FPGA-Based M-QAM Transceiver for RF/FSO Channels with Weather-Aware Performance Prediction Using Machine Learning

OBJECTIVES

Objective 1.Design of FPGA-based Modulator and Demodulator

Objective 2.Development of Adaptive Testbed Architecture

Objective 3.. Simulation of Diverse Atmospheric Conditions

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Objective 4.ML-based Statistical Performance Evaluation

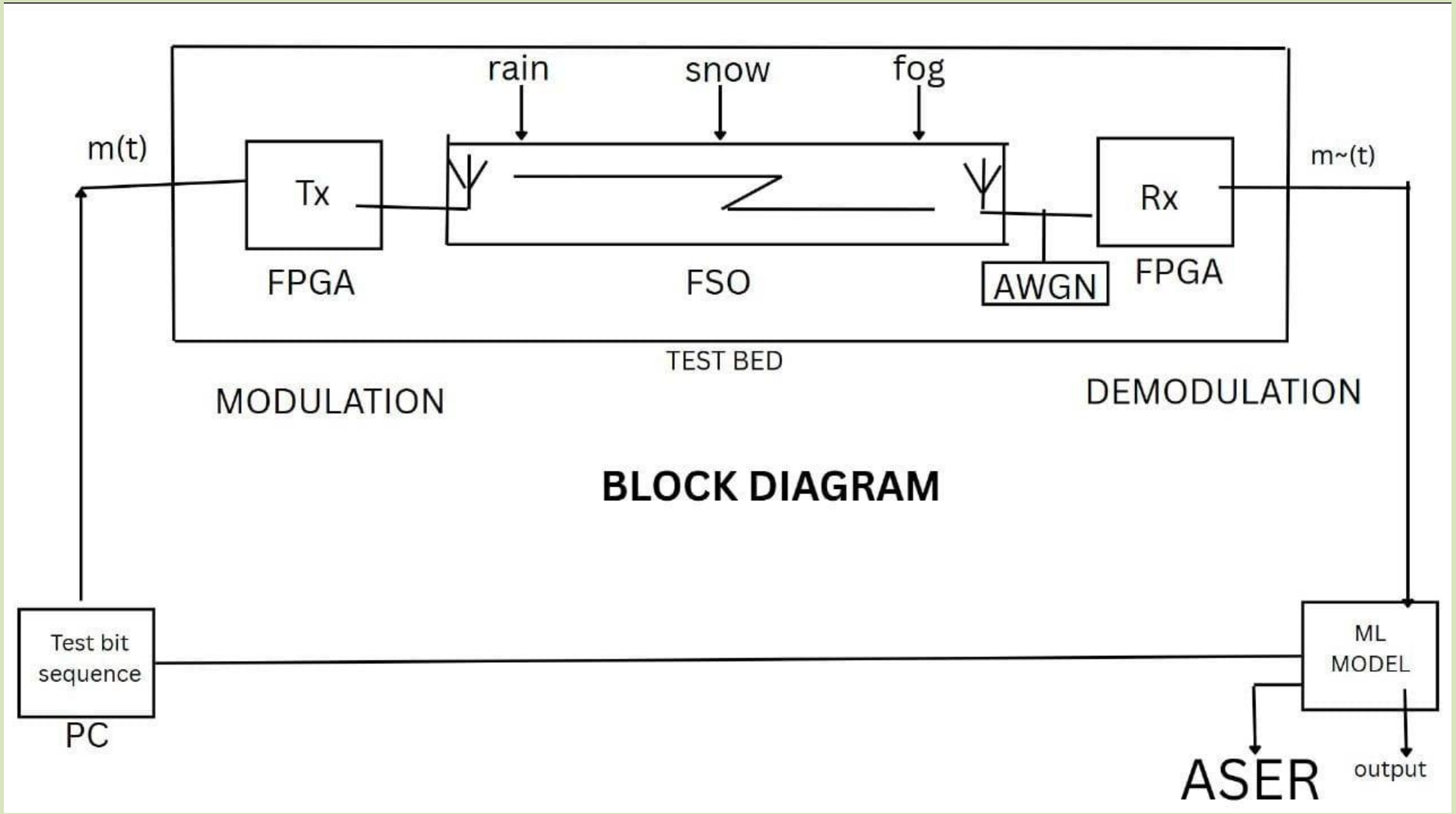
Objective 5.Development of Modular and Reconfigurable Testbench

Methodology

- **Step 1:** System Design and Planning
- **Step 2:** Modulation Block (Verilog Implementation)
- **Step 3:** Demodulation Block (Verilog Implementation)
- **Step 4:** Simulation and Functional Verification
- **Step 5:** Testbed Development for RF and FSO Channel Simulation
- **Step 6:**FPGA Hardware Implementation and Real-Time Evaluation
- **Step 7:**Integration of Machine Learning for Performance Prediction

Abstract of the Project

This project introduces a smart and adaptive testbed for high-speed digital communication using M-ary QAM modulation and demodulation, simulated in Verilog and implemented on FPGAs. Designed to operate over both RF and FSO links, the system supports real-time switching between channels and multiple modulation formats, such as 16-QAM and 64-QAM. To replicate real-world conditions, the testbed can simulate various weather effects - including rain, fog, and drizzle - enabling detailed performance evaluation. Additionally, machine learning models are integrated with the demodulated output to intelligently predict key metrics such as SNR and BER, facilitating data-driven insights and adaptive system behaviour. The platform serves as a versatile benchmark for future studies on physical layer communication under diverse environmental scenarios.


rain
snow
fog
m(t)
Tx
FPGA
FSO
AWGN
Rx
FPGA
m~(t)
TEST BED
MODULATION
DEMODULATION
BLOCK DIAGRAM
Test bit sequence
PC
ML MODEL
ASER
output

Social Impact of the Proposal

- **Impact 1:**Facilitates fast and reliable communication in underserved rural and remote regions.
- **Impact 2:** Accelerates development and reduces cost through a reconfigurable FPGA-based platform.
- **Impact 3:** Promotes sustainable technological practices by enabling the reuse and adaptation of hardware components
- **Impact 4:**Provides a practical environment for researchers and students to implement and evaluate modulation schemes and error correction algorithms.
- **Impact 5:**Supports innovation and experimentation in emerging technologies such as 5G, IoT, and satellite-based communication.

Expected Outcomes

a. A fully functional FPGA-based transceiver capable of performing M-QAM modulation and demodulation over both RF and Free-Space Optical (FSO) communication links.

b. A modular and reconfigurable hardware testbed that allows real-time switching between RF and FSO channels and supports various modulation formats (e.g., 16 QAM, 64-QAM, etc.).

c. A microcontroller-controlled test environment capable of emulating diverse weather conditions such as rain, fog, and drizzle for realistic channel testing.

d. Successful integration of a machine learning model to predict key statistical parameters such as SNR and BER based on demodulated data.

f. A versatile, reusable platform for future research and development in communication technologies, particularly relevant to 5G, IoT, and satellite systems.

Budget Details

Sl. No.	Hardware	Quantity	Estimated Price
1.	FPGA Development Board	02	30000/-
2.	Peripheral Components (ADC, DAC, Amplifier, PSU, etc.)	-	8000/-
3.	Cables & Accessories	-	3000/-
4.	Machine Learning Resources	-	2000/-
5.	Power Supply & Misc.	-	2000/-

TIMELINE

- **1st Quarter:**
  -> Project planning and hardware requirement analysis.
  ->Study M-QAM and FPGA architecture.
- **2nd Quarter:**
  ->Implement and verify M-QAM modulator in Verilog.
  ->Start designing environmental testbed (rain, fog, drizzle).
- **3rd Quarter:**
  -> Deploy design on FPGA and perform hardware testing.
  -> Integrate weather simulation testbed with system.
- **4th Quarter:**
  -> Interface ML model with FPGA output and test system.
  ->Evaluate performance (SNR, BER) and analyze results.

Current Status

: A. **Transmitter Design:**

- A16-QAM modulation has been successfully implemented using Verilog.
- The modulated output has been verified through simulation in Xilinx Vivado.

B. **Receiver Design**:

- Verilog implementation of 16-QAM demodulation is currently in progress.
- Functional testing and debugging of the demodulation module are ongoing.

C. **Machine Learning Model**:

- A basic machine learning model has been developed for statistical analysis of received signals.
- Integration of the ML model with FPGA output is currently pending.

QAM Modulation Output in Vivado

Uniqueness for Expected Patent

- The proposed system introduces several novel features that distinguish it from existing solutions and hold strong potential for patentability:
- Novel integration of FPGA-based M-QAM modulation/demodulation with machine learning-based performance prediction.
- Real-time switching between RF and FSO channels without manual reconfiguration.
- Microcontroller-controlled testbed capable of simulating weather conditions such as rain, fog, and drizzle.
- Hardware-ML co-design enabling adaptive communication based on real-time channel conditions.
- Modular and scalable architecture supporting multiple modulation formats and communication standards.
- First-of-its-kind unified platform combining environmental modeling, digital communication, and AI-based analysis. g. Serves as a versatile and reusable testbed for researchers and educationists to prototype, simulate, and evaluate next-generation communication systems.

Details of the Project Group

Sl. No.	Post	Name	Reg. No.	Email Id.	Department	Contact No.
1	Team Leader	Devi Manasa	2023UGEC043	2023ugec043@nitjsr.ac.in	Electronics and Communication Engineering	9398374299
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3	Member	Rajneesh	2023UGEC057	2023ugec057@nitjsr.ac.in	Electronics and Communication Engineering	6388531028

Mentorship Details

Sl. No.	Name	Department
1	Dr. Nagendra Kumar	Electronics and Communication Engineering

Role of each members

Sl. No.	Post	Name	Role of the member
1	Team Leader	Devi Manasa	Handled Software simulation of M-ARY QAM Modulation using Vivado & Matlab .
2	Member	Reethika	Handled Software simulation of M-ARY QAM Modulation using Vivado & Matlab .
3	Member	Rajneesh Kumar	Handle the machine learning part of the project

THANK YOU