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Modelling User Distribution in Hexagonal Cellular Networks and Performance Analysis of Slotted vs. Pure ALOHA Using MATLAB

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Abstract: *This paper presents a MATLAB-based framework for modeling random user equipment (UE) distribution within hexagonal cellular cells and evaluating the throughput performance of Pure ALOHA and Slotted ALOHA random-access protocols. The novelty of this work lies in the integration of realistic hexagonal cellular geometry with random UE spatial deployment and ALOHA-based throughput analysis within a unified simulation environment. Hexagonal cell structures with radii of 15 km and 30 km were generated, while uniform random placements of 50 and 100 UEs were achieved using geometric vertex definitions and the in-polygon algorithm to ensure accurate confinement of users within cell boundaries. This approach provides a practical platform for system-level investigations of cellular network capacity, user distribution, and interference characteristics. Furthermore, the study contributes a comparative performance evaluation of Pure ALOHA and Slotted ALOHA through both analytical throughput modeling and a simplified retransmission simulation with up to seven retransmission attempts. Results show that Slotted ALOHA achieves a maximum throughput of approximately 36.8% at an offered load of G = 1, whereas Pure ALOHA reaches only 18.4% at G = 0.5. The findings confirm that time-slot synchronization significantly reduces collision vulnerability and nearly doubles network throughput. The developed MATLAB framework offers an educational and research-oriented tool for visualizing cellular deployments and analyzing random-access channel (RACH) mechanisms, providing insights relevant to LTE, IoT, and emerging 5G/6G random-access systems.*

Keywords: *Pure and Slotted Aloha, RACH, UE, LTE, 5G/6G, IoT, MATLAB*

INTRODUCTION

Wireless and cellular communication systems form the backbone of modern connectivity, supporting an ever-growing number of devices ranging from smartphones and wearables to massive machine-type communications (mMTC) in the Internet of Things (IoT). The efficient modeling of cell coverage areas and the performance analysis of random-access protocols remain fundamental challenges in network design, capacity planning, and interference management. Hexagonal cell geometry has long been the standard abstraction in cellular network planning due to its ability to tessellate the plane with minimal overlap and gaps, providing a more realistic approximation of coverage than circular models while simplifying analytical and simulation studies (Rappaport *et al.,* 2002). In system-level simulations, an accurate representation of user equipment (UE) distribution within hexagonal cells is essential for evaluating key performance indicators such as coverage probability, outage, spectral efficiency, and interference statistics. Random uniform placement of users inside hexagons is a common technique in Monte-Carlo-based simulations, enabling a realistic assessment of downlink/uplink performance and resource allocation strategies. Recent works continue to rely on hexagonal modeling for emerging networks, including cell-free massive MIMO and dense deployments, where stochastic geometry and simulation tools like MATLAB are frequently employed to validate theoretical models (Munari, 2021; Bommisetty *et al.,* 2023).

Parallel to spatial modeling, random access protocols govern how devices contend for channel resources in grant-free or contention-based scenarios. The classic Pure (unslotted) ALOHA and Slotted ALOHA protocols, introduced in the 1970s, laid the foundation for understanding collision-based multiple access (Abramson, 1970; Abramson, 1985). Pure ALOHA achieves a maximum throughput of approximately 18.4% at an offered load G = 0.5, while Slotted ALOHA improves this to approximately 36.8% at G = 1 by synchronizing transmissions to discrete time slots, thereby halving the vulnerability period for collisions. These basic schemes remain highly relevant today, serving as building blocks or benchmarks for advanced modern variants such as Irregular Repetition Slotted ALOHA (IRSA), coded slotted ALOHA, and grant-free access mechanisms in 5G New Radio (NR) and cellular IoT (CIoT) systems (Daraseliya *et al.,* 2025; Dick Maryopi et al., 2024). In 5G NR, the random-access procedure (RACH) is fundamentally based on slotted ALOHA principles with finite preambles, where preamble collisions and retransmission limits directly impact latency, energy efficiency, and connection success rate in massive connectivity scenarios (Mostafa Raeisi *et al.,* 2024; Paolini *et al.,* 2015). Contemporary research has extended these protocols to incorporate successive interference cancellation (SIC), age-of-information optimization, and retry limits, achieving significantly higher throughputs in uncoordinated access for IoT-satellite and cell-free networks (A. Munari *et al.,* 2021; Idris S. I., 2024).

This study leverages MATLAB to simulate two core aspects of wireless cellular systems: (i) uniform random user distribution within hexagonal cells of different radii (15 km and 30 km) with 50 and 100 users, respectively, using geometric vertex definition and rejection sampling via the inpolygon function; and (ii) throughput performance of Pure and Slotted ALOHA protocols through both analytical derivations and a simplified retransmission simulation (up to 7 retransmissions). The objectives are to visualize spatial user placement for cellular capacity studies, derive and plot throughput curves to confirm theoretical maxima (≈18% for Pure ALOHA and ≈37% for Slotted ALOHA), and highlight the performance advantages of slotted synchronization in reducing collision probability. Fig. 1 illustrates the conventional hexagonal cellular network architecture used in wireless communication systems. Each hexagonal cell represents the coverage area of a base station (BS), which serves the user equipment (UEs) located within its boundary. The hexagonal shape is commonly adopted in network planning because it provides seamless coverage without gaps or overlaps while simplifying frequency reuse and capacity analysis. Users are randomly distributed across the cells and communicate with the nearest base station for data transmission and reception. This model forms the basis for evaluating key network performance metrics such as coverage, capacity, interference, and

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access efficiency. Consequently, hexagonal cellular layouts are widely used in the analysis and design of modern wireless systems, including 4G LTE, 5G, and emerging 6G networks.

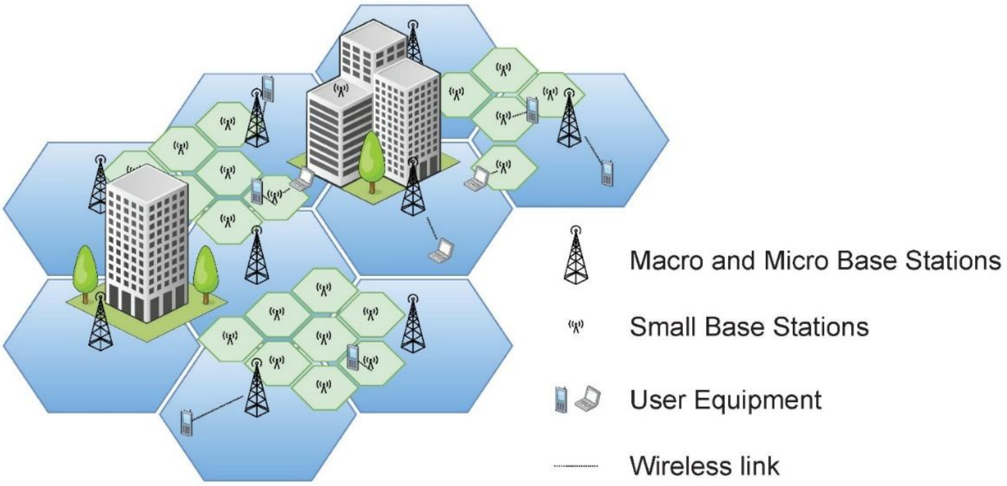

Fig.1 Hexagonal cellular network structure illustrating the coverage area of base stations and user equipment distribution (Nebro, 2022).

MATERIALS AND METHODS

This study employs MATLAB as the primary simulation and visualization tool to model hexagonal cellular geometries and evaluate the throughput performance of random-access protocols. The work is divided into two main simulation components: (i) random user equipment (UE) distribution within hexagonal cells, and (ii) analytical and simplified discrete-event simulation of Pure ALOHA and Slotted ALOHA protocols. All simulations were performed using standard MATLAB functions without external toolboxes beyond the base installation.

2.1 Hexagonal Cell Geometry and Random User Distribution

To realistically represent a single cell in a cellular network, a regular hexagon centered at the origin (0,0) was modeled. Hexagonal geometry is widely adopted in cellular planning due to its efficient tessellation and uniform coverage approximation compared to circular models.

The hexagon vertices were mathematically defined using polar coordinates:

Radius of the hexagon (distance from center to vertex): *R*

Vertices coordinates: $x_i = R \times \sin((i \times \pi)/3)$, $y_i = R \times \cos((i \times \pi)/3)$, where $i = 0, 1, \ldots, 6$ (seven points to close the polygon).

Two scenarios were simulated:

Scenario A: Hexagon radius $R = 15$ km, target number of users $N = 50$

Scenario B: Hexagon radius $R = 30$ km, target number of users $N = 100$

A rejection sampling approach was used to generate uniformly distributed points inside the hexagon:

1. Generate a larger number of candidate points (3*N*) uniformly within a bounding square of side length 2*R* centered at (0,0).
2. Use MATLAB in the polygon function to determine which candidate points lie strictly inside or on the boundary of the hexagon defined by the vertex arrays.
3. From the filtered (valid) points, randomly select exactly *N* points using Rand perm to avoid selection bias.

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The resulting (x, y) coordinates were plotted together with the hexagon outline to visually verify uniform distribution within the cell. Axis scaling was set to square, and grid lines (major and minor) were enabled for clarity.

2.2 Throughput Analysis of Pure ALOHA and Slotted ALOHA

The second part of the study focuses on the classic random-access protocols: Pure (unslotted) ALOHA and Slotted ALOHA. Both analytical derivations and basic simulation approaches were implemented.

2.3 Analytical Throughput Models

Throughput S is defined as the expected number of successful transmissions per packet transmission time.

For **Pure ALOHA**, the vulnerability period is two packet durations. The throughput is given by: $S = G \times e^{-2G}$ where G is the offered traffic load (average number of transmission attempts per packet time).

For **Slotted ALOHA**, time is divided into synchronized slots equal to one packet duration. The vulnerability period is reduced to one slot, yielding: $S = G \times e^{-G}$

The maximum throughput for each protocol was analytically determined by finding the load G that maximizes S:

Slotted ALOHA: maximum $S \approx 0.368$ (36.8%) at $G = 1$

Pure ALOHA: maximum $S \approx 0.184$ (18.4%) at $G = 0.5$

Throughput curves were generated by evaluating S over a range of traffic loads $G = 0$ to 7 with increments of 0.25.

2.4 Simplified Slotted ALOHA Simulation with Retransmissions

A basic discrete-event style simulation was implemented to illustrate the effect of limited retransmissions on access performance:

Total number of users' equipment (UEs): $n = 250$

Initial available preamble resources: $N = 95$ (conceptually analogous to LTE-like preamble pool)

Maximum retransmission attempts: 8 (indexed 0 to 7)

For each retransmission round $r = 1$ to 8:

Each UE attempts transmission with probability $p = 1$ (simplified aggressive model)

Poisson-like arrival behavior was approximated using poisoned

Successful access occurs if preamble resources remain ($N > 0$); otherwise, the attempt is rejected

Counters track total requests, successes, and rejections

Although this simulation does not implement a full backoff mechanism or realistic collision probability scaling, it provides insight into access success rate under resource limitation and repeated attempts. Throughput was estimated as: Throughput (%) = (successful accesses / total access attempts) × 100

All plots were generated using MATLAB's plotting functions (plot, hold on, title, xlabel, ylabel, legend, grid) with consistent formatting, labels, and figure captions. This methodology combines geometric modeling, rejection sampling, analytical derivation, and simplified event-based simulation to provide both visual and quantitative insights into cellular user distribution and random-access protocol performance.

RESULTS AND DISCUSSION

This section presents the key outcomes from the MATLAB simulations and analytical models, followed by a discussion of their implications for cellular network design and random-access protocols.

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3.1 Hexagonal Cell User Distribution

The hexagonal cell modeling successfully generated uniform random distributions of user equipment (UE) within geometrically accurate hexagons. For Scenario A (radius R = 15 km, N = 50 users), the plotted points clearly lie inside the hexagon boundary with no clustering artifacts, as verified visually through the in-polygon filtering and random subsampling process Fig. 2. Similarly, Scenario B (R = 30 km, N = 100 users) produced a denser but still uniformly distributed set of points Fig. 3.

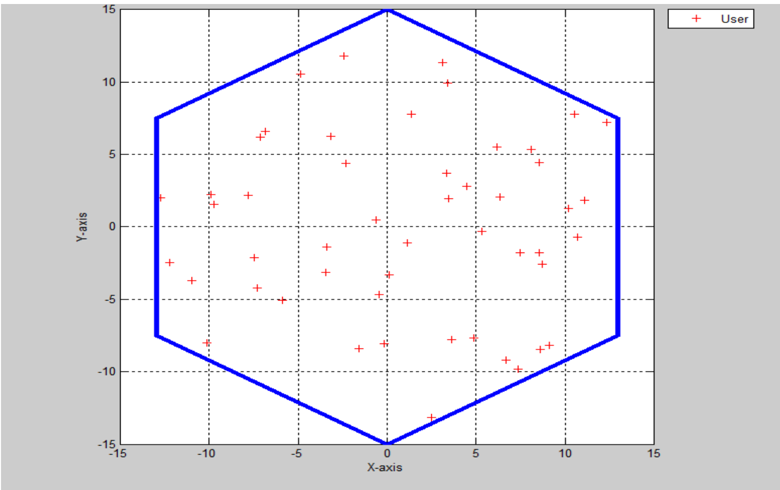

Fig. 2 Hexagonal Cell with 50 Users

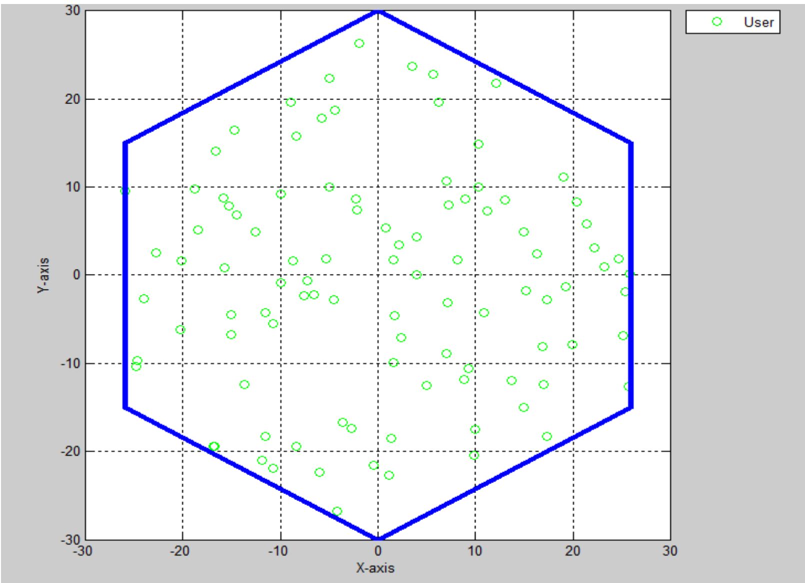

Fig. 3 Hexagonal Cell with 100 Users

The area of each hexagon is calculated as $A = (3\sqrt{3} / 2) R^2$, yielding approximately 584.8 km² for R = 15 km and 2,339.3 km² for R = 30 km. These simulations confirm that rejection sampling effectively approximates uniform spatial distribution, a critical prerequisite for realistic Monte-Carlo evaluations of coverage, interference, and capacity in hexagonal-based cellular planning. Such visualizations are directly applicable to system-level simulations in tools like MATLAB or NS-3 for assessing downlink signal-to-interference-plus-noise ratio (SINR) distributions or uplink resource allocation in dense deployments.

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3.2 Slotted ALOHA Simulation with Retransmissions

The simplified discrete-event simulation of Slotted ALOHA with up to 7 retransmissions (0–7 attempts) was implemented for 250 UEs and an initial preamble pool of 95 resources, as shown in Fig. 4. The code tracked successful accesses, rejections, and total requests across retransmission rounds. Although the implementation used a simplified aggressive transmission model (p = 1) without exponential backoff, it illustrated the impact of resource limitation and repeated attempts on access success. The estimated throughput, computed as (successful accesses / total attempts) × 100%, varied across retransmission rounds but remained below classical theoretical maxima due to the finite preamble constraint and lack of collision resolution mechanisms (e.g., no successive interference cancellation). This result aligns with expectations for contention-based access under heavy load: repeated attempts increase the chance of eventual success but also amplify collision probability when resources are exhausted. Recent studies on slotted ALOHA variants with finite retransmission limits in fading channels confirm that throughput degrades significantly beyond a certain number of retries due to persistent collisions and resource blocking.

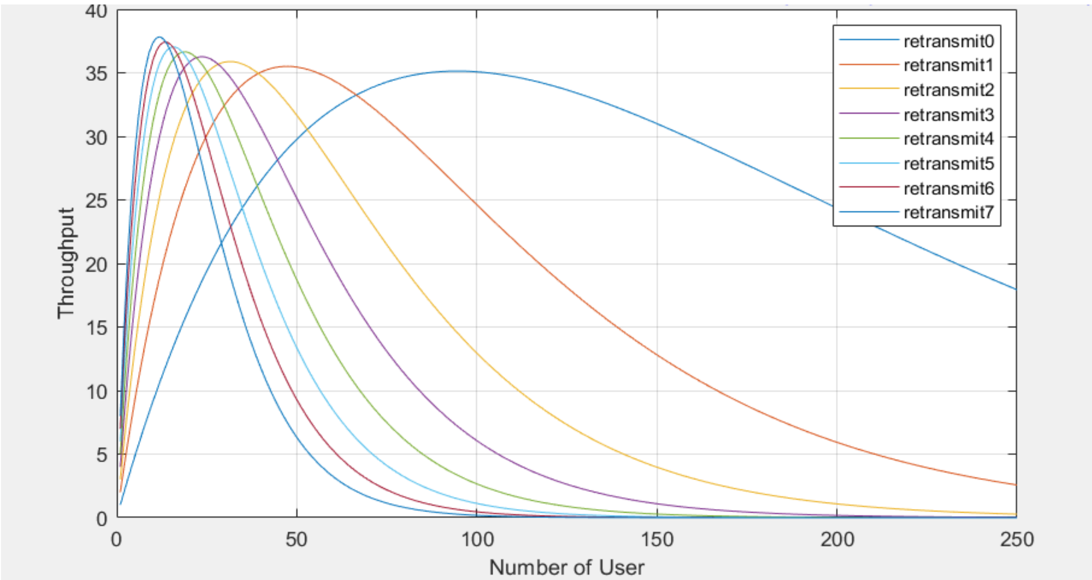

Fig. 4 Throughput Graph for 0-7 Re-transmission with maximum throughput of 37%

3.3 Analytical Throughput of Pure and Slotted ALOHA

The analytical throughput curves provide the most robust and interpretable results. For **Slotted ALOHA**, the throughput is given by:

S = G × e^{-G}

Numerical evaluation over G = 0 to 7 (step 0.25) yields a maximum of approximately 0.368 (36.8%) at G = 1 (Figure 4).

For **Pure ALOHA**, the equation is:

S = G × e^{-2G}

with a maximum of approximately 0.184 (18.4%) at G = 0.5 (Figure 5).

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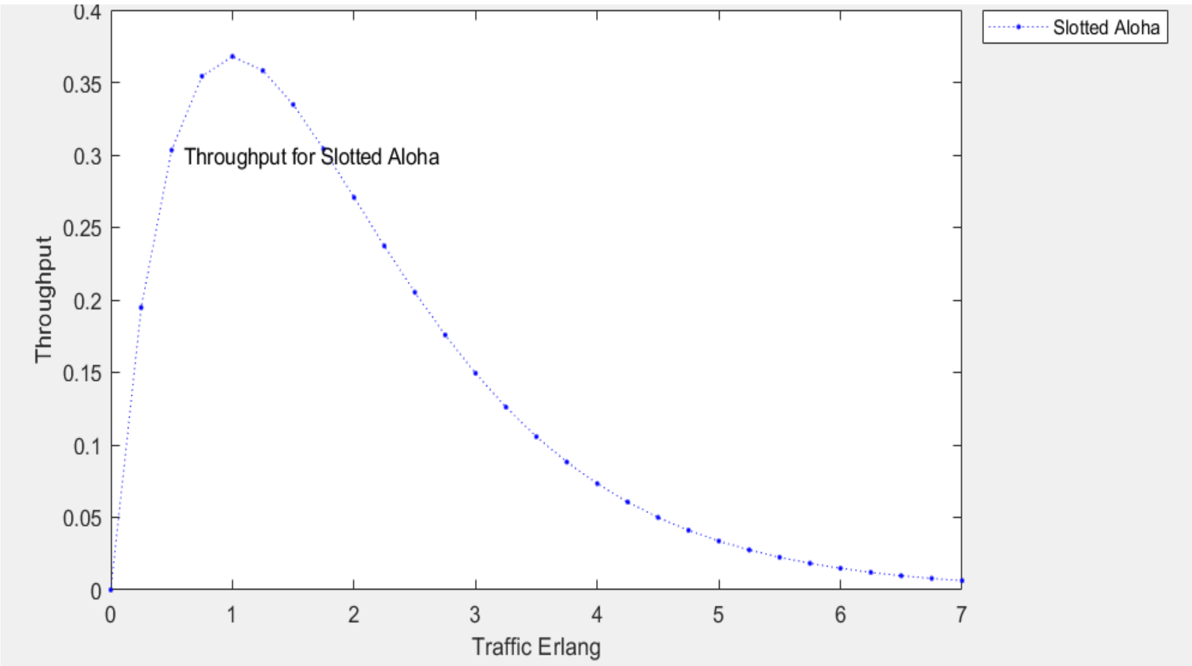

Fig. 5 Slotted Aloha Throughput Graph for a single transmission

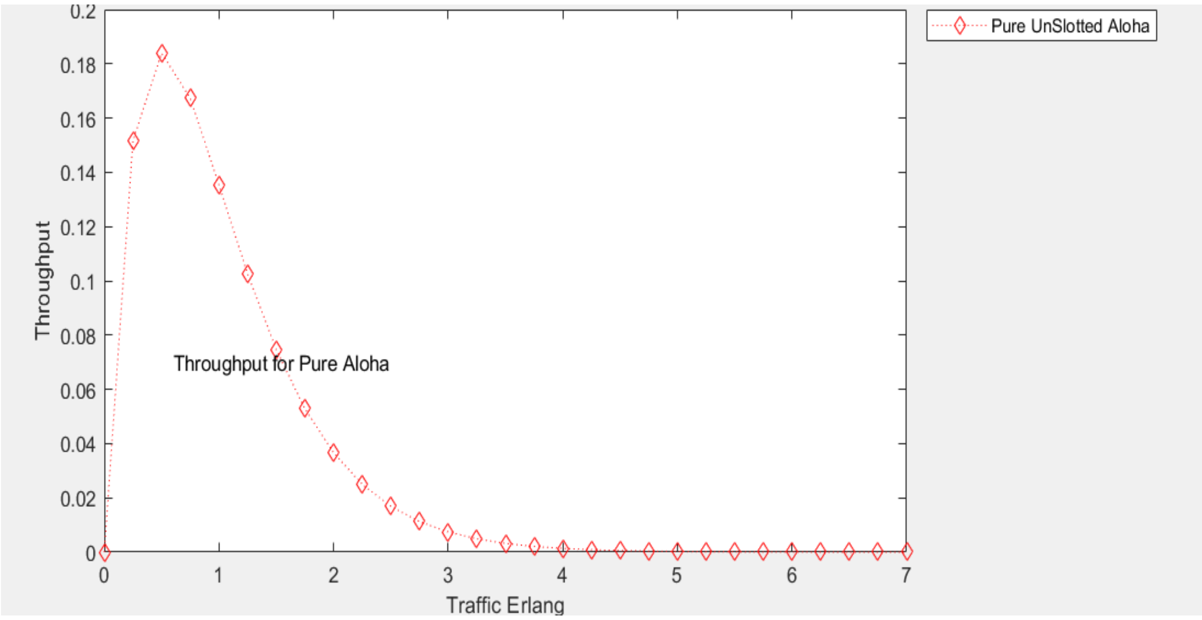

Fig. 6 Pure Aloha Throughput Graph for a single transmission

Fig. 7 clearly demonstrated that Slotted ALOHA achieves nearly twice the peak throughput of Pure ALOHA. This improvement arises directly from synchronization: the vulnerable period is reduced from 2T (Pure) to T (Slotted), halving the collision probability at equivalent loads and shifting the optimal operating point from G = 0.5 to G = 1. At the maximum points, the collision probability in Slotted ALOHA is approximately 26% (1 − 2e^{-1} ≈ 0.264). These theoretical maxima (≈37% for Slotted and ≈18% for Pure) match classical results and the plotted curves, validating both the MATLAB implementation and the underlying Poisson arrival assumption.

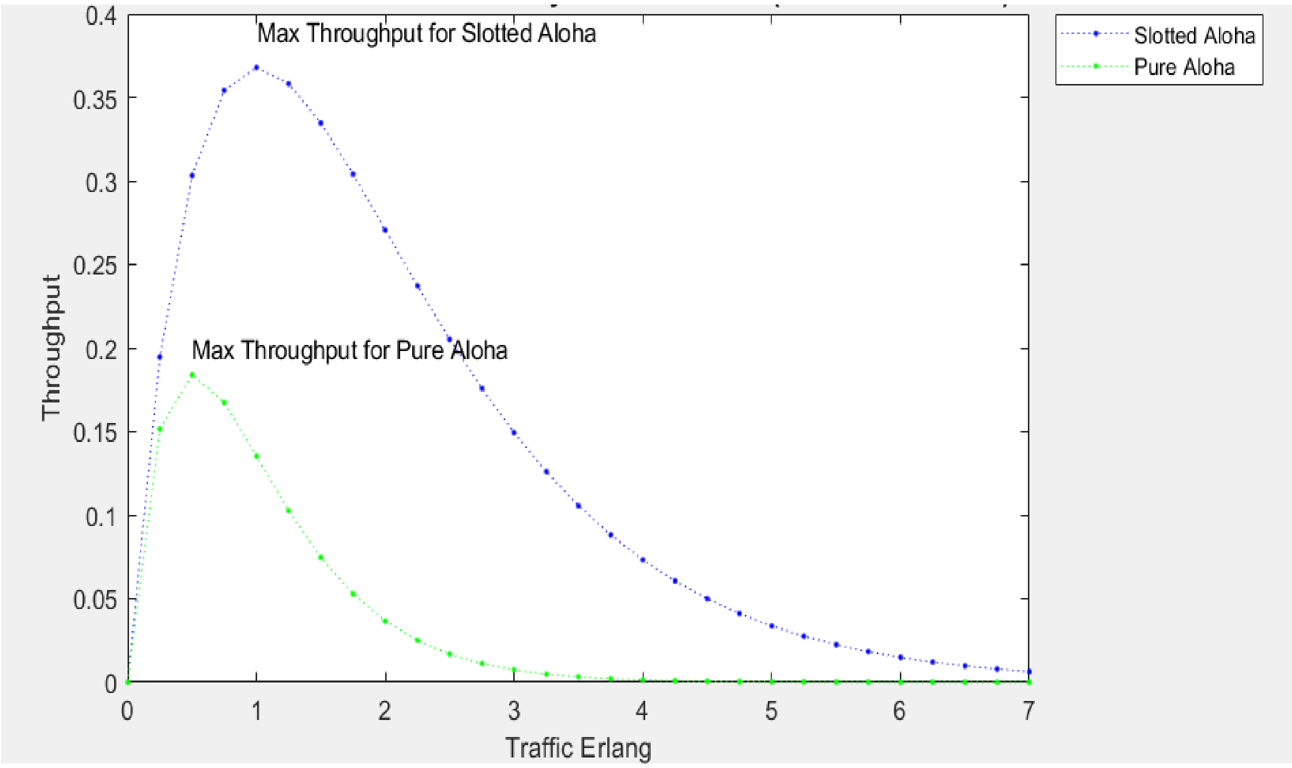

Fig. 7 Slotted and Pure Aloha Throughput Graph for a single transmission

3.4 Comparison with the Advance Rach-Techniques

This section provides a comparison between the proposed techniques and the Advanced Random-Access Technique. This segment compares the characteristics of Pure ALOHA and Slotted ALOHA with advanced schemes, including Irregular Repetition Slotted ALOHA (IRSA), Coded Slotted ALOHA (CSA), and grant-free NOMA-based access. The discussion highlights differences in throughput performance, synchronization requirements, receiver complexity, interference management, and applicability to LTE, 5G, and future 6G massive machine-type communication scenarios. A comparative table has also been included to provide a clearer assessment of the strengths and limitations of each technique. Table-1 provides a comprehensive comparative analysis between the proposed work and the existing random-access techniques. While Pure ALOHA and Slotted ALOHA remain fundamental benchmarks for studying contention-based channel access, modern wireless systems employ more sophisticated random-access mechanisms to overcome the throughput limitations imposed by packet collisions. In particular, Irregular Repetition Slotted ALOHA (IRSA), Coded Slotted ALOHA (CSA), and grant-free Non-Orthogonal Multiple Access (GF-NOMA) have been proposed to support the massive connectivity requirements of IoT, LTE-A, 5G NR, and future 6G networks (Paolini *et al.*, 2015; Idris, 2024; Maryopi *et al.*, 2024).

IRSA extends Slotted ALOHA by allowing users to transmit multiple replicas of the same packet in randomly selected slots according to a predefined repetition distribution. At the receiver, Successive Interference Cancellation (SIC) is applied to recover collided packets iteratively. This approach significantly improves throughput and can achieve values close to 0.8–0.97 packets per slot under favorable loading conditions (Dick Maryopi *et al.*, 2024; Idris, 2024; Maryopi *et al.*, 2024). CSA further enhances IRSA by replacing simple packet repetition with erasure-correcting coding across multiple transmission slots. The coded packet structure provides additional diversity and enables more effective SIC operations, allowing throughput values approaching or even exceeding 0.9 packets per slot in optimized configurations (Paolini *et al.*, 2015; Idris, 2024).

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Grant-free NOMA-based random access departs from traditional orthogonal channel allocation by allowing multiple users to share the same time-frequency resources simultaneously. User separation is achieved through power-domain multiplexing and SIC at the receiver. Such schemes are particularly attractive for massive machine-type communications (mMTC) because they reduce signaling overhead and access latency while supporting a large number of simultaneous users (Idris, 2024; Dick Maryopi *et al.,* 2024). Although these advanced techniques provide substantially higher throughput than conventional ALOHA protocols, they require increased receiver complexity, accurate channel estimation, SIC processing, and tighter synchronization. Consequently, Pure ALOHA and Slotted ALOHA remain useful baseline models for understanding collision behavior and evaluating the performance gains offered by more advanced random-access solutions. The maximum throughput obtained in this study for Slotted ALOHA (36.8%) represents a useful baseline for evaluating advanced random-access schemes. Compared with Slotted ALOHA, IRSA can more than double the achievable throughput through packet diversity and iterative SIC. CSA provides additional gains through coding across slots, while grant-free NOMA exploits non-orthogonal resource sharing to support significantly higher user densities. However, these improvements come at the cost of increased computational complexity, receiver processing requirements, channel estimation overhead, and synchronization constraints. Therefore, the simplicity of Pure and Slotted ALOHA remains valuable for low-complexity systems and for benchmarking next-generation random-access protocols.

Table-1 Comparative analysis with Advanced Random-Access Techniques

Technique	Synchronization Requirement	Collision Handling	Typical Maximum Throughput	Receiver Complexity	Main Application Areas
Pure ALOHA	None	Packet discarded and retransmitted	≈ 0.184	Very Low	Early packet radio systems, educational studies
Slotted ALOHA	Slot synchronization required	Reduced collision window	≈ 0.368	Low	Satellite systems, LTE/5G RACH foundations
IRSA	Slot synchronization required	Packet repetition + SIC	≈ 0.8–0.97	Moderate	Massive IoT, mMTC, satellite IoT
CSA	Slot synchronization required	Coding + SIC	≈ 0.9–1.0	High	High-density IoT and future wireless systems
Grant-Free NOMA	Tight synchronization and power control	Multi-user detection + SIC	>1 packet/slot equivalent throughput	Very High	5G/6G mMTC, ultra-dense access networks

CONTRIBUTION TO KNOWLEDGE

The Key Contributions of this work are as follows:

i. **Development of a MATLAB framework** that combines hexagonal cellular modeling, random UE deployment, and ALOHA protocol analysis.
ii. **Realistic user distribution modeling** within cellular boundaries using geometric constraints and the in-polygon technique.
iii. **Comparative analytical and simulation-based evaluation** of Pure ALOHA and Slotted ALOHA, including retransmission behavior.
iv. **Validation of throughput improvements** achieved by Slotted ALOHA, demonstrating nearly double the maximum throughput of Pure ALOHA.

v. **Provision of a practical platform** for studying random-access mechanisms applicable to LTE, IoT, and future 5G/6G wireless networks.

CONCLUSION

The results obtained in this study highlight the fundamental advantage of time-slot synchronization in random-access communication systems. By restricting transmissions to predefined time slots, Slotted ALOHA significantly reduces the collision vulnerability period and achieves substantially higher throughput than Pure ALOHA. Although slot synchronization introduces additional system complexity, such synchronization can be readily provided through base station control signaling in cellular networks, making Slotted ALOHA a more efficient choice for practical wireless communication systems. The relevance of these classical protocols extends beyond theoretical analysis. Modern cellular standards, including 5G New Radio (NR), employ slotted random-access mechanisms within the Random-Access Channel (RACH), where preamble collisions and retransmission procedures directly influence access delay, reliability, and network capacity. Furthermore, advanced random-access schemes such as Irregular Repetition Slotted ALOHA (IRSA), Coded Slotted ALOHA (CSA), and grant-free Non-Orthogonal Multiple Access (GF-NOMA) build upon the principles of Slotted ALOHA to further improve access efficiency. Through packet repetition, coding diversity, and successive interference cancellation (SIC), IRSA and CSA can achieve throughput values approaching 0.8–1.0 packets per slot under favorable conditions, while GF-NOMA enables multiple users to share the same resources simultaneously, supporting even higher access capacities. However, these gains are achieved at the expense of increased receiver complexity, more stringent synchronization requirements, channel estimation overhead, and sophisticated interference management techniques.

This work presented a MATLAB-based framework for modeling random user equipment (UE) distribution within hexagonal cellular cells and evaluating the throughput performance of Pure ALOHA and Slotted ALOHA protocols. Hexagonal cellular geometries with radii of 15 km and 30 km were successfully generated, while uniform random distributions of 50 and 100 UEs were obtained using geometric vertex definitions and the in-polygon algorithm. The resulting framework provides a practical platform for studying cellular coverage, user deployment, and random-access behavior.
Analytical and simulation results demonstrated that Slotted ALOHA achieves a maximum throughput of approximately 36.8% at an offered load of $G = 1$, whereas Pure ALOHA reaches only about 18.4% at $G = 0.5$. The retransmission analysis further illustrated the impact of finite retry limits on system performance, revealing the trade-off between limiting access delay and maintaining fairness under heavy network loads. While these throughput levels are lower than those reported for advanced schemes such as IRSA, CSA, and GF-NOMA, the simplicity, low implementation complexity, and analytical tractability of Pure and Slotted ALOHA make them valuable benchmark protocols for evaluating the performance gains of more sophisticated random-access solutions.

Overall, the study confirms the theoretical superiority of Slotted ALOHA over Pure ALOHA and demonstrates the effectiveness of MATLAB for visualizing cellular network topologies and evaluating random-access protocols. The proposed framework serves as a useful baseline for investigating advanced RACH mechanisms in LTE, 5G, and emerging 6G networks. Future research may extend the model to multi-cell environments, realistic propagation channels, user mobility, capture effects, and interference-cancellation techniques, while incorporating modern access schemes such as IRSA, CSA, and GF-NOMA to provide a more comprehensive assessment of next-generation massive connectivity solutions. In conclusion, the analytical and simulation results verify that Slotted ALOHA nearly doubles the maximum achievable throughput of Pure ALOHA, achieving approximately 37% compared with 18%. Although advanced random-access techniques can significantly exceed these throughput levels through coding, diversity transmission, and interference cancellation, the results presented in this work establish an important benchmark for understanding contention-based channel access. These findings reinforce the importance of synchronization in random-access systems and provide a valuable reference for the design, evaluation, and optimization of future LTE, 5G, and 6G

RACH mechanisms supporting massive machine-type communications and Internet of Things applications.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

REFERENCES

Abramson, N. (1970). The ALOHA system—Another alternative for computer communications. In Proceedings of the AFIPS Fall Joint Computer Conference (pp. 281–285).

Abramson, N. (1985). Development of the ALOHANET. IEEE Transactions on Information Theory, 31(2), 119–133.

Abid, M., Khan, A., Ma, H., & Aamir, S. M. (2021). Optimizing the performance of pure ALOHA for LoRa-based ESL.

Bommisetty, L., et al. (2023). Performance analysis of connection establishment procedure under beamforming in 5G NR networks. IEEE Transactions on Mobile Computing, 22(11), 1–14.

Daraseliya, A., et al. (2025). Resource allocation in 5G cellular IoT systems with early transmissions at the random-access phase. Sensors, 25(7), 2264.

Idris, I. S. (2024). A comprehensive survey on congestion control mechanisms for 4G LTE random access channels (RACH). International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 10(2), 1245–1253. https://doi.org/10.32628/CSEIT25113400

Maryopi, D., Al Adumy, D., Musa, O., Jung, P., & Virgono, A. (2024). Performance of slotted ALOHA in user-centric cell-free massive MIMO (No. 447).

Maryopi, D., et al. (2024). Performance of slotted ALOHA in user-centric cell-free massive MIMO. arXiv. https://arxiv.org/abs/2405.17979

Munari, A. (2021). Modern random access: An age of information perspective on irregular repetition slotted ALOHA. IEEE Transactions on Communications, 69(6), 10495–10508.

Munari, A., et al. (2021). Irregular repetition slotted ALOHA over the Rayleigh block fading MAC: Throughput performance and energy efficiency. IEEE Transactions on Wireless Communications, 20(3), 2025–2039.

Nebro, A. J., Galeano-Brajones, J., Luna, F., & Coello Coello, C. A. (2022). Is NSGA-II ready for large-scale multi-objective optimization? Mathematics and Computers in Simulation Applications, 27, 103. https://doi.org/10.3390/mca27060103

Paolini, E., Liva, G., & Chiani, M. (2015). Coded slotted ALOHA: A graph-based method for uncoordinated multiple access. IEEE Transactions on Information Theory, 61(12), 6815–6831.

Polonelli, T., Brunelli, D., Marzocchi, A., & Benini, L. (2019). Slotted ALOHA on LoRaWAN—Design, analysis, and deployment. Sensors, 19(4), 838. https://doi.org/10.3390/s19040838

Raeisi, M., et al. (2024). Power control of 5G-connected vehicular network using PPO-based deep reinforcement learning algorithm. IEEE Access. https://doi.org/10.1109/ACCESS.2024.3427124

Rappaport, T. S. (2002). Wireless communications: Principles and practice (2nd ed.). Prentice Hall.