Security is a key concern in contemporary wireless communication, especially when there are eavesdroppers present. By utilizing Massive MIMO, Directional Modulation (DM), and Artificial Noise (AN) to preserve data integrity, this system is intended to guarantee secure transmission. There are several steps in a signal's trip from transmission to receipt, and each is essential to maintaining security and efficiency.

1. Transmitter Block (Massive MIMO + Beamforming + Directional Modulation + Artificial Noise)

The transmitter plays a crucial role in encoding, modulating, and directing the signal toward the legitimate receiver while ensuring security using **Directional Modulation (DM)** and **Artificial Noise (AN)**.

Components & Working:

1. **Input Data Source:**
   - Generates raw data to be transmitted.
   - Data can be voice, video, or digital information.
2. **Digital Baseband Processor:**
   - Converts raw input data into **symbols**.
   - Implements **error correction coding (LDPC: low density parity check code)**.
   - Performs **serial-to-parallel conversion** for MIMO.
3. **IQ Modulator:**
   - Maps symbols onto **in-phase (I) and quadrature (Q)** components.
   - Uses **modulation schemes** (QPSK, QAM).
   - Ensures **spectral efficiency** before up-conversion.
4. **Up-Converter:**
   - Converts baseband signal to **radio frequency (RF)**.
   - Use **mixer** to shift frequency.
5. **Directional Modulation (DM) Encoder:**
   - Modifies phase and amplitude **depending on transmission direction**.
   - Ensures signal is properly received **only at the intended angle**.
6. **Massive MIMO Antenna Array:**
   - Uses **Uniform Linear Array (ULA)** or **Planar Array**.
   - Multiple antennas provide **spatial diversity** and **beamforming gains**.
7. **Phase Shifters:**

- Adjusts **phase of each antenna element**.
- Ensures correct **beamforming direction**.

8. **Weight Computation Unit:**
   - Computes **beamforming weights** using **Zero-Forcing**.
   - Optimizes signal strength at the receiver.
9. **Artificial Noise (AN) Generator:**
   - Injects noise in **unintended directions**.
   - Prevents eavesdroppers from decoding the signal.
10. **RF Chain & Power Amplifiers:**

- **DAC (Digital-to-Analog Converter):** Converts digital signals to analog.
- **Mixer:** Converts signal to the desired RF band.
- **Power Amplifier:** Boosts signal strength before transmission.

The above procedure is explained in short for clear understanding of the reader . The process begins at the Input Data Source, where raw data—such as voice, video, or digital signals—is prepared for transmission. This data is then processed in the Digital Baseband Processor, where it is formatted, encoded, and converted into symbols suitable for wireless communication. The IQ Modulator then maps these symbols onto in-phase (I) and quadrature (Q) components, ensuring spectral efficiency through modulation schemes like QPSK or QAM.

To secure the data, the Directional Modulation (DM) Encoder modifies the phase and amplitude of the signal based on the intended receiver's location, preventing interception from unwanted directions. The Massive MIMO Antenna Array and Beamforming Unit then direct the signal precisely to the legitimate receiver while the Artificial Noise (AN) Generator injects noise in unintended directions to disrupt potential eavesdroppers. The RF Chain & Power Amplifiers amplify and convert the signal into an RF signal before transmission through the wireless channel.

2. **Wireless Channel (Multipath Propagation + Doppler Effect + Noise & Interference)**
The wireless channel distorts the transmitted signal due to multiple propagation effects.

Key Effects:

1. **Multipath Propagation:**
   - The signal reflects off obstacles, arriving via **multiple paths**.
   - Causes **constructive and destructive interference**.
2. **Reflection, Diffraction & Scattering:**

- Reflection from buildings, diffraction over edges, and scattering from small objects **distorts the signal**.

3. **Doppler Shift Effect:**
   - If **scatterers (vehicles, people) are moving**, their reflection introduces a **frequency shift**.
   - **Equation:** $\Delta f = (v/c) * f_c \cos(\theta)$:
     - v = velocity of scatterer
     - fc = carrier frequency
     - c= speed of light
     - θ = angle of arrival
4. **Additive White Gaussian Noise (AWGN):**
   - Adds **random thermal noise**.
5. **Interfering Signals from Other Users:**
   - Other transmissions cause **co-channel interference**.

Similar short concise explanation of the above procedure is as follows .Once transmitted, the signal enters the wireless channel, where it encounters various obstacles that affect its integrity. One major challenge is multipath propagation, where the signal reflects off surfaces like buildings, vehicles, and trees, causing multiple versions of the same signal to reach the receiver at different times. The system also experiences Doppler shift, a frequency change caused by moving objects in the environment, even if the transmitter and receiver remain stationary. This frequency shift alters the received signal and requires compensation at the receiver. Additionally, Additive White Gaussian Noise (AWGN) and interfering signals from other users further degrade the signal quality.

3. **Receiver Block (DOA Estimation + Kalman Filtering + Doppler Compensation)**
The receiver **processes the distorted signal** to recover the original message.

Components & Working:

1. **Antenna Array (ULA):**
   - Captures incoming signals **from multiple directions**.
2. **DOA Estimator (MUSIC, ESPRIT, AI-based):**
   - Estimates **Direction-of-Arrival (DOA)**.
   - Uses **covariance matrix computation**.
3. **Covariance Matrix Computation Unit:**
   - Forms **spatial correlation matrix** from received signals.
4. **Eigenvalue Decomposition Unit:**

    - Splits received signal into **signal and noise subspaces**.

5. **Kalman Filter:**
    - Tracks **DOA change over time**.
    - Predicts future angles.
6. **Doppler Shift Estimator:**
    - Detects **frequency shifts** in received signals.
7. **Doppler Compensation Unit:**
    - Corrects for **Doppler-induced distortions**.
    - Uses **frequency offset estimator**.
8. **Demodulator & Decoder:**
    - **Coherent Detector:** Extracts modulated data.
    - **Error Correction Decoder (LDPC):** Corrects transmission errors.

At the receiver, the distorted signal is captured by an Antenna Array (ULA), which collects signals from multiple directions. To ensure proper signal recovery, the DOA Estimator (using techniques like MUSIC or ESPRIT) determines the angle of arrival (DOA) of the signal. The Covariance Matrix Computation Unit and Eigenvalue Decomposition Unit process the incoming signals to separate the intended signal from noise and interference.

Since the Doppler shift alters the signal frequency, a Doppler Shift Estimator detects these shifts, and a Doppler Compensation Unit corrects for them. This ensures that the signal is restored to its original form before demodulation. The Kalman Filter helps in tracking the dynamic changes in the signal's DOA and frequency, providing a smooth and accurate estimation. Finally, the Demodulator & Decoder extract the transmitted data, ensuring that the information received is as close to the original as possible, with error correction mechanisms like LDPC enhancing reliability

4. Eavesdropper (Eve) – Impact of Artificial Noise

An **eavesdropper** tries to intercept the transmission, but **Artificial Noise (AN) disrupts** it.

1. **Noise-Interfered Signal:**
    - Eve receives **a mix of the signal and noise**.
2. **Failed DOA Estimation:**
    - Eve **fails to estimate the correct direction**.
3. **Corrupted Signal Detector:**
    - Eve's **received signal is highly distorted**.
4. **Error Rate Analyzer:**
    - Measures **high BER (Bit Error Rate) → Eve cannot recover data**.

In eavesdropper, commonly referred to as Eve, tries to intercept the communication by capturing the signal with her own antenna array. However, due to the Directional Modulation (DM) and Artificial Noise (AN), the signal she receives is corrupted and unusable. The Noise-Interfered Signal prevents Eve from accurately reconstructing the data. Additionally, Eve's DOA Estimation attempts fail because the beamforming ensures that the legitimate receiver is the only one receiving a properly aligned signal. The Error Rate Analyzer at Eve's end indicates a high Bit Error Rate (BER), confirming that the intercepted signal is unreadable.