Physical Layer Security for Space Shift Keying (SSK) Transmission

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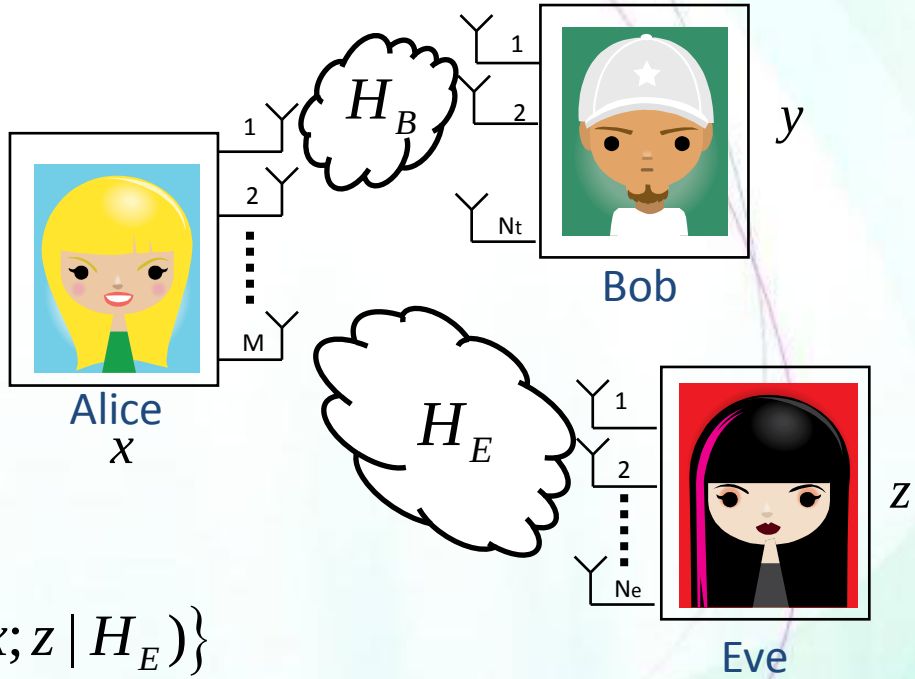
Physical Layer Security

- **Securing the communications at the physical layer;**
  an alternative to the conventional higher network-layer solutions for security
- **Basic principle:**
  to exploit the randomness of communications channels to allow a transmitter to deliver its message to an intended receiver while guaranteeing that a third party cannot maliciously infer any information about the transmitted message.

- **The attempt** is to realize a transmission in such a way so as to maximize the transmission rate over the main channel while keeping the eavesdropper ignorant about the message.

- **Secrecy Capacity:**

The rate at which transmitter can use the main link so as to deliver its message to the legitimate receiver in a way that the eavesdropper cannot successfully decode the same information.



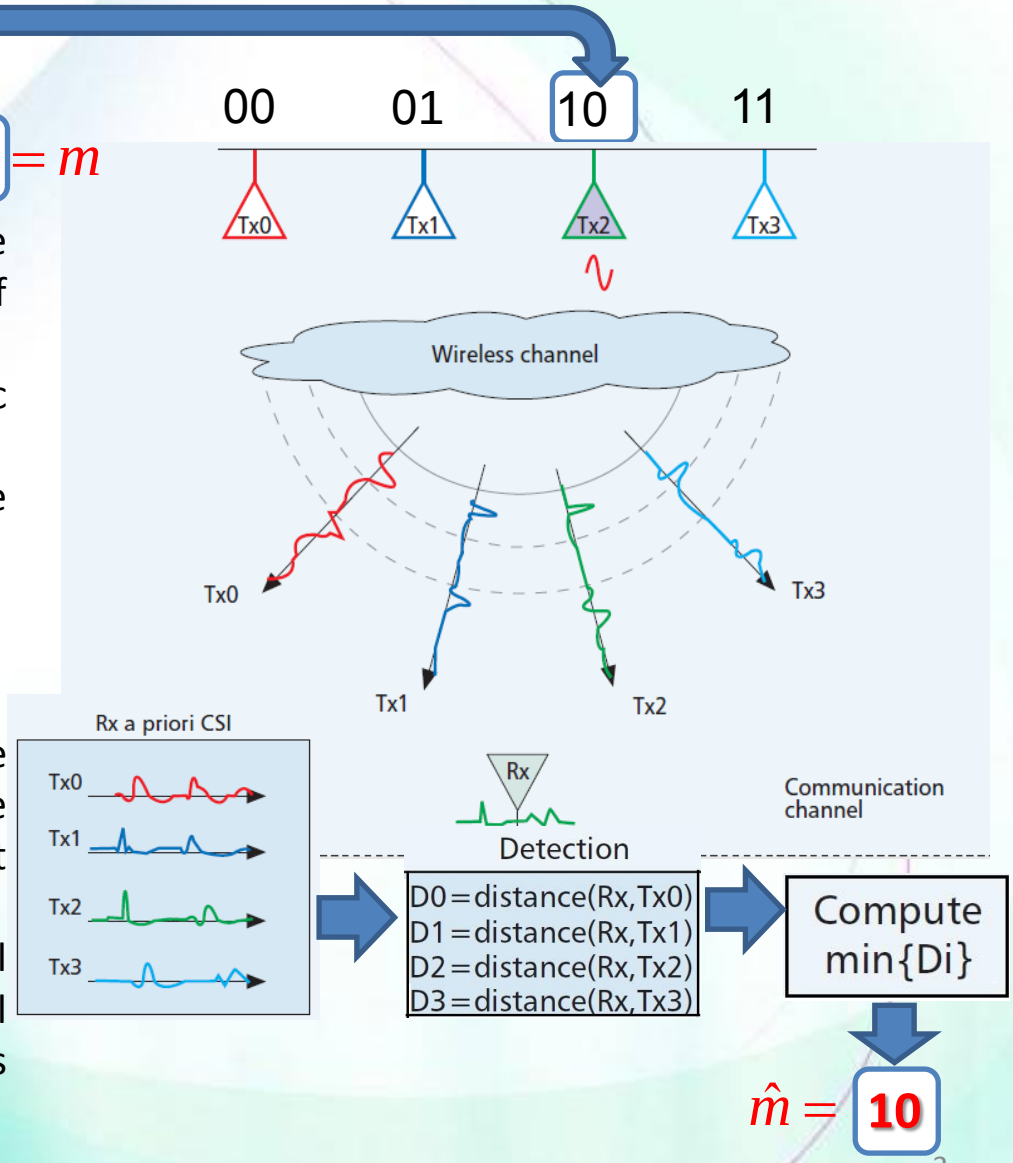
$$C_s = \max_{P_X(x)} \left\{ \underbrace{I(x;y \mid H_B)}_{\text{Mutual information over Bob's channel}} - \underbrace{I(x;z \mid H_E)}_{\text{Mutual information over Eve's channel}} \right\}$$

$P_X(x)$: Input distribution

Space Shift Keying (SSK)

...01001110 → **...01, 00, 11, 10** $= m$

- A recently proposed transmission scheme for low-complexity implementation of MIMO wireless systems
- Takes advantage of the location-specific property of the wireless channel
- Channel coefficients are playing the role of the "modulation unit"
- Each data block is mapped to a symbol x_j which is then transmitted from the j'th antenna.
- With the knowledge of the channel state information (CSI), receiver can detect the activated channel and accordingly detect the transmitted data.
- Spatial modulation (SM) is a more general form of SSK in which a conventional amplitude or phase modulation symbol is spatially modulated (similar to the SSK)



Physical Layer Security for SSK

- **To obtain an achievable secrecy rate for SSK as**

$$R_s = \left[I(x;y \mid H_B) - I(x;z \mid H_E) \right]\Big|_{P_X(x)=\frac{1}{M}} \le \mathrm{C}_S$$

we first obtain the mutual information for SSK as:

$$\begin{cases} \mathrm{H}_B = (h_{1_b}, h_{2_b}, \ldots, h_{M_b}) \\ \mathrm{H}_E = (h_{1_e}, h_{2_e}, \ldots, h_{M_e}) \end{cases}$$

$$I(x;y \mid h_1, h_2, \ldots, h_M) = \frac{1}{M\pi\sigma_n^2} \sum_{m=1}^{M} \int_y \exp(-|y-h_m|^2/\sigma_n^2) \times \log \frac{M \exp(-|y-h_m|^2/\sigma_n^2)}{\sum_{m'=1}^{M} \exp(-|y-h_{m'}|^2/\sigma_n^2)} dy$$

$$y = h_m + n$$

$$P_{Y|XH}(y \mid x, h_1, \ldots, h_M) \sim CN(h_m, \sigma_n^2)$$

$$P_{XY|H}(x, y \mid h_1, \ldots, h_M) \sim CN(h_m, \sigma_n^2) \times 1/M$$

$$P_{X|H}(x \mid h_1, \ldots, h_M) = 1/M$$

$$P_{Y|H}(y \mid h_1, \ldots, h_m) = \frac{1}{M} \sum_{m=1}^{M} P_{Y|XH}(y \mid x, h_1, \ldots, h_m)$$

$$I(x;y \mid h_1, h_2, \ldots, h_M) = \log_2 M - E_{(x,y,H)} \left[\log(1 + \sum_{j \ne i} \exp(-\frac{|d_{ij}+n|^2 - |n|^2}{\sigma_n^2}) \right]$$

where $d_{ij} = h_i - h_j$

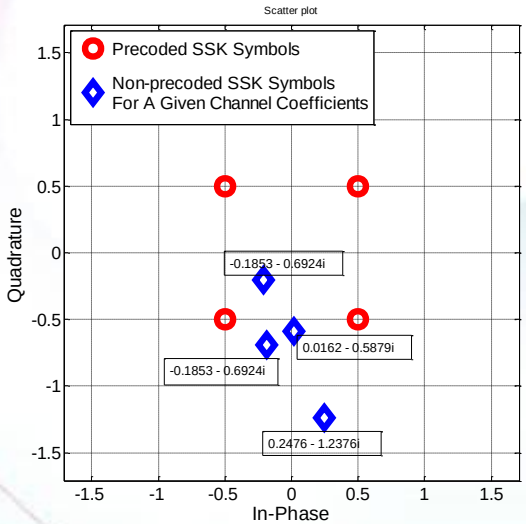
Precoding

With an assumption that the perfect CSI of the main channel is available at the transmitter, an appropriate precoding can be applied so as to maximize d_{ij}

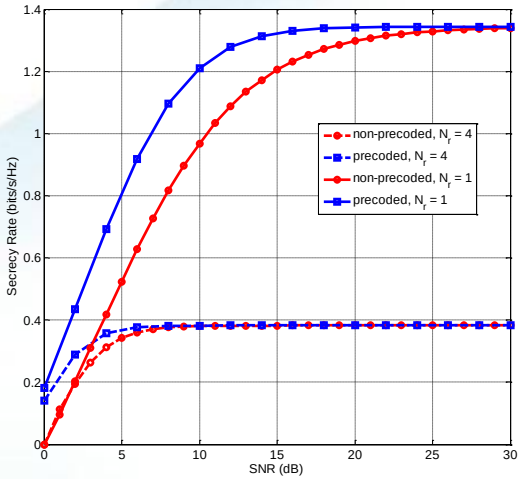
- **Transmission rate is maximized over the main channel.**
- **No gain from the eavesdropper's perspective.**

Numerical Results

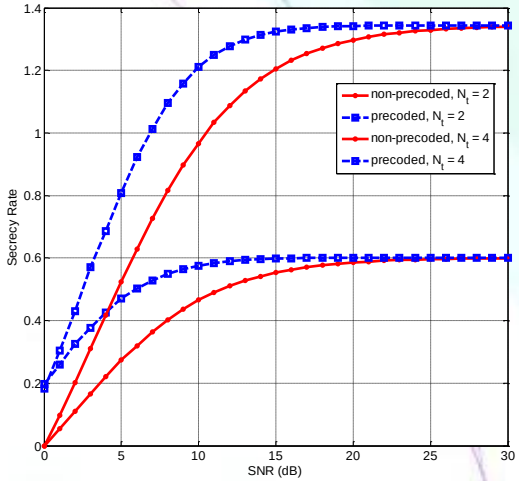
Legitimate receiver's SNR is varied while the eavesdropper's SNR is fixed to **0** dB.



An Example for Precoding



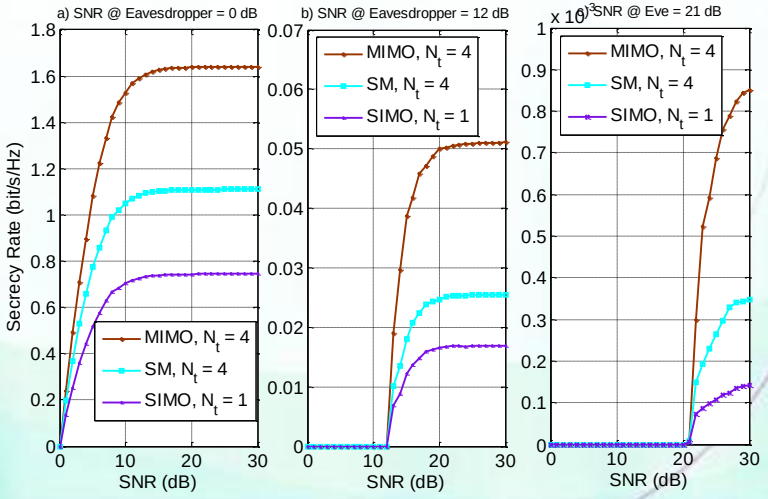
Effect of number of receive antennas on the achievable secrecy rates



Effect of number of transmit antennas on the achievable secrecy rates

Legitimate receiver's SNR is varied while the eavesdropper's SNR is fixed to **0**, **12** and **21** dB.

SM is capable of achieving a better secrecy rate with respect to a single-antenna transmission. However, there is a gap between the secrecy rates of SM and a general MIMO system in which all transmit antennas are activated in each time instant.



Conclusion

- **Derivation and evaluation of the secrecy capacity is one of the fundamental problems for physical layer security using which we can quantify the maximum rate at which a transmitter can send a message to an intended receiver without being decoded by an eavesdropper.**

- **An achievable secrecy rate, i.e. a lower bound on the secrecy capacity, was derived and evaluated for SSK which is a recently proposed wireless transmission scheme for low-complexity implementation of MIMO wireless system.**

- **A precoding scheme which maximizes the minimum Euclidean distance was proposed and the performance improvement achieved by that was evaluated for different number of transmit and receive antennas.**

- **The framework proposed in this poster can serve as a basis for future studies on SSK in context of secure wireless communications.**

References

[1] S. R. Aghdam, T. M. Duman, M. Di Renzo, "On Secrecy Rate Analysis of Spatial Modulation and Space Shift Keying," submitted to *IEEE BlackSeaCom 2015.*

[2] S. R. Aghdam, T. M. Duman, "Physical Layer Security in MIMO Wiretap Channels: A Survey on Secrecy with Imperfect Channel State Information," submitted to IEEE *Commun. Mag.*

[3] M. Di Renzo, H. Haas, and P. M. Grant, Spatial modulation for multiple antenna wireless systems – A survey, *IEEE Commun. Mag.*, vol. 49, no. 12, pp. 182-191, Dec. 2011.