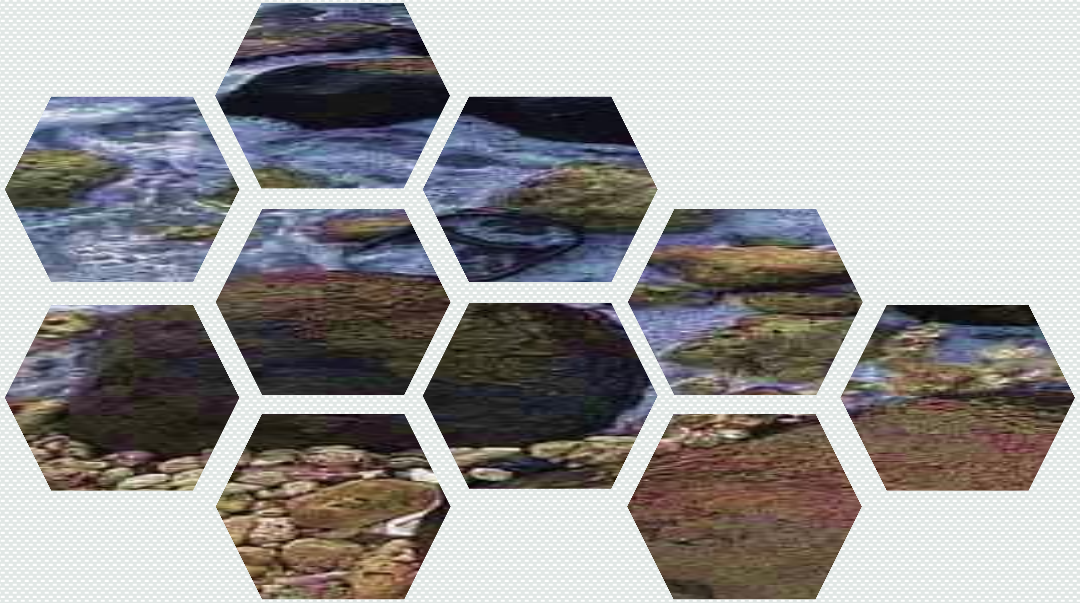
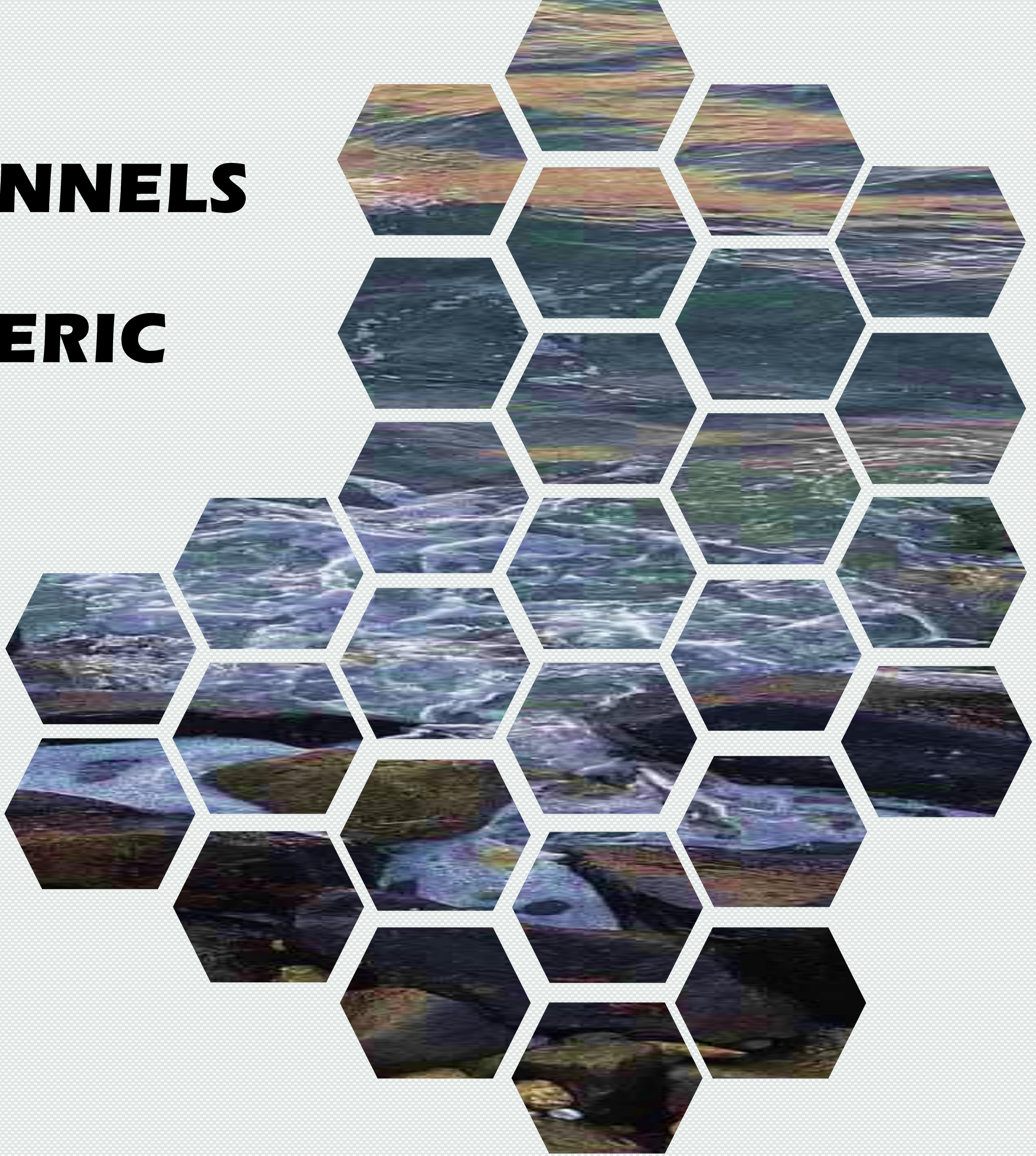
THE SKY'S SECRET CHANNELS

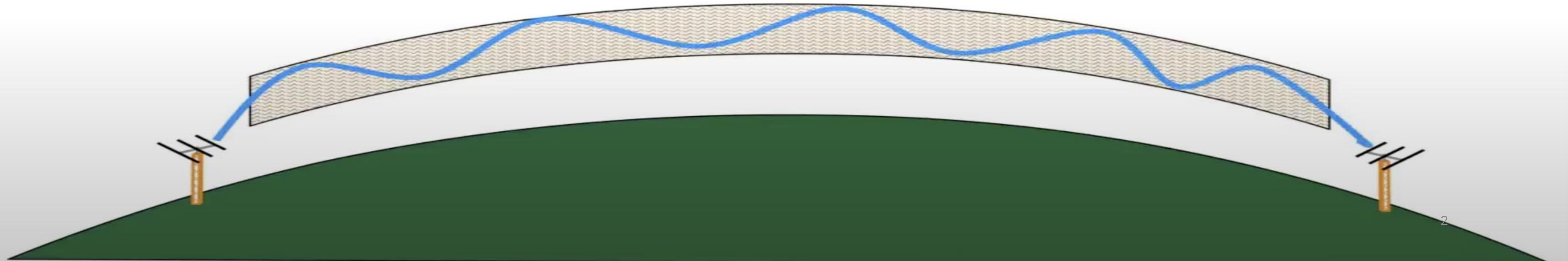
UNVEILING ATMOSPHERIC DUCTING IN 6G



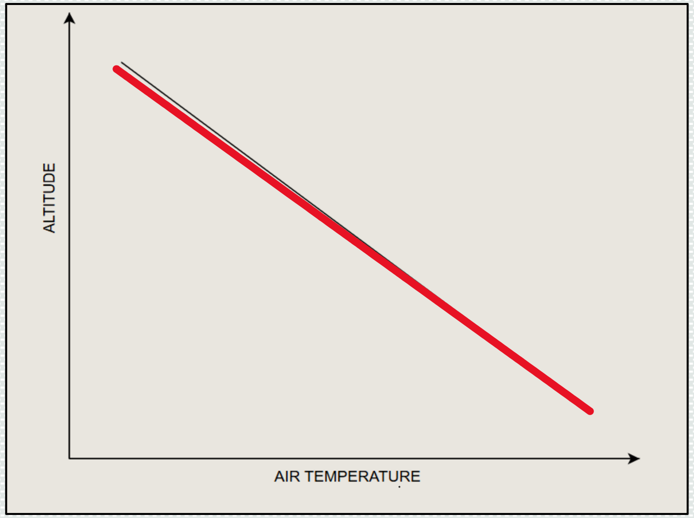


WHAT IS ATMOSPHERIC DUCTING?

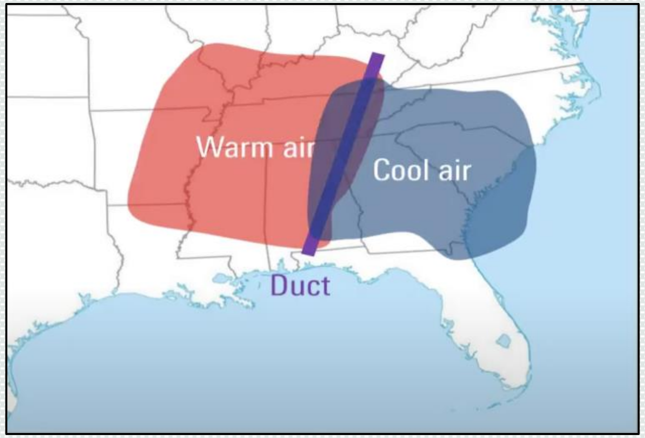
- Atmospheric ducting is a phenomenon that allows radio waves to travel much farther than they normally would be due to specific conditions in the atmosphere.
- Usually, radio waves travel in straight lines and spread out as they move away from the transmitter. They can go only a certain distance before becoming too weak to detect.
- Sometimes, the atmosphere forms special layers due to changes in temperature and humidity.
- These layers can bend radio waves back towards the Earth's surface instead of letting them escape into space. This bending effect is similar to how light bends when it passes through water.
- Because the radio waves are bent back towards the ground, they can travel much farther than usual. It's like the waves are trapped in a "tunnel" created by the atmospheric layers, allowing them to follow the Earth's curvature.
- The atmospheric duct acts as a **WAVEGUIDE ,** i.e. a structure that guides electromagnetic waves from one point to another.



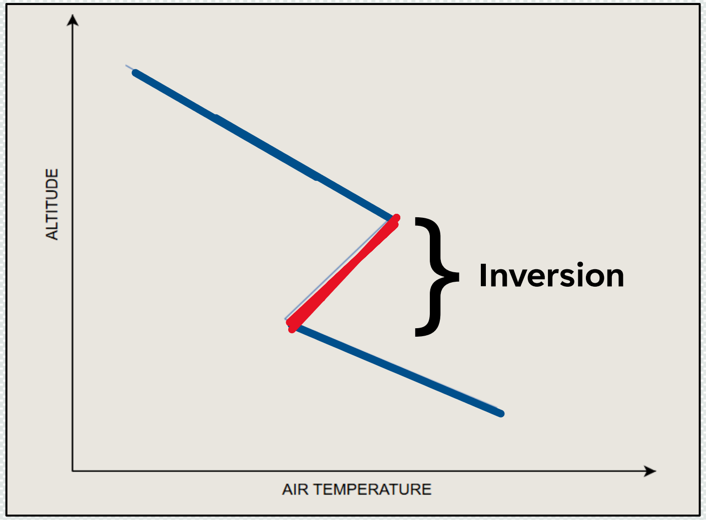
FORMATION OF DUCT



Refraction bends the signals in the direction of higher refractivity and can extend the radio horizon beyond geometric horizon. Bending is the function of refractive index(N) and depend on three atmospheric factors i.e. pressure, temperature and humidity.



In general, as altitude increases, the refractive index (N) of the atmosphere decreases. This is due to the reduction in air density and atmospheric pressure at higher altitudes, causing light to bend less. This gradient in refractive index can influence phenomena like atmospheric ducting.



In some case, a warmer air may be present over colder air called as **TEMPERATURE INVERSION** which can cause abrupt changes in the refractive index which can lead to the formation of **TROPOSPHERIC DUCT.**

PROBLEMS ADDRESSED BY ATMOSPHERIC DUCTING IN 5G AND 6G SOLUTIONS

- **Beyond Line-of-Sight (LoS) Communications:**

  Conventional cellular, satellite, and optical fiber communications are limited by line-of-sight requirements. Atmospheric ducting allows for beyond LoS communications, particularly beneficial in areas with limited coverages.

- **Increased Capacity and Data Rates:**

  Atmospheric ducting enables high data rates and increased capacity, vital for 6G networks, with MIMO (Multiple Input Multiple Output) and cognitive radio enhancing efficiency.

- **Efficient Spectrum Utilization:**

- By leveraging atmospheric ducting for communication, spectrum can be efficiently utilized, reducing congestion and improving overall network performance, which is critical for 5G and 6G networks.

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MATHEMATICAL MODEL OF ATMOSPHERIC DUCTING

$$M = N + \frac{z}{a_e} \cdot 10^6 \approx N + 0.157z,$$

Here the modified refractivity is defined by M, where N is the radio refractivity, which is related to the meteorological parameters, such as the atmospheric pressure, temperature, and humidity, z is the altitude in meters, and ae is the curvature radius of the earth in meters.

The negative gradient of the modified refractivity, denoted as

$$\partial M / \partial z < 0,$$

	Evaporation duct	Surface duct	Elevation duct
Occurrence	In coastal and maritime areas	Often in clear nights or after rains	Caused by monsoon and motions of cloud clusters
Probability of Occurrence	Up to 90% of the time	Up to 40% of the time	Up to 50% of the time
Height of upper boundary	<40 m	<300 m	<3000 m
Applications and Challenges	Enable beyond LoS com munications with high availability	Cause strong remote interference to the TDD terrestrial communication	Affect the satellite communications

AI-DRIVEN ATMOSPHERIC DUCTING (1/2)

Our initial **Language Model (LLM)** will be **pre-trained** on historical data, encompassing information on the probability of successful duct formation. This model will be **fine-tuned** with real-time data from various applications. Using a specified formula, we will calculate the **probability of a duct being formed** based on the updated information. This approach ensures that our probability assessments remain accurate and reflective of current conditions.

Data collection

To pretrain the model, it is imperative to gather a comprehensive dataset that includes the following variables:

- **Temperature:** The ambient temperature measured in degrees Celsius (°C) or Fahrenheit (°F) and converted to degree Kelvin.
- **Atmospheric Pressure:** The pressure exerted by the atmosphere at a given point, typically measured in hectopascals (hPa) or millibars (mb).
- **Humidity:** The amount of water vapor present in the air, commonly expressed as a percentage (%).
- **Altitude:** The height above sea level, measured in meters (m) or feet (ft).
- **Curvature Radius:** A constant value representing the radius of curvature for the specific geographical location under consideration, usually measured in meters (m).

Each of these factors is crucial for the accurate pretraining of the model, and ensuring it predicts the occurrence of a duct correctly

This approach leverages advanced artificial intelligence techniques to predict atmospheric ducting conditions. By integrating data collection, model selection, and training processes, it combines **Random Forest, LSTM, and CNN-LSTM** models to accurately capture and forecast the spatial and temporal patterns of atmospheric phenomena.

AI-DRIVEN ATMOSPHERIC DUCTING (2/2)

DATA COLLECTION, MODEL SELECTION, AND TRAINING

Model Selection

We select appropriate models for formulating a mechanism specific to the formation of a tropospheric duct. Some of the models that we can select are:

LSTM (Recurrent Neural Networks)

- **Primary Use**: Time-series analysis of atmospheric data.
- **Justification**: Effectively captures temporal dependencies crucial for predicting ducting events.

Random Forest

- **Primary Use**: Classification and regression tasks for initial pattern recognition.
- **Justification**: Robust and effective for handling complex interactions within the data.

Hybrid Models (CNN + LSTM)

- **Primary Use**: Comprehensive analysis combining spatial and temporal data.
- **Justification**: Leverages the strengths of both spatial and temporal analysis, providing high accuracy and robustness.

Model Training Process

- **Data Splitting:** Divide data into training, validation, and test sets (e.g., 70% training, 15% validation, 15% testing).
- **Model training:** Involves fitting data to Random Forest, LSTM, and CNN-LSTM models. Each model captures different patterns: Random Forest handles non-linear relationships, LSTM captures temporal dependencies, and CNN-LSTM combines spatial and temporal features. Fine-tuning through hyperparameter optimization and cross-validation ensures robust and accurate predictions.
- **Fine-Tuning Procedures:**
  - ***Learning Rate Adjustment***: Use techniques like learning rate annealing or adaptive learning rates (e.g., Adam optimizer).
  - ***Early Stopping***: Monitor validation loss and stop training when performance stops improving to avoid overfitting.
  - ***Hyperparameter Tuning***: Use grid search or random search to find the optimal hyperparameters (e.g., number of layers, units per layer, learning rate).
  - ***Cross-Validation:*** Perform k-fold cross-validation to ensure the model's robustness and generalization.

BUDGET DISTRIBUTION

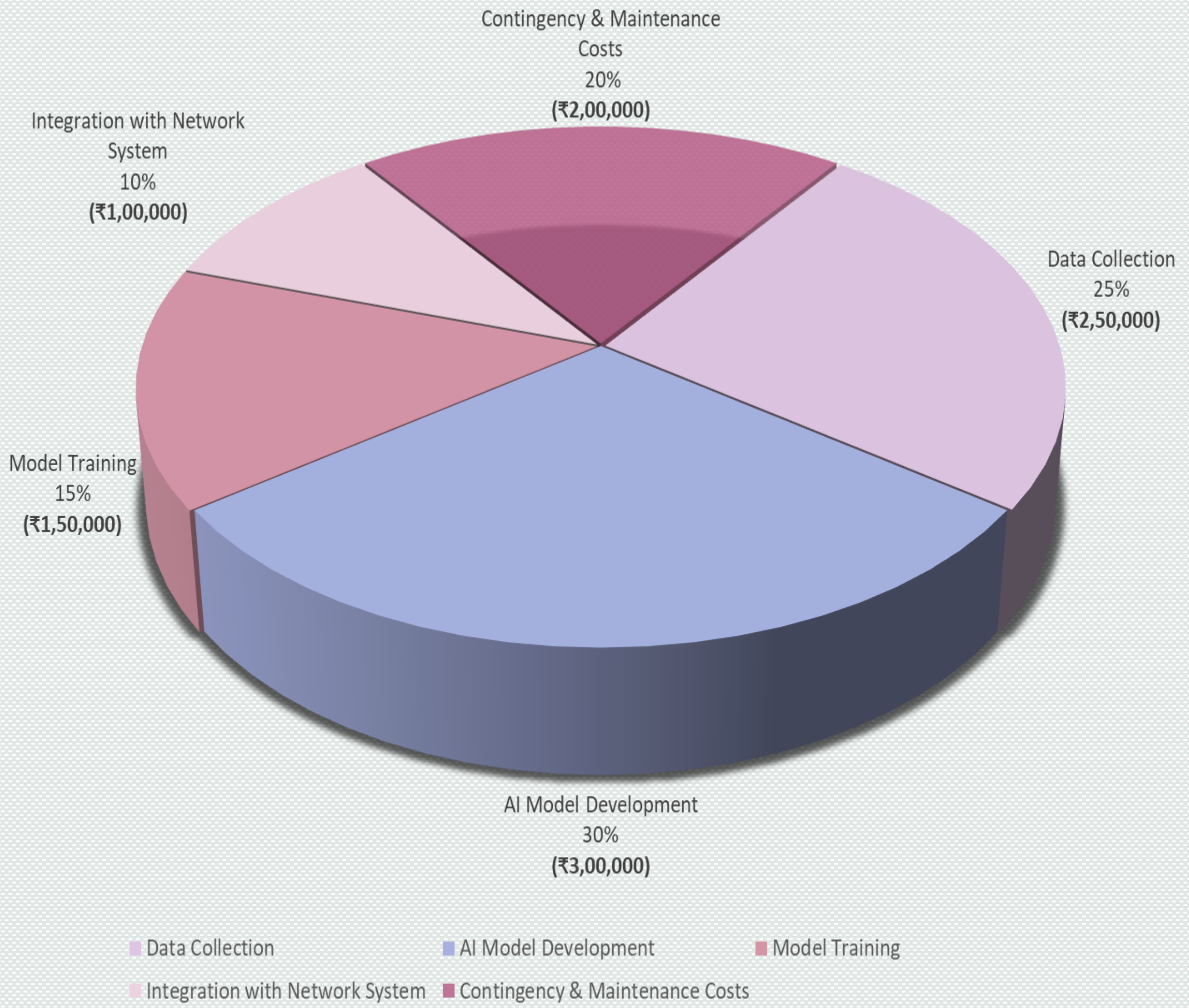
HOW THE PROTOTYPE CAN SUCCEED WITH A BUDGET OF RS. 10,00,000 /-

This budget plan provides a comprehensive breakdown for implementing AI models to manage atmospheric ducting with a total budget of ₹10,00,000.

It includes costs for

- Data Collection
- Preprocessing
- AI Model Development
- Training And Validation
- Prediction And Detection
- Integration with Network Systems
- Continuous Improvement

The allocation ensures **scalability, customization,** and **careful vendor selection**.
It emphasizes the importance of **skilled professionals** and includes **contingency funds** for unforeseen expenses, ensuring effective deployment and management of the AI-driven atmospheric ducting solution.



CONCLUSION

- Refraction bends the signals in the Electromagnetic wave propagation is significantly affected by the atmospheric duct, which is caused by the rapid decrease of tropospheric refractivity under certain weather conditions.

- Atmospheric ducting brings both challenges and opportunities to wireless communications. Based on the investigation of the characteristics of the atmospheric duct and its influence on radio wave propagation, the concept of trapping region is developed.

- The trapping region plays an important role in both remote interference management and beyond LoS communications.

- Future research areas towards 6G include more intelligent and more integrated atmospheric duct affected wireless communications of higher refractivity and can extend the radio horizon beyond geometric horizon. Bending is the function of refractive index(N) and depend on three atmospheric factors i.e. pressure, temperature and humidity.

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