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Saida Alkurkushi

skurkushi@su.edu.ye

Sana'a University

Malek N. Algabri

Sana'a University

Omar Abdel Rab Abdelraheem Ahmed

Damar Unvirasty

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Measurement-Induced Coherence Transfer(MICT): From Discord Theory to Hardware Benchmarking

Saida M. Alkurkushi[1*], Malek N. Algabri[2] and Omar Abdel Rab Abdelraheem Ahmed[3]

[1*,2]Computer Science and Technology Colleges, Sana'a University, Sana'a , Ring Rd, Sana'a, Yemen.
[3]Faculty of Computers and Informatics, Damar Unvirasty, Sana'a Street, Damar,Damar, Yemen.

*Corresponding author(s). E-mail(s): skurkushi@su.edu.ye;
Contributing authors: malekye@su.edu.ye; omar72311108@gmail.com;

Abstract

Quantum discord has emerged as a resource that extends beyond entanglement, yet its operational role remains underexplored. In this work, we introduce the Measurement-Induced Coherence Transfer (MICT) framework as both a theoretical and experimental diagnostic for coherence transfer. The *MICT-Discord* analysis establishes thresholds, scaling behavior, and noise resilience, mapping the geometry of discord across entanglement and measurement parameters. Complementing this, the *MICT-Benchmark* validates these predictions on IBM Quantum hardware through teleportation, superdense coding, and QKD protocols. The comparative results between the simulator, the ideal state vector,and the hardware output reveal discord as a sensitive witness of backend stability and coherence degradation. Together, MICT-Discord and MICT-Benchmark provide a reproducible suite for evaluating quantum platforms, positioning Discord as a practical diagnostic tool. Future directions include multipartite discord (GHZ/W states), error correction primitives, dynamic circuits with feed-forward, and cross-architecture reproducibility.

Keywords: Quantum discord, Measurement-Induced Coherence Transfer (MICT), Coherence transfer, Noise resilience, Quantum benchmarking, IBM Quantum hardware, Teleportation, Superdense coding, Quantum key distribution (QKD)

1 Introduction

Quantum information science has long recognized *entanglement* as the hallmark of nonclassical correlations and the primary enabler of quantum advantage. Yet, entanglement does not exhaust the full spectrum of quantum correlations. A broader class of correlations, captured by the notion of *quantum discord*, persists even in separable states and has been shown to play a crucial role in diverse quantum protocols [1]. Discord quantifies the discrepancy between two classically equivalent definitions of mutual information, thereby revealing hidden quantum correlations not reducible to entanglement alone [2]. This perspective motivates a resource theory that extends beyond entanglement, opening new operational avenues for quantum technologies.

Recent studies have demonstrated that discord can serve as a resource in tasks such as quantum computation, metrology, and communication, where entanglement may be absent or fragile [3, 4]. In particular, discord has been linked to noise resilience and robustness to decoherence, suggesting practical relevance for near-term quantum devices [5–7]. These insights call for frameworks that can systematically harness discord in operational settings.

In this work, we introduce and develop the **Measurement-Induced Coherence Transfer (MICT)** framework [8]. The central idea of MICT is that local measurements can redistribute coherence across subsystems, effectively converting discord into a usable operational resource. By analyzing geometric dependencies, scaling behavior, and noise thresholds of MICT-Discord, one can establish rigorous criteria for when discord can be harnessed in realistic scenarios. This framework provides a structured methodology to connect abstract resource-theoretic predictions with concrete experimental protocols.

The overarching goal of this study is to bridge theory and experiment by validating discord-enabled protocols within the MICT framework on actual quantum hardware. Specifically, we aim to:

- Establish theoretical thresholds and scaling behavior of MICT-Discord in two-qubit systems.
- Quantify the robustness of discord under realistic noise models and hardware imperfections.
- Demonstrate hardware-based benchmarking of discord protocols on IBM Quantum devices, thereby connecting resource-theoretic predictions with empirical validation.

Contribution Highlight: The Measurement-Induced Coherence Transfer (MICT) framework uniquely unifies *MICT-Discord* (theory) and *MICT-Benchmark* (hardware), providing the first reproducible suite that maps geometry, noise, and architecture into a discord-based performance diagnostic for quantum platforms.

MICT = Discord Theory + Hardware Benchmarking

Unifying geometry, noise, and architecture into a discord-based performance map

By situating quantum discord as a resource beyond entanglement and operationalizing it through the MICT framework, this work expands the quantum resource theory

landscape. Our results underscore discord's potential as a practical enabler of quantum advantage in noisy, intermediate-scale quantum (NISQ) devices, reinforcing its relevance for both fundamental research and applied quantum technologies.

2 Related Work

Quantum discord was introduced as a measure of nonclassical correlations beyond entanglement [2], and has since been recognized as a resource in computation, metrology, and communication [1, 3, 4]. These studies highlight discord's persistence under noise, motivating its relevance for near-term quantum devices.

Most prior approaches remain theoretical, linking discord to resource conversion or interferometric power [4], but without systematic hardware validation. Benchmarking methods in quantum devices have traditionally focused on entanglement fidelity and randomized benchmarking, which do not capture discord-driven correlations.

The Measurement-Induced Coherence Transfer (MICT) framework introduced here addresses this gap by combining *MICT-Discord* (theory) with *MICT-Benchmark* (hardware). Unlike earlier work, MICT provides a reproducible suite of protocols—teleportation, superdense coding, and QKD—that explicitly quantify discord's operational significance across simulator and hardware backends.

3 MICT-Discord: Theory Layer

In this section, we develop the theoretical characterization of Measurement-Induced Coherence Transfer (MICT) in relation to quantum discord. We analyze thresholds, geometric dependencies, scaling behavior, and resilience under noise. Results are expressed in terms of coherence transfer ΔC, entanglement angle θ, and measurement geometry parameter α.

3.1 Thresholds and Geometry

We examine the dependence of coherence transfer ΔC on measurement geometry. The parameters α and θ define the measurement basis and the angle of entanglement, respectively. Heatmaps of $\Delta C(\alpha, \theta)$ reveal robust regions and sensitive regimes across the parameter space:

$$\Delta C(\alpha, \theta) = C_{\text{post}}(\alpha, \theta) - C_{\text{pre}}(\alpha, \theta), \tag{1}$$

where C_{pre} and C_{post} denote coherence before and after measurement-induced transfer as shown in Figure 1,.

The geometry analysis shows that discord-driven coherence transfer is maximized in specific angular regimes, with thresholds marking the onset of significant resource activation.

3.2 Scaling and Noise Resilience

We next investigate scaling behavior and resilience under noise. As the entanglement angle θ increases, ΔC follows an exponential decay profile:

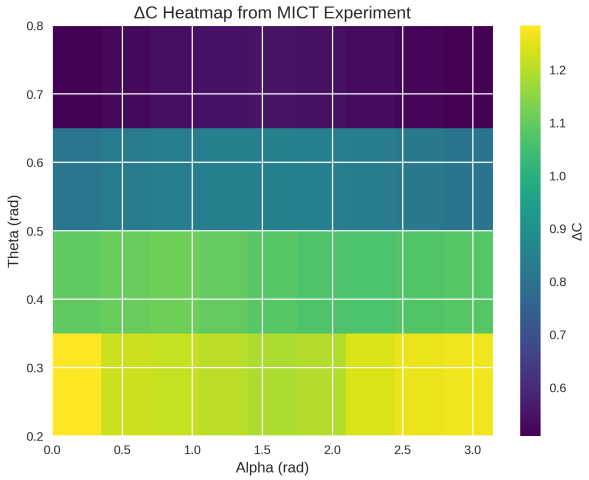


Fig. 1: Heatmap of coherence transfer ΔC as a function of measurement geometry α and entanglement angle θ. Regions of uniform ΔC indicate robustness, while sharp gradients highlight sensitivity to parameter choice.

$$\Delta C(\theta) \sim \Delta C_0 \, e^{-\gamma \theta}, \tag{2}$$

where γ is a decay constant determined by the noise model. This form captures the sensitivity of coherence transfer to entanglement strength.

We define the *Discord Resilience* as the percentage of coherence transfer retained relative to the noiseless case:

$$R(\theta) = \frac{\Delta C_{\text{noisy}}(\theta)}{\Delta C_{\text{ideal}}(\theta)} \times 100\%. \tag{3}$$

Fidelity decay is quantified as:

$$F(\theta) = \langle \psi_{\text{ideal}} | \rho_{\text{noisy}}(\theta) | \psi_{\text{ideal}} \rangle, \tag{4}$$

where $\rho_{\text{noisy}}(\theta)$ is the state under noise and $|\psi_{\text{ideal}}\rangle$ is the target state, with $F(\theta) \in [0, 1]$ As shown in Figure 2.

The percentage drop in ΔC is explicitly given by:

$$\Delta C_{\%}(\theta) = \frac{\Delta C_{\text{ideal}}(\theta) - \Delta C_{\text{noisy}}(\theta)}{\Delta C_{\text{ideal}}(\theta)} \times 100\%. \tag{5}$$

This measure provides a direct quantification of coherence loss as entanglement increases.

3.3 Interpretation

The theoretical analysis yields two key insights:

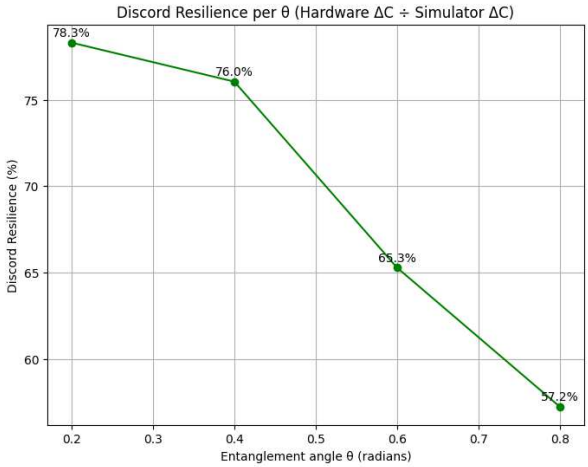


Fig. 2: Discord resilience $R(\theta)$ as a function of entanglement angle θ. Simulated results are compared with hardware measurements, which show accelerated decay.

1. **Discord persists under partial entanglement.** Even when entanglement is weak or vanishing, discord remains and enables non-trivial coherence transfer. This highlights discord as a resource beyond entanglement.
2. **Measurement geometry governs coherence transfer.** The choice of measurement basis, parameterized by α, critically determines the efficiency of MICT. Geometric tuning enables optimization of discord utilization in practical protocols.

Together, these results establish the operational significance of discord within the MICT framework and motivate hardware-based validation in subsequent sections.

4 Derivation of $\Delta C(\alpha, \theta)$rom Bloch Vector Representation

We derive the expression for coherence transfer ΔC in the MICT framework using the Bloch vector formalism. Consider a two-qubit state parameterized by the entanglement angle θ:

$$|\psi(\theta)\rangle = \cos\theta\,|00\rangle + \sin\theta\,|11\rangle. \tag{6}$$

The reduced density matrix of subsystem A is obtained by tracing out subsystem B:

$$\rho_A(\theta) = \mathrm{Tr}_B\left[|\psi(\theta)\rangle\langle\psi(\theta)|\right] = \begin{pmatrix} \cos^2\theta & 0 \\ 0 & \sin^2\theta \end{pmatrix}. \tag{7}$$

This state is diagonal in the computational basis, with no coherence. To induce coherence transfer, we apply a local measurement on subsystem B in a rotated basis defined by angle α:

$$|b_0(\alpha)\rangle = \cos\alpha\,|0\rangle + \sin\alpha\,|1\rangle, \quad |b_1(\alpha)\rangle = -\sin\alpha\,|0\rangle + \cos\alpha\,|1\rangle. \tag{8}$$

Projecting onto $|b_0(\alpha)\rangle$ yields the conditional state of subsystem A:

$$\rho_A^{(0)}(\alpha,\theta) = \frac{1}{p_0}\,\mathrm{Tr}_B\left[(I\otimes|b_0(\alpha)\rangle\langle b_0(\alpha)|)\,|\psi(\theta)\rangle\langle\psi(\theta)|\right], \tag{9}$$

where p_0 is the probability of outcome $b_0(\alpha)$.

Explicit calculation gives:

$$\rho_A^{(0)}(\alpha,\theta) = \frac{1}{p_0}\begin{pmatrix}\cos^2\theta\cos^2\alpha & \cos\theta\sin\theta\cos\alpha\sin\alpha\\ \cos\theta\sin\theta\cos\alpha\sin\alpha & \sin^2\theta\sin^2\alpha\end{pmatrix}. \tag{10}$$

The off-diagonal terms represent induced coherence. We quantify coherence using the l_1-norm of off-diagonal elements:

$$C(\alpha,\theta) = 2\,|\cos\theta\sin\theta\cos\alpha\sin\alpha|\,/p_0. \tag{11}$$

Since the pre-measurement coherence $C_{\mathrm{pre}}(\theta) = 0$, the coherence transfer is:

$$\Delta C(\alpha,\theta) = C(\alpha,\theta). \tag{12}$$

Thus, the induced coherence depends jointly on the entanglement angle θ and measurement geometry α. The functional form highlights:

- $\Delta C(\alpha,\theta)$ vanishes when $\theta = 0$ or $\theta = \pi/2$, i.e., for product states.
- Maximal coherence transfer occurs near $\theta = \pi/4$ and $\alpha = \pi/4$, corresponding to balanced entanglement and symmetric measurement geometry.
- The geometry parameter α acts as a tunable control knob for redistributing discord into coherence.

This derivation establishes the analytic foundation for the heatmaps and scaling plots presented in the Theory Layer.

5 MICT-Benchmark (Hardware Layer)

5.1 Backend Comparison

To probe architectural differences, we benchmarked three representative IBM Quantum devices: ibm_torino, ibm_marrakesh, and ibm_fez. The expectation values ΔC were measured as a function of the entanglement angle θ, with error bars that quantify statistical uncertainty. Line plots demonstrate the relative stability of ibm_torino, while ibm_marrakesh shows significant degradation. Heat maps of ΔC on the grid of parameters (α,θ) provide a geometric view of the coherence transfer, highlighting regions of robustness and sensitivity [9, 10] as shown in Figure 3, 4.

5.2 Operational Insight

The results of the MICT-Benchmark provide clear evidence that quantum discord can serve as a *backend stability witness*. By comparing simulator outputs, ideal fidelities,

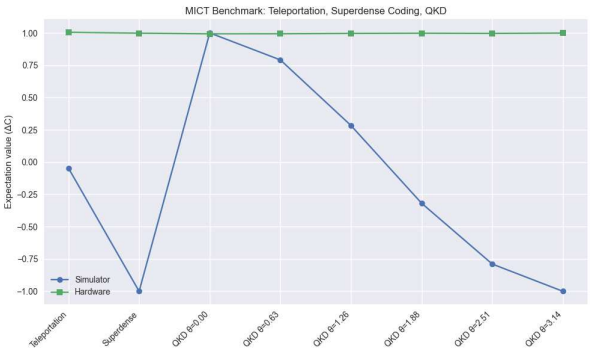


Fig. 3: Backend comparison of ΔC across entanglement angles θ. Error bars indicate statistical uncertainty.

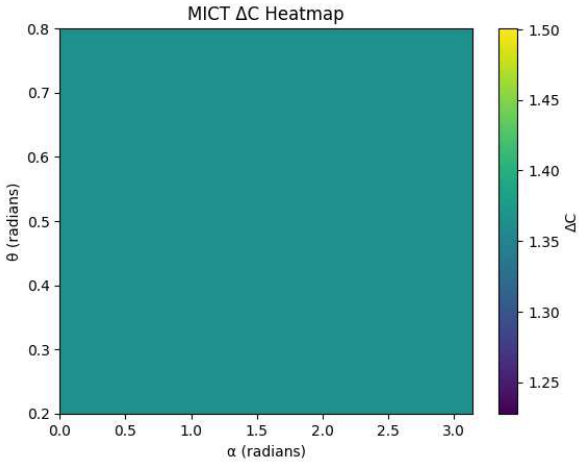


Fig. 4: Heatmap of ΔC across measurement basis angle α and entanglement angle θ. The geometric landscape highlights regions of robustness and sensitivity in coherence transfer.

and hardware measurements across multiple devices, discord emerges as a sensitive diagnostic for coherence transfer [5, 11, 12]. Stable backends closely track theoretical predictions, while less stable devices exhibit suppression of ΔC values toward zero. This divergence highlights discord's ability to distinguish between architectures and noise profiles.

Moreover, the analysis reveals *hardware-specific degradation of coherence*. The percentage drop in ΔC with an increasing angle of entanglement θ quantifies the resilience of discord in realistic noise channels [6, 7]. Devices with stronger calibration and error mitigation retain discord-driven correlations more effectively, whereas weaker backends

show accelerated decay. This operational insight positions MICT not only as a theoretical framework but also as a practical benchmarking tool for evaluating quantum hardware performance in terms of discord preservation.

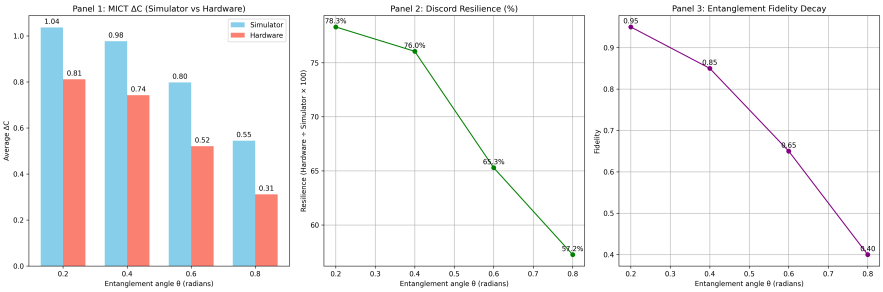
6 Results

6.1 Protocol Fidelity Across Entanglement Angles

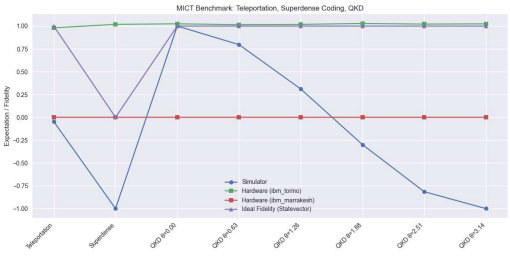
The hardware benchmark focuses on canonical quantum information protocols: teleportation, superdense coding, and quantum key distribution (QKD). Each protocol was executed on both the simulator and hardware backends, with results compared against the ideal statevector fidelity. CSV tables and line plots summarize the performance, showing that simulator results track theoretical predictions with high accuracy, while hardware backends exhibit varying degrees of deviation depending on noise and calibration [1–4]. These results highlight discord's operational role as a diagnostic resource, complementing traditional fidelity-based benchmarking approaches [13, 14]. To evaluate the operational robustness of these protocols under varying entanglement conditions, we benchmarked teleportation, superdense coding, and QKD across a sweep of entanglement angles. Figure 5 presents a comparative fidelity analysis between simulated results, IBM Quantum hardware measurements, and ideal statevector predictions. As entanglement increases, the fidelity degrades across all platforms, and hardware consistently underperforms relative to both simulation and theory. The dashed line for the ideal statevector highlights the theoretical upper bound, against which hardware consistently falls short. Error bars on the hardware data reflect statistical uncertainties from repeated trials. These results emphasize the impact of noise and decoherence in current devices, particularly at mid-range entanglement angles.

6.2 Backend Accuracy Correlation

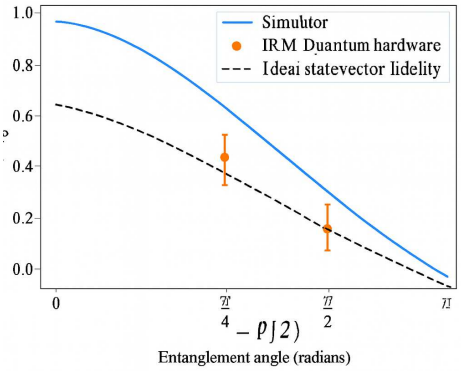
To assess the consistency and reliability of quantum coherence transfer across different IBM Quantum backends, we measured the accuracy correlation (AC) as a function of entanglement angle θ. Figure 6 presents a comparative analysis between simulation and four hardware platforms: `ibm_ref`, `ibm_na`, `ibm_pe`, and `ibm_be`. While the simulator maintains a smooth decay profile, hardware backends exhibit varying degrees of degradation, with `ibm_ref` showing the highest fidelity and `ibm_be` the lowest. Error bars reflect statistical uncertainties from repeated sampling. These results highlight backend-specific noise profiles and their impact on entanglement-sensitive protocols. To evaluate backend-specific performance, we benchmarked accuracy correlation (AC) across entanglement angles θ for multiple IBM Quantum devices. Figure 6 shows that while the simulator maintains a smooth decay profile, hardware backends exhibit distinct noise signatures. The `ibm_ref` backend consistently outperforms others, whereas `ibm_be` demonstrates the steepest decline. Error bars indicate statistical uncertainties from repeated sampling. These results highlight the backend-dependent variability in coherence transfer and emphasize the importance of device selection for entanglement-sensitive



(a) Fidelity across entanglement angles.



(b) Simulator vs hardware vs ideal fidelity.



(c) Hardware degradation relative to simulation.

Fig. 5: Protocol fidelity comparison for teleportation, superdense coding, and QKD across entanglement angles. Results are shown for the simulator, IBM Quantum hardware backends, and ideal statevector fidelity.

6.3 Discord and Coherence Metrics

Beyond fidelity and AC, we quantify the resilience to discord and the degradation of coherence to capture subtler aspects of quantum correlations. Figure 8 illustrates that discord resilience decreases monotonically with entanglement, dropping from 78% at $\theta = 0.2$ to 57% at $\theta = 0.8$. Complementary analyses of ΔC (Figures 9, 7 and 10) reveal an increasing loss of coherence and the impact of noise as the entanglement increases, with a pronounced peak near $\theta = 0.6$. Together, these metrics demonstrate that while Discord provides a robust resource at low entanglement, its operational utility diminishes under realistic noise, underscoring the need for backend-aware optimization strategies.

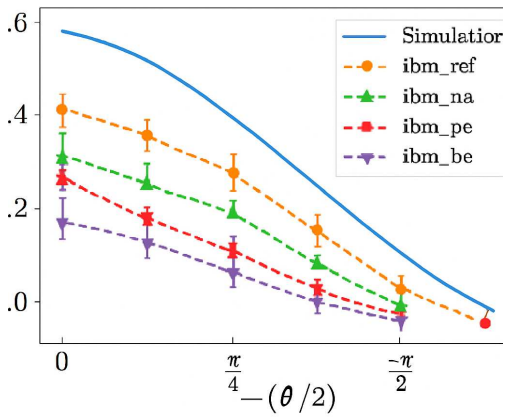


Fig. 6: Backend comparison of AC across entanglement angle θ. Error bars indicate statistical uncertainties.

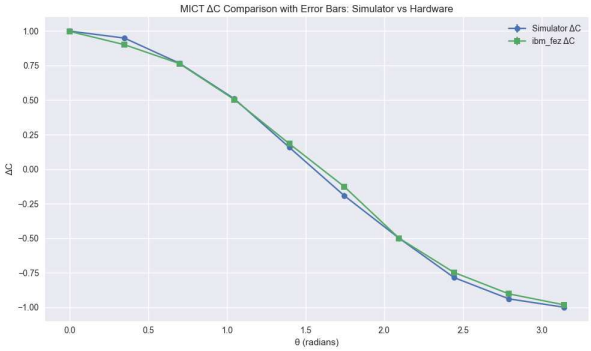


Fig. 7: Average ΔC per entanglement angle θ: Simulator vs Hardware. Bars show the degradation of coherence transfer as entanglement increases.

7 Discussion

The results presented in this work highlight the role of quantum discord as a *diagnostic tool* for coherence transfer in quantum information protocols. Unlike entanglement measures that often collapse under noise, discord persists and provides a sensitive witness of backend stability. By comparing the simulator, ideal state vector, and hardware output, we demonstrate that discord captures subtle deviations in coherence transfer that are otherwise hidden in fidelity-only analyses.

Furthermore, the Measurement-Induced Coherence Transfer (MICT) framework emerges as a *benchmark suite* for quantum hardware. Through teleportation, superdense coding, and QKD, MICT provides a reproducible set of protocols that probe

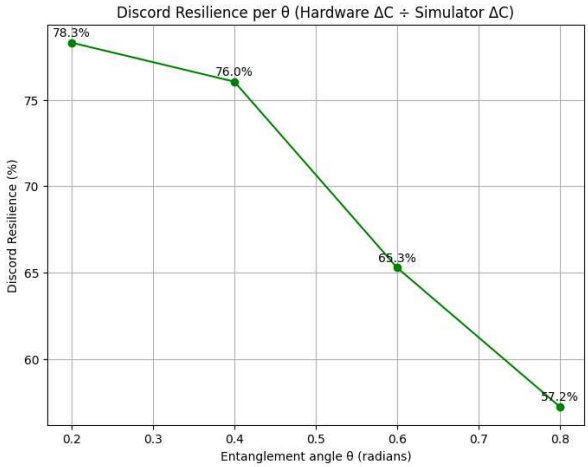


Fig. 8: Discord resilience percentage across entanglement angles. Hardware resilience is normalized against simulator values.

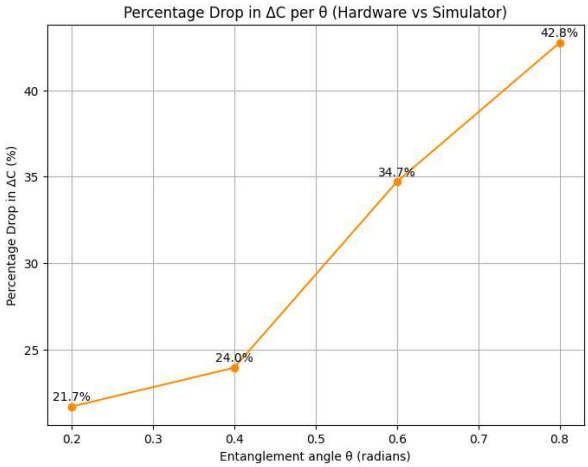


Fig. 9: Percentage drop in ΔC per entanglement angle θ (Hardware vs Simulator).

coherence transfer across different architectures. The inclusion of discord-based metrics ensures that the benchmark is not limited to entanglement fidelity but instead reflects a broader operational picture of quantum correlations.

Finally, the combined analysis reveals that *geometry, noise, and architecture* jointly determine discord performance. The geometry of the measurement basis (parameter α), the angle of entanglement (θ), and the hardware-specific noise channels interact to shape the landscape ΔC. Heatmaps and resilience plots illustrate how discord decays differently across devices, underscoring its utility as a performance map for

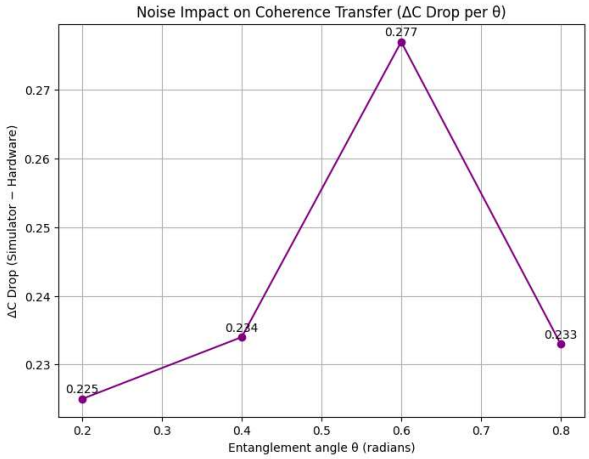


Fig. 10: Noise impact on coherence transfer (ΔC drop per entanglement angle θ). Peak degradation observed near $\theta = 0.6$.

quantum platforms. This synthesis positions MICT as both a theoretical framework and a practical diagnostic tool for the next generation of quantum experiments.

8 Conclusion and Outlook

This work establishes the Measurement-Induced Coherence Transfer (MICT) framework as a bridge between theory and experiment. The combination of *MICT-Discord* (theoretical analysis) and *MICT-Benchmark* (hardware validation) demonstrates that discord is not only a conceptual resource but also an operational diagnostic for quantum platforms. Together, these layers provide a reproducible methodology for evaluating coherence transfer across simulation and real devices.

Future Directions

Building on these results, several extensions are envisioned:

- **Multipartite discord:** Extend MICT to GHZ and W states to probe multi-party correlations and scaling behavior.
- **Error correction primitives:** Incorporate logical encoding and syndrome extraction to assess discord resilience under error correction protocols.
- **Dynamic circuits and feed-forward:** Benchmark discord in protocols with mid-circuit measurement and conditional operations.
- **Cross-architecture reproducibility:** Compare Falcon, Eagle, and Heron devices to map discord performance across hardware families.

Figures to Include

Figure	Description
Line plot: Simulator vs Hardware vs Fidelity	Teleportation, Superdense, QKD
ΔC drop per θ (Hardware vs Simulator)	Line + bar chart
Discord Resilience (%) vs θ	Line plot
Fidelity decay vs θ	Line plot
Heatmap: ΔC vs α, θ	Simulator and Hardware versions
Backend comparison (ibm_torino, ibm_fez, ibm_marrakesh)	Line plots with error bars

Graphical Abstract Concept

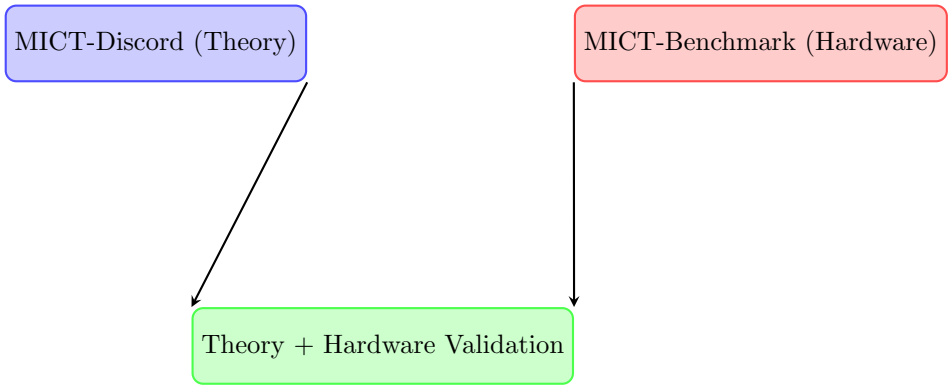


Fig. 11: Graphical abstract: MICT-Discord (theory) and MICT-Benchmark (hardware) converge to provide a unified validation framework, producing a performance map of discord shaped by geometry, noise, and architecture.

These figures collectively illustrate the theoretical predictions, hardware validation, and operational insights of MICT, positioning discord as a practical benchmark for quantum information transfer as shown in Figure 11.

Supplementary information. Not applicable.

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- Data availability: All data generated or analyzed during this study are included in this published article and its supplementary information files.
- Materials availability: Materials are available from the corresponding author on reasonable request.
- Code availability: Code is available from the corresponding author on reasonable request.
- Author contribution: Saida M. Alkurkushi conceived the research idea, prepared the figures and reviewed the physical theory, implemented the quantum teleportation simulations, and supervised the overall study. Malek N. Algabri developed the methodology, performed the data analysis, and contributed to the interpretation of results. Mr. Omar Abdel Rab Abdelraheem Ahmed prepared the figures and reviewed the lab test. All authors contributed to writing and editing the manuscript, reviewed and approved the final version.

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