ENT1099EE02 - AI-Based Prediction and Mitigation of Tropospheric Ducting Interference in Bahrain's Critical RF Communication Networks

Principal Investigator

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Background of the problem

Tropospheric ducting is an abnormal radio-propagation phenomenon caused by sharp changes in atmospheric refractivity, often linked to temperature inversions, humidity gradients, and pressure variations. These conditions can trap VHF, UHF, and microwave signals within atmospheric layers, allowing them to travel beyond normal line-of-sight and potentially interfere with distant or local communication systems.

Previous studies show that ducting is common in coastal and maritime environments, where humidity and sea–land temperature differences can create strong refractive layers. Bahrain's island geography, humid climate, and dense RF environment make this issue important for mobile networks, maritime communication, aviation, broadcasting, and public-safety services.

Existing propagation models can describe ducting mechanisms, but practical prediction remains challenging because ducting depends on local weather, time of day, season, and terrain/sea-surface effects. Recent approaches increasingly combine meteorological data, RF measurements, and machine-learning methods to improve prediction accuracy and risk assessment.

The attached proposal identifies Bahrain-specific concerns, including overseas signal reception, seasonal ducting patterns, degradation of local RF services, and the need to correlate weather data with measured interference events. This PhD builds on that foundation by developing a data-driven prediction and mitigation framework for Bahrain. The study will link meteorological parameters with RF spectrum observations to classify ducting risk levels and provide practical early-warning and mitigation guidance for telecom operators, regulators, and critical communication stakeholders.

List of publications related to the field

Have been attached.

Research Objectives and Expected Outcomes:

Aim

The aim of this study is to develop and validate a data-driven framework for predicting and mitigating tropospheric ducting interference in Bahrain's critical RF communication networks.

Objectives

To investigate the atmospheric conditions that contribute to tropospheric ducting in Bahrain, including temperature inversions, humidity gradients, pressure variation, wind conditions, and seasonal patterns.

To collect and analyse meteorological and RF spectrum data from selected locations in Bahrain.

To identify RF bands and communication services most affected by ducting-related interference, such as mobile, maritime, aviation, broadcasting, and publicsafety systems.

To develop data-driven prediction models that correlate weather parameters with measured RF interference events.

To classify ducting interference risk levels, such as low, medium, and high, for selected RF communication scenarios.

To validate the prediction model using measured RF and meteorological data.

To propose practical mitigation guidelines, including early-warning indicators, spectrum monitoring recommendations, and operational strategies for telecom operators, regulators, and critical communication stakeholders.

Expected Outcomes:

The project is expected to produce a Bahrain-specific framework for predicting and mitigating tropospheric ducting interference in critical RF communication networks. The main outcome will

be a data-driven model that correlates meteorological parameters with RF spectrum measurements to classify ducting risk levels as low, medium, or high.

The study will also identify the atmospheric conditions, seasons, locations, and RF bands most associated with ducting-related interference in Bahrain. It will generate an RF measurement dataset, validated prediction results, and analysis of abnormal long-distance signal reception or interference events.

Practical outcomes will include early-warning indicators, spectrum monitoring recommendations, and mitigation guidelines for telecom operators, regulators, maritime, aviation, and public-safety stakeholders. The research is also expected to support improved network planning, communication reliability, and evidence-based spectrum management in Bahrain.

Research Design/Methodology

This study will adopt an experimental, data-driven, and applied research design to predict and mitigate tropospheric ducting interference in Bahrain's RF communication networks. The research will combine meteorological analysis, RF spectrum measurements, propagation modelling, and machine-learning techniques to develop a Bahrain-specific ducting risk prediction framework.

The first stage will involve a detailed literature review on tropospheric ducting, atmospheric refractivity, temperature inversions, humidity gradients, VHF/UHF/microwave propagation, and interference effects on communication systems. This will establish the theoretical basis for identifying ducting conditions and selecting suitable measurement parameters. The project will build on previous work related to atmospheric ducting, RF interference monitoring, and propagation modelling, including the attached proposal's focus on overseas signal reception, seasonal ducting, and Bahrain's coastal environment. [finance.yahoo.com]

The second stage will focus on meteorological data collection. Historical and, where possible, real-time weather data will be collected from relevant sources such as the Bahrain Meteorological Directorate. Key parameters will include temperature, humidity, pressure, wind speed, wind direction, time of day, and seasonal variation. These parameters are important because tropospheric ducting is strongly associated with temperature inversions, humidity changes, and atmospheric refractivity gradients.

The third stage will involve RF spectrum measurement and monitoring at selected locations in Bahrain, preferably including coastal, urban, airport, maritime, or telecom-sensitive areas. Measurement equipment may include a spectrum analyser, software-defined radio receiver, log-periodic antenna, VHF/UHF antennas, and suitable data logging tools. The study will monitor selected RF bands relevant to mobile, maritime, aviation, broadcasting, and public-safety communications. The collected RF data may include received signal strength, spectrum

occupancy, signal-to-noise ratio, interference peaks, and abnormal long-distance signal reception.

The fourth stage will involve data processing and event identification. RF measurements will be compared with meteorological data to identify possible ducting-related events. Abnormal increases in received signal levels, unexpected distant signals, co-channel interference, or unusual spectrum activity will be classified as candidate ducting events. These events will then be correlated with weather conditions to identify the most significant atmospheric predictors.

The fifth stage will develop data-driven prediction models. Machine-learning and statistical methods will be used to classify ducting risk levels, such as low, medium, and high. Possible models may include decision trees, random forest, support vector machines, gradient boosting, or time-series models. Model performance will be evaluated using accuracy, precision, recall, false alarm rate, and prediction reliability. The best-performing model will be used to propose a Bahrain-specific ducting risk index.

The sixth stage will focus on mitigation and applied recommendations. Based on the prediction results, the study will propose practical guidelines for telecom operators, regulators, and critical communication stakeholders. These may include early-warning indicators, spectrum monitoring procedures, high-risk period alerts, frequency planning recommendations, and operational mitigation strategies.

Ethical considerations are limited, as the study will not involve personal or sensitive user data. RF monitoring will focus only on signal strength, spectrum occupancy, and interference characteristics, not on communication content. All measurements will follow relevant safety, regulatory, and institutional requirements.

The final output will be a validated prediction framework, RF measurement analysis, ducting risk model, and practical mitigation.

Significance and potential impact of research in Bahrain

This research is significant because it addresses a practical risk to Bahrain's RF communication reliability. Tropospheric ducting can cause radio signals to travel beyond normal line-of-sight, creating unexpected long-distance interference that may affect mobile, maritime, aviation, broadcasting, and public-safety communication systems.

The study is especially relevant to Bahrain because of its coastal and humid environment, dense telecom infrastructure, and dependence on reliable wireless services. By linking meteorological data with RF spectrum measurements, the project will improve understanding of when and how ducting-related interference occurs in Bahrain.

The research will contribute a Bahrain-specific prediction and risk classification model for tropospheric ducting events. This can support early-warning indicators and help telecom

operators, regulators, and critical communication users anticipate high-risk periods before service degradation occurs.

The project also supports Bahrain's digital transformation and telecommunications resilience by helping improve spectrum management, network planning, and operational decision-making. Its outcomes may benefit organisations such as telecom operators, TRA, Bahrain Meteorological Directorate, maritime and aviation stakeholders, and public-safety communication users.

Overall, the study will provide scientific, technical, and practical value by improving the prediction, monitoring, and mitigation of ducting-related RF interference in Bahrain's critical communication networks.

Alignment with Bahrain's national research strategy

Contribution to Bahrain Society

Improves reliability of mobile, maritime, aviation, public-safety, and critical RF communications by predicting ducting-related interference.

Alignment with Industry

Relevant to telecom operators, TRA, Bahrain Meteorological Directorate, aviation, maritime, NCC, and BDF stakeholders.

Alignment with National Priorities

Supports Bahrain's digital transformation, 5G readiness, smart infrastructure, and evidence-based spectrum management.

Alignment with EDB Policies

Strengthens communication reliability, supporting digital services, smart cities, logistics, aviation, finance, and industry.

Benefits for Industry Partner

Provides ducting risk models, RF measurement data, early-warning indicators, and mitigation guidelines for better network planning and service reliability.