DESIGN AND SIMULATION OF A RADIO-OVER-FIBER (ROF) SYSTEM FOR 5G BACKHAUL WITH 6G TERAHERTZ EXTENSIONS USING OPTISYSTEM

Report submitted to GITAM (Deemed to be University) as a partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Electronics And Communication Engineering

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DECLARATION

I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.

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CERTIFICATE

This is to certify that (Student Name) bearing (Regd. No.:) has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIth semester, Bachelor of Technology in "Electrical, Electronics and Communication Engineering" and submitted this report during the academic year 20252026.

[Signature of the Guide] [Signature of HOD]

Table of contents

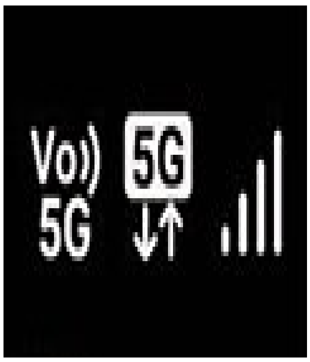
Chapter 1: Introduction

1.1 Overview of the problem statement

The exponential growth of mobile data traffic, driven by 5G services such as IoT, cloud applications, and ultra-HD video, requires robust backhaul networks. Traditional microwave and fiber-only backhaul systems face limitations: microwave lacks capacity, while pure fiber is costly in dense deployments. Radio-over-Fiber (RoF) provides a hybrid solution by carrying high-frequency RF signals over optical fiber, enabling centralized processing, high bandwidth, and long-distance transmission. However, challenges such as chromatic dispersion, fiber nonlinearities, and wireless hop attenuation— particularly in the mmWave and THz bands—must be addressed.

1.2 Objectives and goals

- To design and simulate a Radio-over-Fiber system for 5G backhaul using OptiSystem.
- To investigate performance with varying fiber lengths (2–40 km) and RF carrier frequencies (10–60 GHz).
- To analyze modulation schemes (64-QAM and 256-QAM) in OFDM systems.
- To extend the RoF architecture for 6G Terahertz links (140–300 GHz).
- To evaluate performance metrics such as Error Vector Magnitude (EVM), Bit Error Rate (BER), Q-factor, and constellation diagrams.
- To propose improvements and recommendations for real-world deployment

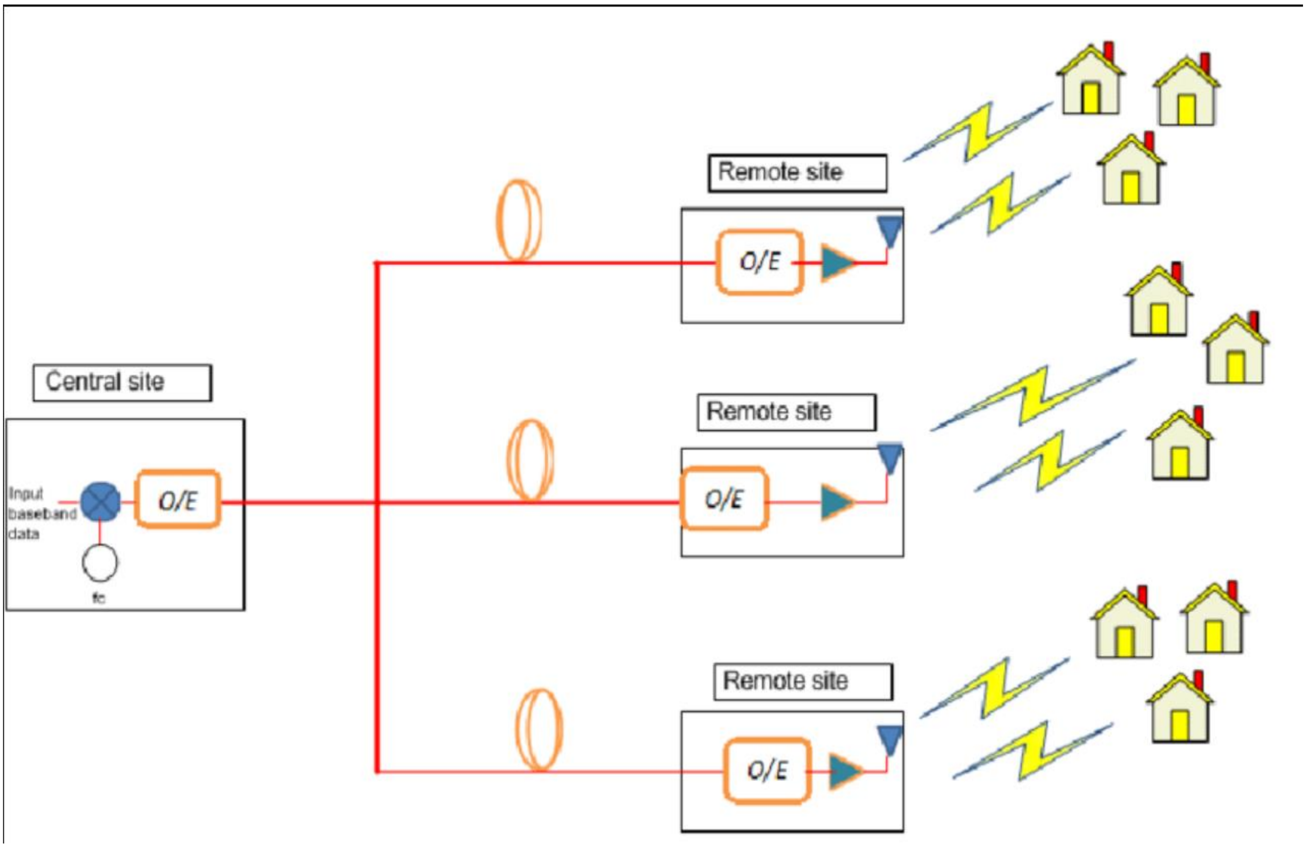


Chapter 2 : Literature Review

Several studies have highlighted the potential of RoF systems in future communication networks:

- Agrawal (2012): Fundamentals of fiber-optic communication systems.
- Seeds & Williams (2006): Introduced microwave photonics as the foundation of RoF.
- Saleh & Simmons (2019): Discussed network architectures for 5G multi-tier cellular networks.
- Koenig et al. (2013): Demonstrated wireless sub-THz communication at multi-Gbps rates.
- Rappaport et al. (2019): Discussed opportunities and challenges in THz frequencies for 6G.

These works show that RoF is a mature candidate for 5G backhaul, while photonic THz generation offers strong potential for 6G. OptiSystem is widely used for simulation and analysis due to its comprehensive optical and RF component libraries.



Chapter 3 : Methodology

3.1 Description of the approach

The project follows a simulation-based approach using OptiSystem. The system consists of three parts:

- **Transmitter**: OFDM signal generation → mapped onto optical carrier using Mach–Zehnder Modulator.
- **Channel**: Transmission over single-mode fiber with attenuation and dispersion.
- **Receiver**: Optical-to-electrical conversion using a PIN photodiode → RF recovery → performance analysis.

Extension to 6G is achieved via photonic THz generation using optical heterodyning.

3.2 Tools and techniques utilized

- **Software**: OptiSystem 17 for optical simulation.

- **Techniques**:
- OFDM with QAM modulation (64-QAM, 256-QAM).
- External modulation using MZM.
- Optical heterodyning for THz signal generation.
- DSP-based impairment compensation (phase noise, dispersion).

- **Performance Analysis**: BER Analyzer, Q-factor, EVM Analyzer, Eye Diagram Visualizer.

3.3 Design considerations

- **Fiber length**: 2–40 km, considering typical metro backhaul distances.
- **Wavelengths**: 1310 nm and 1550 nm, optimized for low loss and dispersion.
- **Modulation format**: Trade-off between spectral efficiency and robustness (64-QAM vs. 256-QAM).
- **THz frequency**: Short-range wireless links (140–300 GHz) limited by path loss and antenna alignment.
- **System margin**: Maintaining $Q > 6$ and $EVM < 8\%$ for reliable communication.

Chapter 4: Conclusion

The simulation results confirm that RoF is a feasible backhaul solution for 5G networks, supporting mmWave frequencies with acceptable EVM and BER up to 20–40 km fiber lengths. While 64-QAM offers robustness for longer links, 256-QAM is viable only for short, high-SNR connections. The extension to 6G THz links demonstrates that photonic heterodyning can generate stable THz carriers, supporting short-range ultra-high-speed wireless hops. Overall, RoF provides a cost-effective and scalable backhaul solution for next-generation networks.

References

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