Exploiting Multi-Path for Safeguarding mmWave Communications Against Randomly Located Eavesdroppers

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Why MIMO at mmWave?

- Abundance of bandwidth to support Gbps data rates
- Small wavelength enables small-sized arrays
- Large arrays provide high directivity to combat path loss

Note: log scale so even smaller over here


Examples of security threats

- Eavesdropping attack
- Information extraction
- Message replay attacks
- Message falsification attack

Important to secure communication links
Physical layer encryption

**PHY LAYER SECURITY**

- Tx uses multiple antennas to degrade eavesdropper’s channel
- Does not rely on upper-layer data encryption or secret keys

**LIMITATIONS**

- Traditional PHY encryption not suitable for mmWave systems (hardware limitations)
- Recent mmWave PHY techniques are not suitable for mainlobe security
Address the problem of overlapped communication channel paths between the receiver and eavesdropper

Two transmission techniques that enhance the security of mmWave systems with NLoS channels are proposed

Proposed techniques enhances secrecy by employing path and antenna selection to jam eavesdroppers.
System model

• We consider a mmWave system where the transmitter communicates with a single antenna receiver via NLoS communications paths.
• The transmitter has one RF chain and \( N \) antennas.
• To transmit \( k_{th} \) information symbols \( s(k) \) to the receiver the transmitter multiplies \( s(k) \) by unit norm transmitting vector \( f(k) \).
• The received signal at the receiver in the presence of additive noise \( z(k) \) is given by

\[
y(k) = h^* f s(k) + z(k)
\]

• The channel \( h \) is given by

\[
h = \sqrt{\frac{N}{L}} \sum_{l=1}^{L} \alpha l a_T(\theta_l)
\]
Enhancing Secrecy with random path selection

• In this technique the transmitter transmits each data symbol along random path. The transmitters inner antenna phase shifts are set as:

\[ \gamma_n(k) = \left( \frac{N - 1}{N} - n \right) \pi \frac{2d}{\lambda} \cos(\theta_L) \]

• The beam forming vector is given by

\[ f_n(k) = \frac{1}{\sqrt{N}} e^{j\gamma_n(k)} \]

• At the receivers end we get

\[ y_R(k, \theta_L) = h^* f(k) s(k) + z_R(k) \]

\[ = \underbrace{s(k)}_{\text{information symbol}} + \alpha_L \sqrt{\frac{N}{L}} \underbrace{\sqrt{N}}_{\text{effective channel and array gain}} + \underbrace{z_R(k)}_{\text{additive noise}} \]
Enhancing Secrecy with random path selection

- At the eavesdropper we get

\[ y_E(k, \theta_E) = h f(k) s(k) + z_E(k) \]

\[ = \underbrace{s(k)}_{\text{information symbol}} \underbrace{\alpha_E \sqrt{1/LN} B(\theta_l)}_{\text{channel gain}} + \underbrace{z_E(k)}_{\text{additive noise}} \]
Enhancing Secrecy with random path selection

• The drawback here is that we require large number of paths $L$, to induce randomness.

• We propose to randomize both antennas and angle of departure to maximize artificial noise when $L$ is small.
Enhancing secrecy with joint path and antenna selection

• A random set $I_M$ of antennas is used to transmit along the strongest path and the remaining set $I_L$ of antennas are used to transmit along a random path.

• The transmit antenna phase shifts are set as

$$\gamma_n(k) = \begin{cases} (\frac{N-1}{2} - n) 2\pi \frac{d}{\lambda} \cos(\theta_S), & n \in I_M(k) \\ (\frac{N-1}{2} - n) 2\pi \frac{d}{\lambda} \cos(\theta_i), & n \in I_L(k) \end{cases}$$

• The receiver receives

$$y_R(k, \theta_S, \theta_i) = h^* f(k) s(k) + z_R(k)$$

$$= \underbrace{s(k)}_{\text{information symbol}} \underbrace{\frac{1}{\sqrt{LN}} \left( \alpha_S M + \alpha_i (N - M) + \beta_R \right)}_{\text{effective beamforming and channel gain}} + \underbrace{z_R(k)}_{\text{additive noise}}$$
Enhancing secrecy with joint path and antenna selection

- The eavesdropper receives

\[ y_E(k, \theta_S, \theta_i, \theta_E) = h^* f(k) s(k) + z_E(k) \]

\[ = s(k) + \alpha_E \beta_E \text{ effective artificial noise} + z(k) \text{ additive noise} \]
Performance evaluation

Setup
- A transmitter (Tx) with a single RF chain is communicating to a single antenna receiver (Rx) via NLoS links.
- Tx is equipped with ULA with half wavelength separation and \( N = 32 \) antennas.
- Eavesdropper and strongest receiver AoD overlap at AoD 40 degrees.

Assumptions
- Tx and Rx have perfect knowledge of their channels and path/antenna selection sequence.
- Tx and Rx are not aware of eavesdropper presence.

Secrecy Rate

\[
R = \left[ \log_2(1 + \text{SNR}_R) - \log_2(1 + \text{SNR}_E) \right]^+ 
\]

Secrecy rate versus the eavesdropper’s angle of departure for different number of transmission paths
Performance evaluation

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Assumptions
• Tx and Rx have perfect knowledge of their channels and path/antenna selection sequence.
• Tx and Rx are not aware of eavesdropper presence.

Secrecy Rate

\[ R = \left\lfloor \log_2(1 + SNR_R) - \log_2(1 + SNR_E) \right\rfloor^+ \]

Secrecy rate versus the eavesdropper’s Evesdropper average channel gain to receiver noise ratio; \( L = 12 \), eavesdropper located along the strongest path AoD 40 deg.
Conclusions

• Problem of PLS in the presence of an eavesdropper with overlapped channel paths with the target receiver is addressed.
• Two transmission techniques suitable for mmWave systems with analog antenna architectures are proposed.
• Random path selection and joint path and antenna selection induces noise-like signals at an arbitrary eavesdropper and improves the secrecy of the communication system.
• Proposed techniques require the number of paths $L>1$. For single path, LoS link, the proposed techniques can not safeguard against eavesdropping.
Questions

Please forward all questions/comments to the authors

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