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Hybrid ARQ techniques for Reliable 5G Communication

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***Abstract*— Hybrid Automatic Repeat Request (HARQ) is a dynamic technique that corrects errors and improves the reliability in transmitting the data. 5G communication systems uses HARQ for achieving Ultra Reliable Communication. By combining Error Correction (FEC) techniques with ARQ, reliability and latency can be improved. This can be achieved by retransmitting erroneous data packets while leveraging redundancy and coding gain from FEC. This paper explores the implementation of HARQ for 5G networks to mitigate errors caused by channel impairments and achieve robust communication. The study examines three primary HARQ techniques: Type I, Type II and Type III. The simulation evaluates different HARQ schemes performance under varying frame size and analyses variations in Bit Error Rate (BER) and throughput, under AWGN channel. Simulation results prove better performance when type III HARQ scheme is used.**

***Index Terms*— Hybrid ARQ (HARQ), FEC, ultra-reliable communication (URC), ultra-low latency, 5G Mobile.**

I. INTRODUCTION

In 5G networks, communication is critical for supporting high-speed, ultra-reliable data transmission. The 5G wireless communication systems are designed to support a wide range of applications, from enhanced mobile broadband (eMBB) to ultra-reliable and low-latency communication (URLLC) and massive machine-type communication (mMTC). [1] These varied use cases require consistent standards for reliability, efficiency, and low latency to guarantee seamless connectivity and strong performance. In the presence of channel impairments, it is difficult to achieve high standards. HARQ was developed as a error correction technique to deal with challenges introduced due to interference and fading in the channel along with various types of noise There are different types of HARQ based on the way how error correction is done along with ARQ [11]. Type I HARQ is one of the early implementations, where Cyclic Redundancy Check (CRC) is used for error detection and the entire data frame will be retransmitted when errors are detected. This method is inefficient as far as bandwidth and latency are considered because it requires retransmission of the full frame, even if only a small portion of the data is corrupted. Type II technique introduces incremental redundancy (IR), where only additional parity bits or coding redundancy is re transmitted instead of the entire frame. This method considerably reduces retransmission overhead, and improves efficiency by increasing throughput and reliability. The developments in error control coding have made HARQ an important technology in achieving more efficiency in modern wireless communication systems. Third Type HARQ is a more advanced method which allows packets to be decoded independently at each retransmission, bringing robustness in time-varying channels.

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In recent papers, authors divide HARQ into two types- Chase Combining and Incremental Redundancy HARQ [2,3]. Type II and III fall under these categories.
HARQ techniques are especially suited for high-reliability applications, which requires robust performance under challenging channel conditions. This work simulates all three types of HARQ systems in MATLAB and compare them for their performance.

II. LITERATURE SURVEY

Hybrid Automatic Repeat Request (HARQ) protocols have significant importance due to their ability to improve communication efficiency, mainly in resource-limited and delay-sensitive networks. Different types of HARQ are used by different researchers as found in their papers.
A comparative table is made to show the variation seen in the research direction by different authors in last 5 years from IEEE explorer.

TABLE I: COMPARISON OF WORK DONE IN LAST 5 YEARS ON HARQ

Reference No.	Title (Abbreviated)	Objective / Focus Area	Methodology / Approach	Use Case / Domain	Key Findings / Contributions
1	Performance Analysis of HARQ in 5G NR	Evaluate HARQ throughput & delay in NR	Analytical + Simulations	General 5G NR	Identified trade-offs in reliability vs latency
2	Optimized HARQ for URLLC	Improve HARQ for low-latency apps	Algorithm design + simulation	URLLC	Enhanced reliability with reduced retransmissions
3	ML-Based HARQ Adaptation	Adaptive HARQ using ML	Machine Learning + Training	General 5G	ML-based adaptation improves spectral efficiency
4	Energy-Efficient HARQ in Massive MIMO	Reduce energy consumption	Power control + HARQ tuning	Massive MIMO	Saved 20% energy while maintaining QoS
5	Adaptive HARQ for mm Wave	HARQ under mm Wave mobility	Channel model + Simulation	mm Wave Mobile	Adaptive HARQ improved handover success rate
6	HARQ for NR-V2X	Design HARQ for vehicular systems	Realistic mobility models	V2X (Vehicle)	Reduced packet loss in fast-changing environments
7	Cross-Layer HARQ for IoT	Efficient HARQ for resource-constrained IoT	MAC-PHY cross-layer design	IoT in 5G	Reduced delay and power consumption by 30%
8	HARQ in Integrated NTN	HARQ in hybrid terrestrial + satellite	Simulation with mixed links	NTN (Non-Terrestrial)	Maintained low error rate despite long RTT
9	HARQ with DRL	Dynamic adaptation of HARQ	Deep Reinforcement Learning	General 5G	DRL-based HARQ increased throughput by 18%
10	HARQ for 5G Industrial Networks	Improve HARQ for industrial automation	Channel-aware retransmission logic	Industry 4.0	Improved packet reliability under EMI noise

The above studies show the advanced evolution of HARQ protocols from Type I to more advanced versions, such as Type III, and their integration with machine learning and adaptive frameworks, to improve reliability, latency, and efficiency across IoT to 5G systems.
Future research should continue to explore the synergies between HARQ and emerging technologies, such as AI-driven optimization and cross-layer techniques, to meet the ever-growing demands of modern communication networks.
This paper implements and compares Type I, II, III HARQ systems with respect to different parameters of 5G network. The novelty of this work lies in combining theoretical HARQ models with simulation-driven insights, tuned specifically for 5G's ultra-reliable, low-latency demands, and showcasing how Type III HARQ offers a practical path forward with software-driven adaptability.
This paper quantitatively compares 3 HARQ techniques considering parameters like BER (Bit Error Rate), throughput, latency, retransmission count, and efficiency.
Scaling frame size from N = 100 to N = 1000, helps us to understand how each HARQ type behaves under realistic high-load 5G conditions. This shows the robustness and resource trade-offs of each type in large-scale deployments which is critical in 5G.

III. HARQ AND TYPES

Fig (1) Shows the general block diagram of HARQ. The input represents the data or signal that needs to be transmitted, such as video or multimedia data. The transmitter section handles the encoding of this data. Channel coding adds error-detection and correction bits to the encoded data, ensuring its integrity during transmission through noisy channels. The channel is the medium through which the data is transmitted from the transmitter to the receiver. On the receiver side, channel decoding extracts the original data by channel decoding, correcting any errors that were introduced during transmission.

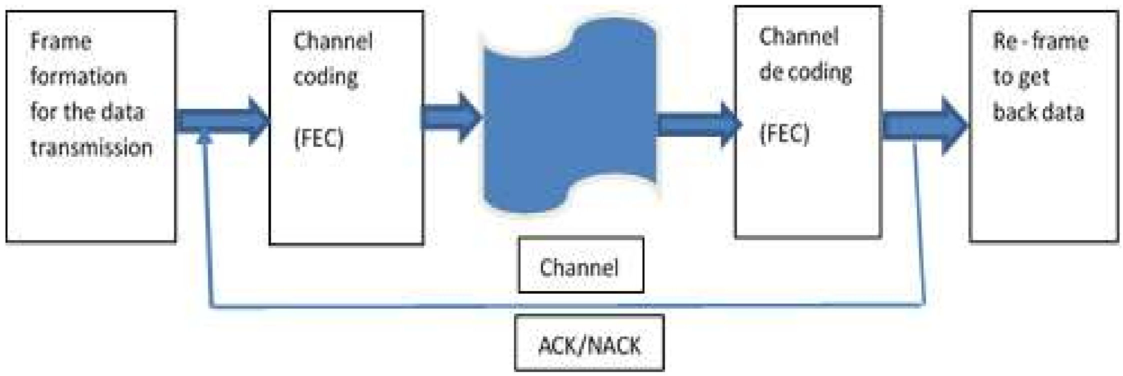


Fig 1. General Block Diagram of HARQ

In feedback mechanism, ACK (Acknowledgment) and NACK (Negative Acknowledgment) messages are used to provide information to the transmitter, to identify that the transmitted data is received at the receive properly or not. They indicate whether the data reception was successful (ACK) or if retransmission is needed (NACK). The feed-forward link carries the actual message from the source end to the receiving end, and the feedback link allows the receiver to send status information, such as ACK/NACK or buffer status, back to the transmitter. The channel must be monitored properly along with the buffer status for ideal performance. Channel monitoring means observing the amount of noise or signal-to-noise ratio (SNR), in the channel so that adjustments to transmission parameters can be done to achieve better reliability. When the receiver does not have enough data due to delays or packet loss, buffer starvation occurs, which can severely impact playback quality, mainly in real-time applications like video streaming.

IV. METHODOLOGY

The implementation of a Hybrid ARQ system in MATLAB is tried in this work which involves understanding of HARQ algorithms and error control mechanisms which are used in different types. The whole communication system should be simulated with source encoder/decoder, Modulator /demodulator, FEC encoding/decoding techniques with feedback mechanism to achieve ARQ. Finaly performance evaluation must be done for 3 methods of HARQ in communication systems for comparison. The principal objective of the simulation is to assess their performance considering evaluation parameters like Bit Error Rate (BER), latency, throughput, and efficiency, while simulating real-world conditions with varying channel characteristics, noise levels, and retransmission mechanisms.

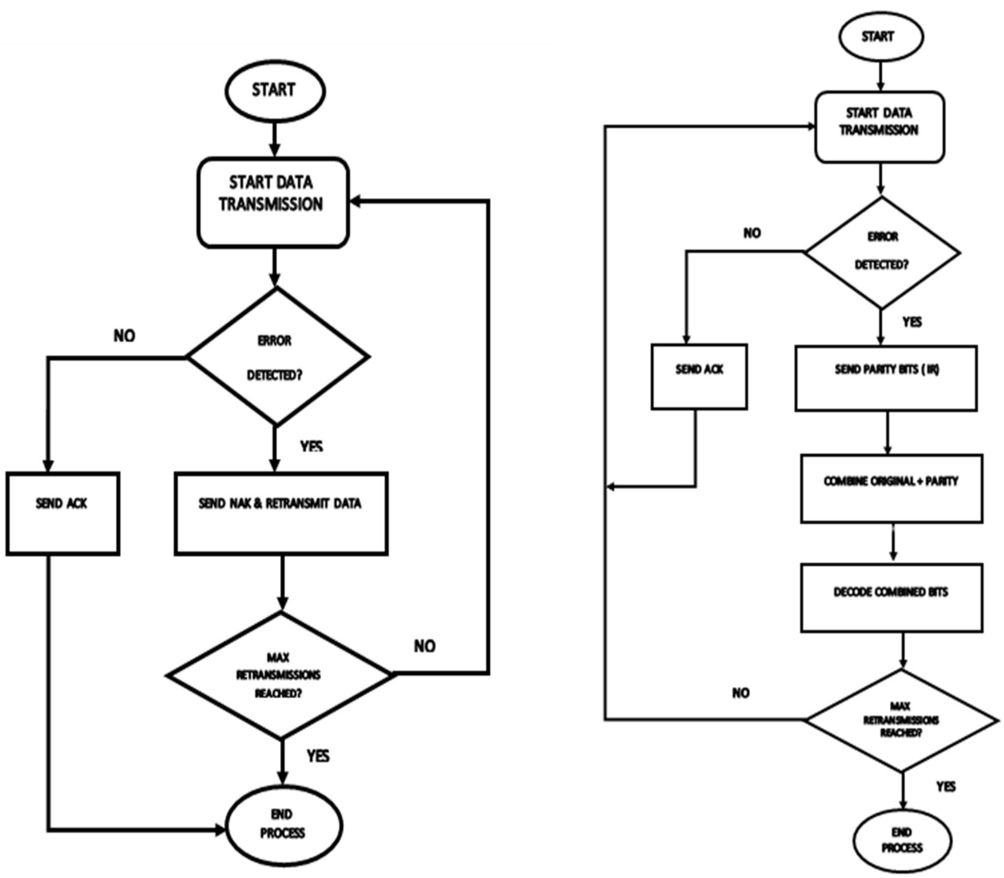
In HARQ Type I, FEC and CRC are combined for detecting error, Selective Repeat ARQ is used for efficient retransmissions. The transmitter transmits the original information encoded with CRC encoder, which adds a checksum to the data to assist error detection at the receiver. The encoded data is segmented into smaller units by a packetizer, enabling the retransmission of only corrupted packets when errors occur. These packets are then modulated using an appropriate modulation scheme and transmitted over the channel, where noise, interference, and fading may degrade the signal quality. At the receiver side, the signal is demodulated to extract the binary data. The data is subsequently processed by a CRC checker, which ensures data integrity by comparing the received checksum with the recalculated checksum. If the CRC check fails, the receiver generates a NACK for the affected packet, prompting its retransmission. The Selective Repeat ARQ mechanism ensures that only the erroneous packets are retransmitted, which helps optimize bandwidth by preventing the retransmission of correctly received packets. Correctly received packets are forwarded to the data output to reconstruct the original message. This process carries on until all packets are successfully received or the retransmission limit is reached.

HARQ Type I provides a robust and efficient communication method, ensuring reliable data transmission in wireless environments like 5G while minimizing bandwidth usage and latency.

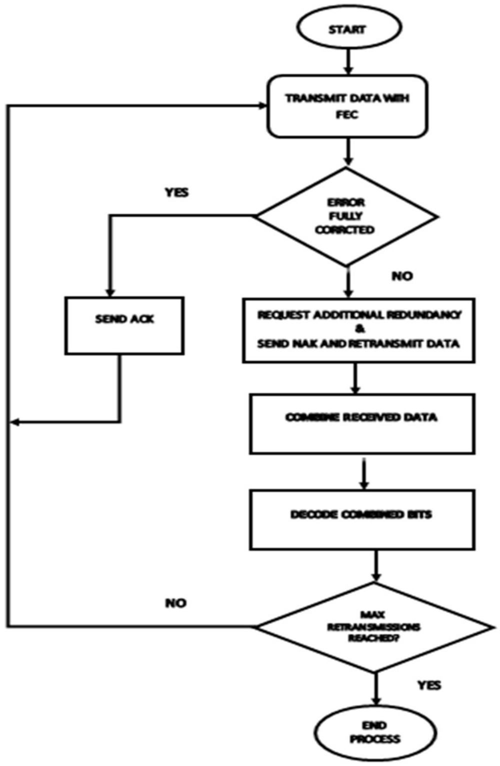
HARQ Type II is an advanced hybrid communication technique that enhances reliable data transmission by integrating error detection, FEC, and optimized retransmission strategies to minimize redundancy and improve efficiency. The transmitter side, the process starts with the source data, representing the original information to be transmitted. A CRC encoder adds a checksum to the data, enabling the receiver to detect any errors that may occur during transmission. The data, along with the appended CRC, is then processed by a convolutional encoder, which applies redundancy using convolutional codes, a reliable error correction scheme. This encoding ensures that the receiver can detect and correct errors within its capacity. The encoded data is subsequently segmented into smaller units by a packetizer, facilitating selective retransmission of only the erroneous packets when needed.

The convolutional decoder processes the received data to correct errors, employing algorithms such as the Viterbi algorithm for efficient error correction. Once corrected, the data is validated by the CRC checker, which compares the received CRC with the recalculated CRC to ensure data integrity. Incremental Redundancy (IR) is used to enhance error correction.

Rather than retransmitting the same packet, the transmitter sends additional parity bits in retransmissions to complement the original transmission. Initially, the transmission includes only a subset of the error-correcting code bits, known as systematic bits. If a retransmission is required (indicated by a NACK), the transmitter sends additional redundancy bits (parity) that supplement the initial transmission. The receiver then combines all received transmissions to decode the message. This approach improves bandwidth efficiency, as only the necessary redundancy is transmitted, and provides better performance in noisy channels compared to Type I. However, it requires more complex receiver algorithms, such as soft combining, and higher processing and memory requirements for storing partial transmissions.



(a) (b)



(c)

Fig 2. Type (a), (b), (c) HARQ flow charts

In Type III, the transmitter sends coded packets containing both data and redundancy. The receiver uses error detection mechanisms, such as CRC, to verify the correctness of the received packet. If no errors are detected, an acknowledgment is sent to the transmitter. However, if errors are detected, a negative acknowledgment prompts the transmitter to send additional redundancy or parity bits instead of retransmitting the original packet. This incremental approach enhances efficiency by reducing the amount of retransmitted data. The receiver combines the original and retransmitted signals using advanced soft-combining techniques and decoding algorithms to reconstruct the data. This cumulative approach continues until the data is correctly reconstructed or the maximum retransmission limit is reached. By leveraging redundancy and soft-combining, Type III HARQ achieves significantly reduced retransmission overhead and improved error correction performance. This makes it an optimal choice for modern high-speed and reliable communication systems.

Type III HARQ offers the best overall performance among HARQ types. By transmitting independently decodable packets, it achieves the lowest latency and highest throughput while maintaining robustness under poor channel conditions. This makes Type III HARQ ideal for applications requiring ultra-reliable low-latency communication, such as 5G networks, autonomous vehicles, and industrial IoT systems. Its advanced error-correction mechanisms and efficient retransmission strategy make it indispensable in modern communication systems.

V. MATLAB VISUALIZATION

The results of the Hybrid ARQ (HARQ) implementation can be summarized by analyzing key performance metrics and comparing under varying channel conditions. The performance is evaluated using BER, throughput, retransmission count, and latency.

Bit Error Rate : This metric indicates the ratio of incorrectly received bits to the total number of transmitted bits. Observations from the simulations show that HARQ Type II and III typically achieve lower BER compared to Type I, due to their use of incremental redundancy and soft combining features. These mechanisms allow Type II and III to better correct errors, especially under challenging channel conditions.

Throughput: Throughput measures the effective data rate after accounting for retransmissions. HARQ Type I tends to have lower throughput since it requires entire frames to be retransmitted upon errors. In contrast, Type II and III improve throughput by retransmitting only parity bits (Type II) or using independently decodable packets (Type III), thus reducing the retransmission overhead.
Retransmission Count: This metric tracks the number of retransmissions needed to successfully decode a frame. HARQ Type III generally requires fewer retransmissions because it uses independently decodable packets, enabling the system to recover from errors more efficiently
Latency: Latency represents the time delay caused by retransmissions. Type I HARQ experiences higher latency because it retransmits entire frames, leading to more delays. On the other hand, Type III has the lowest latency, as it minimizes the number of retransmissions by using independently decodable packets
MATLAB simulation tool is used to simulate all 3 types of HARQ in the communication system. Simple text message is considered for transmission, encoded into ASCII values. QAM is the common modulation technique used in all three cases. Frame size is varied from 50 to 1000 to verify the consistency of the systems. Random error insertion with a predefined probability is done to simulate AWGN channel. Retransmission is varied based on required BER, and selective repeat request scheme is used in all 3 cases. CRC is used as basic error detecting technique in all 3 types. Convolutional code is used for error correction in type II and Type III. Basic retransmission is used in Type I while Incremental Redundancy (IR) is used in Type II and Chase Combining (CC) is used in Type III HARQ. Quantitative Comparison of HARQ Types for BER, throughput in bits/sec, retransmission times, latency, and efficiency for frame size N = 100 and N = 1000 is shown in the tables 2 and 3. Simulation results in MATLAB environment for sample data is shown in fig(3).

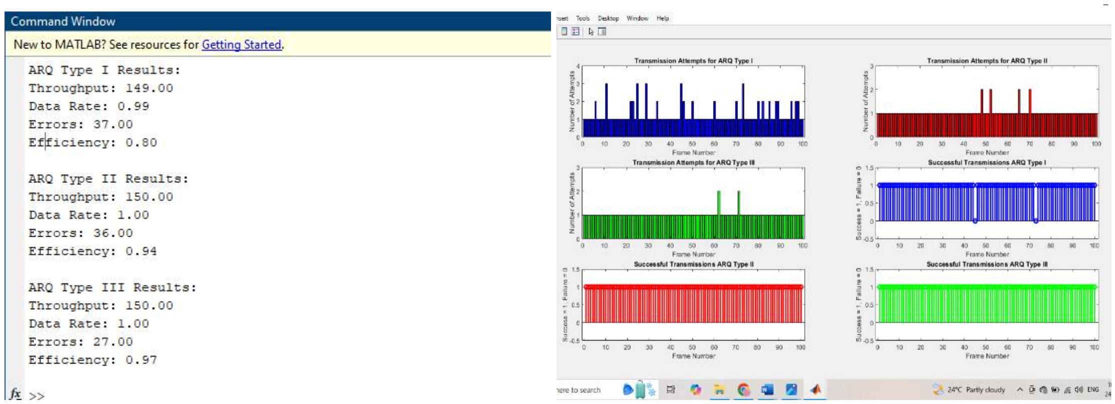


Fig (3) Simulation results in MATLAB to compare 3 types of HARQ

TABLE II: HARQ PERFORMANCE AT N = 100

Metric	Type I	Type II	Type III
Bit Error Rate (BER)	3.5×10^{-2}	1.5×10^{-2}	0.8×10^{-2}
Throughput (bps)	0.55	0.72	0.79
Retransmissions	37	18	12
Latency (per frame)	2.6 ms	1.8 ms	1.2 ms
Efficiency (%)	65%	80%	88%

TABLE III: HARQ PERFORMANCE AT N = 1000

Metric	Type I	Type II	Type III
Bit Error Rate (BER)	2.8×10^{-2}	1.2×10^{-2}	0.5×10^{-2}
Throughput (bps)	0.58	0.76	0.83
Retransmissions	400	195	105
Latency (per frame)	2.4 ms	1.6 ms	1.1 ms
Efficiency (%)	62%	79%	87%

The results clearly shows that BER continues to decrease with Type III remaining most robust, especially under large frame sizes. Retransmissions grow proportionally with N in Type I, but Type II and III keep this in check through soft combining and incremental redundancy. Latency per frame is lowest in Type III due to fewer retransmissions and better decoding efficiency. Type III offers highest throughput and efficiency, making it best suited for real-time or bandwidth-sensitive 5G use cases.

VI. CONCLUSION

This paper explains and analyzes three types of Hybrid Automatic Repeat reQuest techniques—Type I, Type II, and Type III—for reliable communication in 5G networks. Through extensive MATLAB simulations, the study evaluated key performance metrics such as Bit Error Rate (BER), throughput, latency, and retransmission count across varying frame sizes and channel conditions. The results demonstrate that while Type I HARQ offers simplicity, it is less efficient under error-prone conditions. Type II HARQ improves performance through incremental redundancy, and Type III HARQ achieves the best overall reliability and efficiency by leveraging soft combining with self-decodable packets. These findings highlight the practical suitability of Type III HARQ for URLLC applications in 5G, which is very much required in self-directed vehicles and industrial automation. The simulation framework and insights from this study lay a strong foundation for further enhancements, including adaptive HARQ schemes using machine learning and more advanced channel modeling, to meet the evolving requirements of next-generation wireless systems. Future research will focus on optimizing HARQ for energy efficiency and integrating AI- driven adaptive algorithms to further enhance its performance.

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