What are the different models of beam tracking modules

Overview

This work presents an overview of the different beam-tracking methods used in mmWave communications, focusing on hybrid beamforming techniques.

Key Takeaways

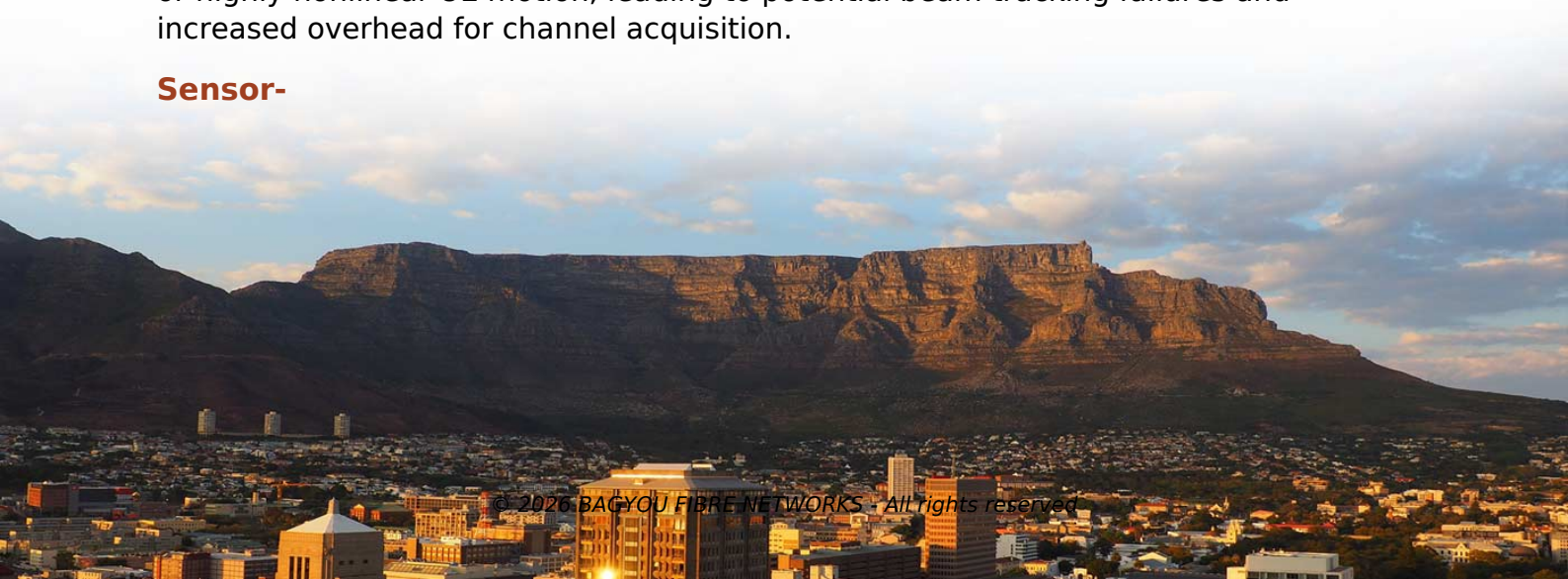
Beam tracking modules can be broadly categorized into traditional model-based, sensor-assisted, and AI/ML-based models, each designed to maintain optimal beam alignment in dynamic wireless environments.

Traditional Model-

Based Beam Tracking

Traditional beam tracking relies on mathematical and linear models to predict and adjust beam directions. Techniques such as Kalman filters (including extended Kalman filters) are commonly used to track the movement of user equipment (UE) and maintain beam alignment in massive MIMO systems. These models are effective for moderate mobility scenarios but may struggle with rapidly time-varying channels or highly nonlinear UE motion, leading to potential beam tracking failures and increased overhead for channel acquisition.

Sensor-



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Assisted Beam TrackingSensor-assisted models incorporate inertial measurement units (IMUs), GPS, or other positioning sensors to aid beam alignment. For example, in UAV mmWave communication, models can use geodetic positions, UAV-BS unit vectors, and height information to predict and track beams. These models improve tracking accuracy by leveraging real-time positional data, which is particularly useful in high-mobility scenarios where traditional models may fail.

AI/ML-Based Beam TrackingArtificial intelligence and machine learning models, especially deep learning (DL) and neural networks, are increasingly used for beam tracking. These models can capture complex nonlinear relationships in high-dimensional data, such as UE motion patterns and environmental scattering effects. AI-based models can predict optimal beam directions and adapt to dynamic channel conditions, reducing the need for exhaustive beam scans and improving throughput in mmWave and terahertz bands.

Examples include deep neural networks (DNNs) for temporal channel modeling and reinforcement learning for adaptive beam selection.

Hybrid Approaches

Some modern beam tracking modules combine traditional, sensor-assisted, and AI-based methods to leverage the strengths of each. For instance, a system may use a Kalman filter for baseline tracking while employing a DNN to refine predictions based on sensor data and environmental context. This hybrid approach enhances robustness and efficiency, especially in high-speed or complex propagation environments.

Summary

In summary, beam tracking modules can be classified into: Traditional model-based: Kalman filters, linear prediction models. Sensor-assisted: GPS, IMU, and UAV positional data integration. AI/ML-based: Deep learning, neural networks, reinforcement learning.

Hybrid models: Combining traditional, sensor, and AI methods for improved performance. These models are essential for maintaining high-quality directional communication in 5G, 6G, and mmWave systems, addressing challenges like narrow beamwidths, rapid UE mobility, and environmental blockages.

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Fig. 4(e) depict the total delivered traffic for different beam tracking algorithms. We observe that MAMBA-X performs better and the total delivered traffic increases by up to 46.8% and 142%

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Massive multiple-input multiple-output (MIMO) systems at millimeter wave have been touted as a possible technology for 5 G wireless communications. The massive MIMO systems,

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Consequently, we propose schemes based on deep learning for beam prediction tracking in this paper. On the basis of received signals from both the present and previous beam training, we apply long

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Building on this, we propose a multimodal beam tracking model for UAV communication, integrating image and GPS data to predict UAV movement and optimize beam tracking. The model

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