* (blog), accessed June 16, 2024, <https://www.state.gov/joint-report-of-the-u-s-india-information-and-communications-technology-ict-working-group/>.

Indian Development of Quantum Technology and Security Dilemma for Pakistan

By analyzing recent advancements in Indian quantum technology, several key focus areas emerge.

- i. Secure Communication
- ii. Quantum Computers
- iii. Quantum Sensing
- iv. Material for Quantum Devices

In the following section, the study analyzes the how quantum communication, quantum computers and quantum sensing can be used for defense.

Quantum Communication and Networks

The establishment of quantum networks with quantum memory has potential to significantly impact Indian military's intelligence and military operations capabilities. With the ability to distribute secure quantum keys across distances of up to 2000 kilometers, India can guarantee the confidentiality and legitimacy of vital government and military communications.³⁹ This innovation is vital for reducing the possibility of enemies intercepting or decrypting strategic planning and operations, which is essential for keeping them confidential. In addition, different parts of the military and intelligence community can work together securely and efficiently if they can offer encrypted communications across several nodes. When it comes to coordinating intricate defense measures and operations in real-time, this facility is very crucial.⁴⁰ With the anticipated long-distance encrypted connection, India's political and military communications would be enhanced. Moreover, secure channels with allied states

³⁹ Ankit Tiwari, "The Security Implications of Quantum Computing and India's National Quantum Mission," *News and Analysis, The Diplomat*, June 9, 2023.

⁴⁰ Niels M. P. Neumann, Maran P. P. van Heesch, and Patrick de Graaf, "Quantum Communication for Military Applications" (arXiv, 2020).

and international entities will enhance cooperation and coordination in military and intelligence-sharing operations.⁴¹

To build a robust quantum communication network, India will need to establish ground stations approximately 2000 miles apart.⁴² These ground stations likely to serve as hubs for encrypted communications within the nation and with foreign allies, thus strengthening the infrastructure for national security. Given that quantum communication is intrinsically secure against eavesdropping due to its foundation in quantum physics, vital military communications will be safeguarded from cyberattacks and foreign intelligence agencies, reducing exposure to cyber espionage.⁴³ The military's operational capabilities are likely to be strengthened with improved secure communication channels. Instantaneous, interference-free transmission of commands and information is essential for military activities and coordination especially during time of crisis.⁴⁴

Secure quantum communication is likely to enable the encrypted transfer of intelligence data between different military branches. It has the potential to improve the ability of the army to collect, analyze, and share information without the risk of data espionage.⁴⁵ As a result of a secure medium of quantum communication, decisions and strategies can be communicated in a better way. In addition, India's robust quantum communication infrastructure and superior counter-intelligence capabilities are likely to make it challenging for Pakistan to infiltrate or interrupt

⁴¹ Ibid., 12.

⁴² Ankit Tiwari, "The Security Implications of Quantum Computing and India's National Quantum Mission," *The Diplomat*, June 3, 2023.

⁴³ NATO, "Using Quantum Technologies to Make Communications Secure," *Official Website, NATO*, September 27, 2024.

⁴⁴ Choi, Captain Daniel, "Quantum Technology and the Military-Revolution or Hype? The Impact of Emerging Quantum Technologies on Future Warfare," *Expeditions with MCUP 2023*, No 1 (2023): 1-24.

⁴⁵ Ibid.

Indian military communications. As a result of secure medium of quantum communication, decisions and strategies can be communicated in better way. In addition, India's robust quantum communication infrastructure and superior counter-intelligence capabilities are likely to make it challenging for Pakistan to infiltrate or interrupt Indian military communications.⁴⁶ Quantum networks also offer numerous applications beyond defense and can be useful for ensuring overall national security. Their high capacity, speed, and reduced susceptibility to interference can enhance the reliability and efficiency of communications in the long term.⁴⁷ As a result, new technologies and applications in quantum sensing, quantum cryptography, and quantum computing may emerge, boosting India's technological capabilities and fostering innovation across various sectors.

One of the most significant impacts of quantum communication technology is its potential to revolutionize the intelligence and surveillance capacities of the Indian military system. For instance, quantum networks could eventually provide highly secure communication channels that are nearly impervious to attacks.⁴⁸ This level of protection is essential for critical national infrastructure, including power grids, banking systems, and communication networks, as well as military and intelligence operations.⁴⁹ Moreover, civilian cybersecurity will greatly benefit from advancements in quantum communication technology. Traditional encryption methods are becoming less effective against

⁴⁶ Michal Kreliina, "Quantum Technology for Military Applications," *EPJ Quantum Technology*, Vol. 8, No. 1 (2021): 1–53.

⁴⁷ Burnashev, M. V., and A. S. Holevo, "On Reliability Function of Quantum Communication Channel," *arXiv preprint quant-ph/9703013* (1997).

⁴⁸ Nelson Alex Roso, "Challenges in Defense Operational Applications Using Quantum Communication and Networks," (2023).

⁴⁹ Hughes, Richard J., Jane E. Nordholt, Kevin P. McCabe, Raymond T. Newell, Charles G. Peterson, and Rolando D. Somma., "Network-Centric Quantum Communications," *Frontiers in Optics* (2013): FW2C.1, <https://doi.org/10.1364/FIO.2013.FW2C.1>.

increasingly sophisticated cyber threats. Quantum cryptography, a new and potentially impenetrable method of encryption based on the principles of quantum physics, offers a solution. This approach can better protect the security and privacy of sensitive data from cyberattacks.⁵⁰ The development of quantum communication networks will also spur further research into quantum computers.⁵¹ Quantum networks with quantum memory will pave the way for the creation of the quantum internet, a next-generation communication network utilizing quantum mechanics to deliver data at ultra-secure, high-speed rates.⁵² The quantum internet has the potential to revolutionize data exchange and processing, enabling unprecedented new applications and services.⁵³

Quantum Computing Platforms: Photonic and Superconducting Technologies

India is tactically prioritizing the development of photonic and superconducting technologies to fulfil the demands of its national security. Photonic quantum computers use photons as qubits. They provide rapid data transport along with robust error correction capabilities.⁵⁴ Superconducting quantum computers use superconducting circuits to generate qubits, providing the necessary

⁵⁰ Phani Sekhar Emmanni, “The Impact of Quantum Computing on Cybersecurity,” *Journal of Mathematical & Computer Applications*, Vol. 2, No. 2 (2023): 1–4.

⁵¹ Mckinsey, “Shaping the Long Race in Quantum Technologies,” *Organizational Website, Mckinsey*, December 21, 2021.

⁵² Knaut, C. M., A. Suleymanzade, Y-C. Wei, D. R. Assumpcao, P-J. Stas, Y. Q. Huan, B. Machielse et al., “Entanglement of Nanophotonic Quantum Memory Nodes in a Telecom Network,” *Nature*, Vol. 629, No. 8012 (2024): 573–78, <https://doi.org/10.1038/s41586-024-07252-z>.

⁵³ Antonio Abelem, Don Towsley, and Gayane Vardoyan, “Quantum Internet: The Future of Internetworking,” *arXiv preprint arXiv:2305.00598* (2023): <https://doi.org/10.48550/ARXIV.2305.00598>.

⁵⁴ Rohit Chaurasiya and Devanshi Arora, “Photonic Quantum Computing,” *Quantum and Blockchain for Modern Computing Systems: Vision and Advancements: Quantum and Blockchain Technologies: Current Trends and Challenges*, Vol. 133, (2022): 127–56.

stability and scalability for intricate calculations.⁵⁵ The integration of photonic and superconducting quantum computers has the potential to revolutionize military planning by efficiently solving difficult optimization problems at an unprecedented rate. Quantum algorithms excel in optimizing force deployments, supply chain logistics, and resource provision, beyond the capabilities of conventional computers. As a result, it will guarantee the ability to function effectively and gain a competitive edge.⁵⁶ Moreover, quantum computers have the capability to replicate military situations instantaneously, therefore offering commanders unique perspectives on probable consequences of different tactics. The capacity to adapt rapidly to evolving battlefield circumstances is of utmost importance for planning extensive military operations and carrying out collaborative military exercises, thereby assuring India's armed forces can effectively respond to dynamic situations.⁵⁷ Situational awareness in modern warfare relies on the ability to process and analyze vast amounts of data from multiple sources.⁵⁸ Quantum computing platforms can enhance this capability by rapidly analyzing satellite imagery, surveillance data, and intelligence reports. With their high-speed data transmission capabilities, Photonic quantum computers can process and analyze satellite data more in an efficient manner. This enables faster

⁵⁵ Huang, He-Liang, Dachao Wu, Daojin Fan, and Xiaobo Zhu. "Superconducting quantum computing: a review." *Science China Information Sciences*, Vol. 63 (2020): 1-32.

⁵⁶ Ambika, N. "Secure Distinctive Data Transmission in Fog System Using Quantum Cryptography." *Quantum Computing in Cybersecurity* (2023): 17-31.

⁵⁷ Brandi Vincent, "Navy Eyes Quantum Tech to Simulate Warfighting Probabilities," *DefenseScoop* (blog), December 5, 2023.

⁵⁸ Arslan Munir, Alexander Aved, and Erik Blasch, "Situational Awareness: Techniques, Challenges, and Prospects," *AI*, Vol. 3, No. 1 (2022): 55–77.

identification of threats, such as missile launches or troop movements, providing real-time intelligence to defense planners.⁵⁹

The ability to analyze the complex data sets is the cornerstone of effective decision making.⁶⁰ Quantum computing platforms can enhance decision-making processes through advanced data analysis and predictive modeling. Quantum algorithms can analyze historical data and identify patterns that predict future events. This capability is invaluable for anticipating adversary actions and developing proactive countermeasures. Quantum computers have the potential to provide decision-makers with deeper insights and more robust strategic options by simulating various scenarios and assessing potential outcomes.⁶¹ In addition, quantum computing has the potential to stimulate progress in materials science and engineering, resulting in the creation of sophisticated weaponry and defense systems.⁶² Quantum computers can do accurate simulations that may expedite the process of discovering novel materials and enhancing their characteristics for military purposes. Photonic quantum computers can model chemical interactions at the atomic level, which may help in identifying materials that possess exceptional strength, flexibility, and stealth properties.⁶³ This has the potential to result in the creation of armor

⁵⁹ Sergei Slussarenko and Geoff J. Pryde, "Photonic Quantum Information Processing: A Concise Review," 2019, *Applied Physics Reviews*, Vol. 6, No 4 (2019): <https://doi.org/10.48550/ARXIV.1907.06331>.

⁶⁰ US Department of Defense, "DOD Moves to Use Data More Effectively in Decision-Making U.," *Official Website, Department of Defense*, February 14, 2020.

⁶¹ Dominic Widdows, Jyoti Rani, and Emmanuel M. Pothos, "Quantum Circuit Components for Cognitive Decision-Making," *Entropy*, Vol. 25, No. 4 (2023): 548, <https://doi.org/10.3390/e25040548>.

⁶² Camino, B., J. Buckeridge, P. A. Warburton, V. Kendon, and S. M. Woodley. "Quantum Computing and Materials Science: A Practical Guide to Applying Quantum Annealing to the Configurational Analysis of Materials." *Journal of Applied Physics*, Vol. 133, No. 22 (2023).

⁶³ Maurizio Di Paolo Emilio, "Quantum Computing for the Discovery of Materials,"

that is both lighter and more durable, propulsion systems that are more effective, and new technologies for achieving stealth.⁶⁴

The synergy between quantum computing and AI can significantly enhance defense capabilities. Quantum-enhanced AI can process and analyze data at unprecedented speeds, enabling more advanced machine learning algorithms and more accurate predictive models.⁶⁵ Quantum computing can enhance AI-driven surveillance systems, improving threat identification accuracy and reducing false positives. Moreover, quantum algorithms can strengthen cybersecurity by developing robust encryption methods and identifying vulnerabilities in existing systems.⁶⁶ Quantum computing platforms likely to significantly improve the analysis of satellite data, providing Indian defense forces with more accurate and timely intelligence. Photonic quantum computers, in particular, can handle the vast amounts of data generated by satellites, enabling quicker and more detailed analysis.⁶⁷ Quantum algorithms can process high-resolution satellite imagery to identify patterns and anomalies, such as troop movements or construction activities. This

News and Analysis, EE Times Europe, December 9, 2020, <https://www.eetimes.eu/quantum-computing-for-the-discovery-of-materials/>.

⁶⁴ Johns Hopkins University, "Quantum Algorithm Could Improve Stealth Fighter Design,"

Official Website, Science Daily, August 20, 2013, <https://www.sciencedaily.com/releases/2013/08/130820161201.htm>.

⁶⁵ Richard Blech, "Quantum Security, Quantum Computing, AI Convergence for Cybersecurity," *XSOC CORP*, May 27, 2024, <https://www.xsoccorp.com/post/the-convergence-of-ai-and-quantum-computing-pioneering-the-future-of-cybersecurity>.

⁶⁶ *Ibid.*

⁶⁷ Rocutto, Lorenzo, Marco Maronese, Daniele Dragoni, Andrea Cavalli, and Carlo Cavazzoni. "Comparing Adiabatic Quantum Computers for Satellite Images Feature Extraction." *Future Generation Computer Systems*, Vol. 159 (2024): 105-113.

capability enhances the ability of Indian defense forces to monitor and respond to potential threats.⁶⁸

In addition, drones are increasingly vital in modern military operations, providing surveillance, reconnaissance, and combat capabilities.⁶⁹ Quantum computing can enhance drone technology by improving navigation, communication, and decision-making processes. Superconducting quantum computers can improve the processing power of drones, enabling them to navigate complex environments more effectively.⁷⁰ Moreover, quantum communication technologies can provide secure and reliable communication links between drones and command centers, reducing the risk of interception and jamming.⁷¹ Air denial capabilities are essential for protecting national airspace and preventing adversaries from achieving air superiority. Quantum computing can enhance these capabilities by improving radar systems, missile guidance, and electronic warfare measures.⁷² Quantum algorithms have the capability to interpret radar data with more efficiency, resulting in improved accuracy in detecting and monitoring airborne threats. Furthermore, the use of superconducting quantum computers has the potential to enhance

⁶⁸ Monica Hernandez, "TQD - Testing Utility of Quantum Algorithms for Satellite Imagery - Poland," *The Quantum Insider*, May 24, 2021.

⁶⁹ Lee, Minho, Minwoo Choi, Taehoon Yang, Jingu Kim, Jaeoh Kim, Ojeong Kwon, and Namsuk Cho. "A Study on the Advancement of Intelligent Military Drones: Focusing on Reconnaissance Operations." *IEEE Access* (2024).

⁷⁰ Kumar, Adarsh, Diego Augusto de Jesus Pacheco, Keshav Kaushik, and Joel JPC Rodrigues. "Futuristic View of the Internet of Quantum Drones: Review, Challenges and Research Agenda." *Vehicular Communications*, Vol. 36 (2022): 100487.

⁷¹ Kami Shah, "Quantum Computing and Drones: The Future of Navigation and Data Processing," *Drones Technology* (blog), April 4, 2024, <https://dronstec hnology.com/quantum-computing-and-drones-the-future-of-navigation-anddata-processing/>.

⁷² Michal Krelina, "Quantum Warfare: Definitions, Overview and Challenges," *EPJ Quantum Technol*, Vol. 8, No. 24 (2021): <https://doi.org/10.48550/ar Xiv.2103.12548>.

missile guidance systems. They will facilitate more precise calculations for the purpose of targeting and interception.⁷³

In modern warfare, missile defense systems are essential for protecting national security. They provide protection against both ballistic and cruise missile threats. Quantum computing platforms may enable improvements to these systems' threat identification, monitoring, and interception capabilities. Quantum computers are likely to enhance the detection, surveillance, and interception capabilities of missile defence systems. India already possesses multiple missile defenses and is planning to acquire more in the future.⁷⁴ Incorporating quantum technology is likely to increase the Indian missile defense capabilities. The use of quantum algorithms has the potential to greatly improve the handling of sensor data, leading to far faster missile detection and tracking.⁷⁵ The likelihood of an intercept being effective is enhanced by reducing the launch time of interceptors. Quantum simulations may also improve missile defense system design and efficiency, leading to more effective and reliable systems.⁷⁶

Quantum Sensors and Military Power

Quantum sensors leverage the principles of quantum physics to detect physical events with unparalleled sensitivity and precision. These sensors can identify minute changes in environmental factors

⁷³ Hasan Abbas Al-Moahmmmed, "Quantum Radar: A Brief Analytical Study," *16th International Computer Engineering Conference (ICENCO)* (Cairo, Egypt: IEEE, 2020): 174–80.

⁷⁴ David Vergun, "Quantum Science to Deliver Cutting-Edge Technology to Warfighters, Official Says," Official Website, U.S. Department of Defense, February 23, 2021.

⁷⁵ Alghamdi, Wajdi, Reda Salama, S. Hemalatha, Laith H. Alzubaidi, Uzakov Akrom, and R. Senthilkumar, "Quantum Computing: Algorithms, Architectures, and Applications." *E3S Web of Conferences*, Vol. 399 (2023): 04041, EDP Sciences.

⁷⁶ Ibid.

such as magnetic and gravitational fields.⁷⁷ India is actively developing quantum sensors for various military applications.⁷⁸ The accuracy of missile systems is crucial for effective offensive and defensive strategies.⁷⁹ Quantum sensors, by enhancing the precision of missile location and surrounding data, can significantly improve missile guidance systems.⁸⁰ Conventional Inertial Navigation Systems (INS) suffer from drift over time, leading to accumulating errors in location estimates.⁸¹ Quantum sensors, particularly those utilizing atom interferometry, can detect acceleration and rotation with extraordinary accuracy, mitigating these errors.⁸² These sensors could reduce ballistic missile positioning errors by orders of magnitude, thus significantly enhancing the accuracy of inertial navigation systems. This heightened precision benefits both

⁷⁷ Degen, Christian L., Friedemann Reinhard, and Paola Cappellaro. "Quantum sensing." *Reviews of Modern Physics*, Vol. 89, No. 3 (2017): 035002, <https://doi.org/10.48550/ARXIV.1611.02427>.

Degen, Christian L., Friedemann Reinhard, and Paola Cappellaro. "Quantum sensing." *Reviews of modern physics* 89, no. 3 (2017): 035002.

⁷⁸ Maurya, S. Sagar, Korak Biswas, Umakant D. Rapol, Pranab Dutta, Jay Mangaonkar, Sumit Sarkar, And Kushal Patel., "A Decade of Advancement of Quantum Sensing and Metrology in India Using Cold Atoms and Ions," *Journal of the Indian Institute of Science*, Vol. 103, No. 2 (2023): 609–32, <https://doi.org/10.1007/s41745-022-00335-8>.

⁷⁹ Kosta Tsipis, "The Accuracy of Strategic Missiles," *Scientific American*, Vol. 233, No. 1 (1975): 14–23, <https://www.jstor.org/stable/24949839>.

⁸⁰ Sarah Jacobs Gamberini and Lawrence Rubin, "Quantum Sensing's Potential Impacts on Strategic Deterrence and Modern Warfare," *Orbis*, Vol. 65, No. 2 (2021): 354–68.

⁸¹ Mahdi, Ahmed E., Ahmed Azouz, Ahmed E. Abdalla, and Ashraf Abosekeen, "A Machine Learning Approach for an Improved Inertial Navigation System Solution," *Sensors (Basel, Switzerland)*, Vol. 22, No. 4 (2022): 1687, <https://doi.org/10.3390/s22041687>.

⁸² Saywell, Jack C., Max S. Carey, Philip S. Light, Stuart S. Szigeti, Alistair R. Milne, Karandeep S. Gill, Matthew L. Goh et al., "Enhancing the Sensitivity of Atom-Interferometric Inertial Sensors Using Robust Control," *Nature Communications*, Vol. 14 (2023): 7626, <https://doi.org/10.1038/s41467-023-43374-0>.

offensive attacks and defensive systems designed to intercept incoming missiles.⁸³

Counterforce attacks target an adversary's military capabilities, especially strategic nuclear weapons.⁸⁴ Such sensors can substantially enhance counterforce strategies by providing more precise information and targeting data. For instance, quantum-enhanced radar systems can more accurately detect and track mobile missile launchers, making it more challenging for adversaries to conceal their strategic assets.⁸⁵ They can also detect minute gravity anomalies, aiding in the identification of subterranean structures such as command bunkers and missile silos. This capability could give India a significant advantage in identifying and striking adversary strategic assets, thereby improving its counterforce strike capabilities. Furthermore, development of quantum sensor might have implications for second strike capability. A nation's second-strike capability, or its ability to retaliate after a nuclear attack, is crucial for maintaining credible deterrence and peace.⁸⁶ Quantum sensors, by enhancing the effectiveness of counterforce attacks, could complicate an enemy's second-strike capability. The precise detection and targeting of critical assets using quantum sensors could diminish the survivability of an adversary's second-strike forces. For example, advances in quantum magnetometry could enhance the detection of submarines, often used as second-strike

⁸³ Kai Bongs et al., "Taking Atom Interferometric Quantum Sensors from the Laboratory to Real-World Applications," *Nature Reviews Physics*, Vol. 1, No. 12 (2019): 731–39.

⁸⁴ Keir A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security*, Vol. 41, No. 4 (2017): 9–49.

⁸⁵ Gamberini and Rubin, "Quantum Sensing's Potential Impacts on Strategic Deterrence and Modern Warfare," *Orbis*, Vol. 65, No. 2 (2021): 354-368.

⁸⁶ Jan Lodal, Jan, Keir A. Lieber, Daryl G. Press, James M. Acton, Hans M. Kristensen, Mathew Mckinzie, and Ivan Oelrich., "Second Strike: Is the U.S. Nuclear Arsenal Outmoded?" *Foreign Affairs*, Vol. 89, No. 2 (2010): 145–52, <https://www.jstor.org/stable/20699857>.

platforms due to their stealth and mobility. If quantum sensors erode the rival's confidence in their second-strike capabilities by improving the detection of these systems, the strategic equilibrium could be disrupted.⁸⁷ The rapid advancements in India's quantum communication and computing capabilities under its NQM present a significant national security challenges for Pakistan.

National Security Challenges for Pakistan

India's progress in quantum sensing and communication technology⁸⁸ likely to seriously jeopardized Pakistan's intelligence and surveillance capabilities. Quantum sensors, which can detect minuscule variations in gravitational and magnetic forces,⁸⁹ would greatly benefit India. As a result, they might utilize them to monitoring Pakistani military operations and vital assets. This technological edge may compromise the secrecy and efficacy of Pakistan's defense measures, allowing India to conduct more precise intelligence operations. India is now in the process of constructing quantum communication networks to safeguard Indian military communications against the unauthorized interception by other nations. These networks provide highly secure routes of communication, allowing India to enhance the coordination of its military activities.⁹⁰ The robust communication infrastructure

⁸⁷ Samanvya Hooda, "Quantum Sensors and Submarine Invulnerability," *News and Analysis*, 9DASHLINE, October 26, 2023.

⁸⁸ ET, "World Quantum Day 2024: India Aspires to Lead the World in Quantum Science and Technology," *News and Analysis*, ET Government, April 14, 2024, <https://government.economicstimes.indiatimes.com/news/technology/world-quantum-day-2024-india-aspires-to-lead-the-world-in-quantum-science-and-technology/109281782>.

⁸⁹ Stephen Battersby, "Core Concept: Quantum Sensors Probe Uncharted Territories, from Earth's Crust to the Human Brain," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 116, No. 34 (2019): 63–65.

⁹⁰ Manjeet Negi, "Indian Army Set to Possess Quantum Communication Tech, Joins Elite List," *News and Analysis*, India Today, August 15, 2022.

ensures that Pakistan has significant challenges in accurately anticipating or effectively countering Indian actions.

Moreover, by integrating quantum computers and sensors into its missile guidance systems,⁹¹ India is expected to enhance the accuracy and dependability of its offensive and defensive missile capabilities. This advancement increases the vulnerability of Pakistan's missile stockpiles to pre-emptive strikes and enhance India's counterforce temptations,⁹² which may possibly undermine the country's strategic deterrence capabilities. Therefore, Pakistan has to reassess its strategies for discouraging potential adversaries in response to India's increasing precision in counterforce capabilities, which might pose a risk to the stability of the region. In addition, India's capacity to detect and monitor important resources, such as mobile missile launchers, via the use of advanced satellites⁹³, radar systems, and sensors that are strengthened by quantum technology, poses a risk to Pakistan's ability to retaliate with a second attack. Pakistan's capacity to deter effectively depends on its assured second-strike capability,⁹⁴ which might be undermined if India manages to accurately detect and target Pakistan's retaliatory troops. Consequently, Pakistan may be required to enhance its technological capabilities or create portable systems to guarantee its ability to endure, which might possibly trigger a competition for weapons. Moreover, quantum computing presents a substantial risk to Pakistan's conventional encryption

⁹¹ Sherryn Groch and Felicity Lewis, "Quantum Sensors, Sea Drones and Hypersonic Missiles: What Are the New Frontiers of War?" *Official Website, Australian Air Power Today*, April 10, 2023.

⁹² Christopher Clary and Vipin Narang, "India's Counterforce Temptations: Strategic Dilemmas, Doctrine, and Capabilities," *International Security*, Vol. 43, No. 3 (2019): 7–52.

⁹³ Mian Zahid Hussain and Raja Qaiser Ahmed, "Space Programs of India and Pakistan: Military and Strategic Installations in Outer Space and Precarious Regional Strategic Stability," *Space Policy*, Vol. 47 (2019): 63–75.

⁹⁴ Staff Reporter, "Pakistan Says Second Strike Capability Attained," *Dawn*, March 30, 2018, <https://www.dawn.com/news/1398418>.

technology used to safeguard military and governmental communications. India's use of quantum computers to decipher conventional encryption might potentially jeopardize Pakistan's sensitive data, hence posing a significant threat to national security.⁹⁵

Recommendations for Pakistan

First, Pakistani military leadership fully acknowledges the importance of Quantum technology. For instance, Pakistan's Army Chief stated in 2024, "advancements in technologies, including artificial intelligence, robotics, and Quantum computing, are changing the use of air power while also expanding its scope".⁹⁶ He included Quantum technology with AI and robotics, which signifies that Pakistan is understanding the importance of these emerging technologies in the evolving domain of warfare. Advisor to Strategic Plans Division (SPD), Zahir Kazmi, has also written two articles on the development of Quantum technology. In those articles, he highlighted the importance of Quantum technologies for strategic stability in South Asia. As he asserted that, "to maintain its deterrence posture, Pakistan must in quantum-resistant encryption, develop indigenous Quantum technologies and explore multilateral collaboration".⁹⁷ He further added, "transitioning to post-quantum cryptographic solutions is critical to safeguarding nuclear command, control and communication systems. If hostile countries and actors

⁹⁵ Najam Ul Hassan Naqvi, "Understanding the Quantum Threat and the Need for Robust Encryption Standards in Pakistan," *Global Defense Insight* (blog), April 27, 2024, <https://defensetalks.com/understanding-the-quantum-threat-and-the-need-for-robust-encryption-standards-in-pakistan/>.

⁹⁶ Express Tribune, "COAS Says Army Aware of Constitutional Limits," *The Express Tribune*, May 2, 2024, <https://tribune.com.pk/story/2464862/coas-says-army-aware-of-constitutional-limits>.

⁹⁷ Zahir Kazmi, "Quantum Technologies and South Asia's Strategic Stability," *CISSAJK*, December 2, 2024, <https://cissajk.org.pk/2024/12/02/quantum-technologies-and-south-asias-strategic-stability/>.

can wreak havoc in deterrence and operations if they break into NC3 systems.”⁹⁸

To meet these challenges, Pakistan has started taking steps to develop Quantum technologies. In 2024, Minister for Planning and Development announced the establishment of first Quantum Computer center. However, there are many challenges that Pakistan is facing in this sphere. First, establishing Quantum infrastructure requires substantial resources. For instance, the Verge reported in 2017 that 15 million dollars are required to purchase D-wave quantum computer. The price in 2024 would be much higher as compared to 2017.⁹⁹ Pakistan is facing economic challenges, and it is in the phase of economic recovery. Therefore, in the current environment, investment in Quantum technology would remain a challenge. Second, to work on the Quantum technology, Pakistan needs skilled workforce. The country is grappling with brain drain which poses a substantial hurdle in the way of developing indigenous Quantum technology. In this way, Pakistan’s investment in the Quantum computers should be strategic. The country can adopt a pyramid model in investing in Quantum technology because it will not be feasible to invest in all the areas of Quantum technology. It should focus on the areas which are more likely to be successful and vital to national interests. Third, Moreover, Pakistan already has a significant defense cooperation with China. China is spending almost 15 billion dollars on Quantum technology.¹⁰⁰ It has already achieved breakthrough in this domain, through this, Pakistan can also get dividends. Fourth, The United Nations has also announced the year 2025 as the year of Quantum technology. Pakistan can utilize this year and highlight the implications of

⁹⁸ Ibid.

⁹⁹ Chaim Gartenberg, “D-Wave Is Now Shipping Its New \$15 Million, 10-Foot-Tall Quantum Computer,” *The Verge*, January 25, 2017.

¹⁰⁰ “Betting Big on Quantum,” accessed December 16, 2024, <https://www.mckinsey.com/featured-insights/sustainable-inclusive-growth/charts/betting-big-on-quantum>.

Quantum divide. It can establish a forum of states of Global South which can work together to reduce the negative implications of Quantum divide faced by the Global South.

Furthermore, to protect its cyber infrastructure against cyber-attacks that use quantum technology, Pakistan should get encryption solutions that are resistant to quantum assaults.¹⁰¹ To reduce the impact of potential quantum computing threats, Pakistan must reinforce its command-and-control systems. The quantum magnetometry developments may help India in finding Pakistan's submarines, which are essential component of nuclear triad. Moreover, due to enhance ability of quantum sensor to detect submarines, Pakistan's naval forces, especially those used for deterrence, face a serious threat. Pakistan needs to take specific countermeasures to reduce the possible impact of quantum technologies. Finally, Policymakers need to develop an understanding of Quantum technology. Although Quantum technology is in an early stage of development, it does not mean that Pakistan should wait for other countries to develop it then work on it. As a state, Pakistan needs to adopt a proactive approach.

Conclusion

This study predicts that challenges to Pakistan's national security will arise from Indian investments in quantum technology. The Indian investment in quantum computing, sensing, and communication is likely to enhance Indian military capabilities. First, advancements in quantum communication are likely to improve coordination between different military branches because secure communication is available. Moreover, it has the potential to improve the Indian military's decision-making capabilities during

¹⁰¹ Najam Ul Hassan Naqvi, "Understanding the Quantum Threat and the Need for Robust Encryption Standards in Pakistan," *Global Defense Insight*, April 27, 2024, <https://defensetalks.com/understanding-the-quantum-threat-and-the-need-for-robust-encryption-standards-in-pakistan/>.

the conflict. The availability of quantum communication is likely to pose a significant challenge to Pakistan's intelligence-gathering and surveillance capabilities. With the help of quantum technology, India can analyze complex data to enhance its situational awareness, monitor strategic assets, and track troop movements. Second, by using quantum computers and sensors, India is likely to enhance the precision of its defensive and offensive missiles.

India is already investing a substantial amount in missile defense systems. The utilization of quantum computers and sensors is likely to strengthen India's missile defense systems. As a result, carrying out missile strikes inside India is likely to be difficult. Furthermore, quantum computers and sensors have the potential to help India locate submarines, which are significant components of the nuclear triad, and other strategic assets. These technologies also make it difficult for conventional aircraft to carry out strikes inside India. Due to the massive computational power of quantum computers, traditional encryption is likely to face serious challenges; as a result, cyber security threats to critical infrastructure are likely to increase. India is already investing in disruptive technologies such as AI, Space, and drones. The development of quantum technology can play a role in force multipliers.

As a result, it, India might adopt a more assertive nuclear posture. It might enhance India's counter-force temptation and challenge Pakistan's second-strike capability. India is conventionally superior to Pakistan; it relies on nuclear assets to deter India from aggression. Therefore, it signifies potential challenges for Pakistan national security and creates security dilemma for Pakistan. These advancements are likely to enhance the threat perception of policymakers in Pakistan. It may effectively handle these concerns by taking proactive measures. Pakistan needs to make high priority to quantum research and development to tackle these security challenges. Collaboration with other countries such as China and academic institutions may facilitate the advancement of

quantum computing, sensing, and communication capabilities. It needs to focus on economic improvement so that it can invest in modern technologies. Creating and implementing encryption solutions that are resistant to quantum computing is crucial for safeguarding communications and data.