Physical Layer Security over Wiretap Channels with Random Parameters

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- Alternative approach to cryptography:
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  - **Computationally unlimited** eavesdroppers.
- Appropriate for securing **low complexity** devices such as IoT.

Some Background

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- **Mutual Information:** $$\begin{aligned} I(X;Y) &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X). \end{aligned}$$

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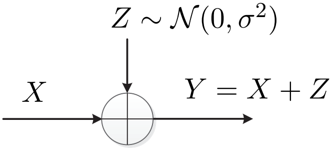

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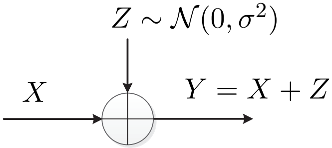

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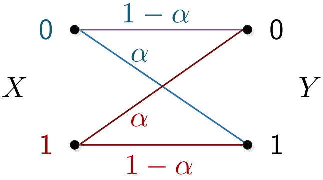

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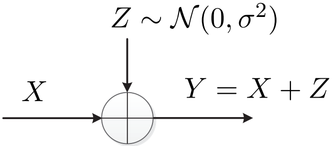

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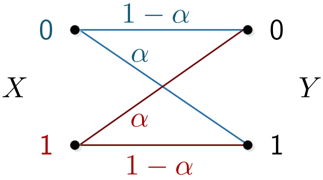

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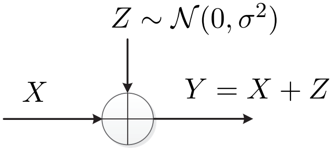

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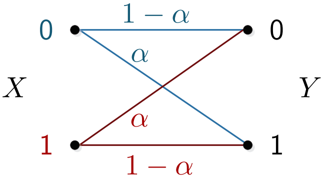

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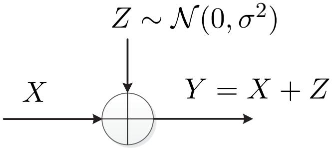

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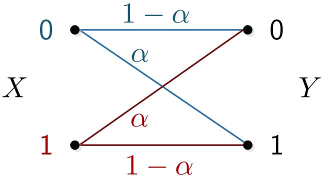

- **Questions we ask:**

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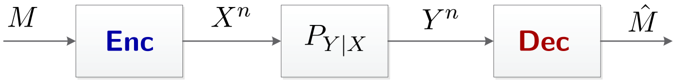
  - How to design codes at that rate?

Physical Layer Communication - Formal Definition



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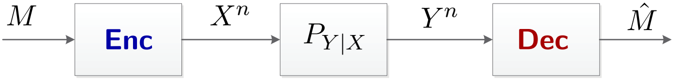

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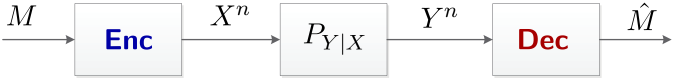

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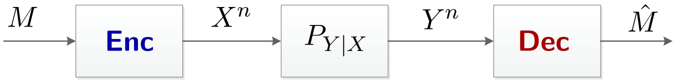

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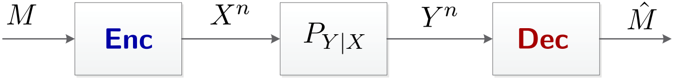

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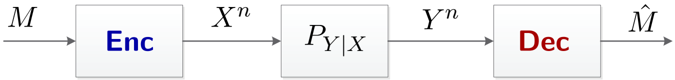

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Theorem (Shannon 1948)

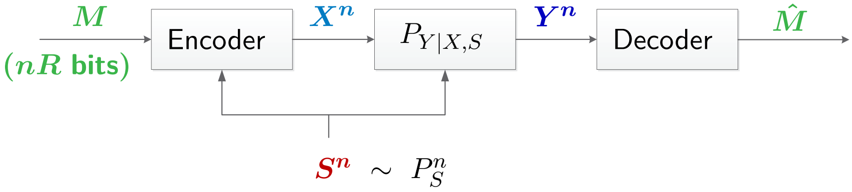
The capacity of a channel $P_{Y|X}$ is $\mathsf{C} = \max_{P_X} I(X;Y)$.

Reminder: $I(X;Y) = H(Y) - H(Y|X)$

State-Dependent Wiretap Channels

State-Dependent Channels

[Gelfand-Pinsker 1980]



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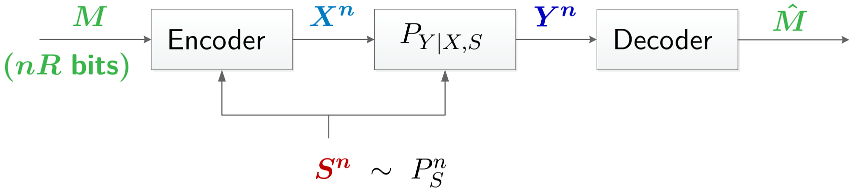

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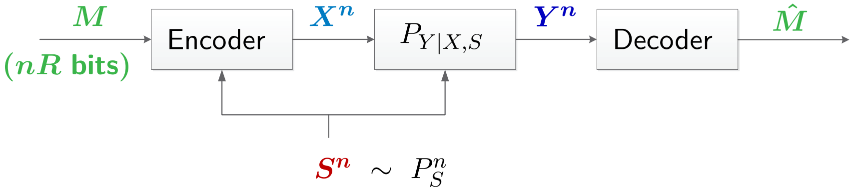

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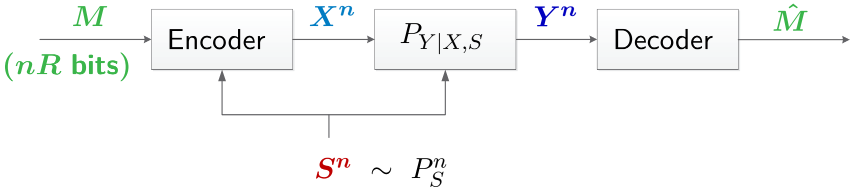

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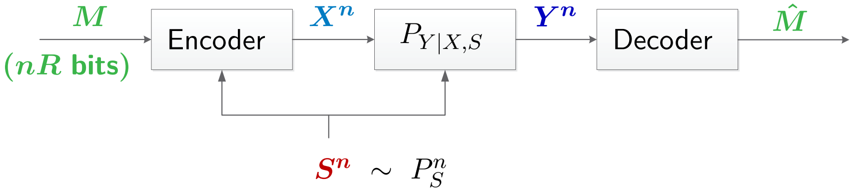

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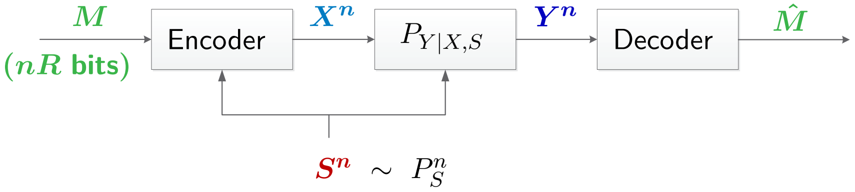

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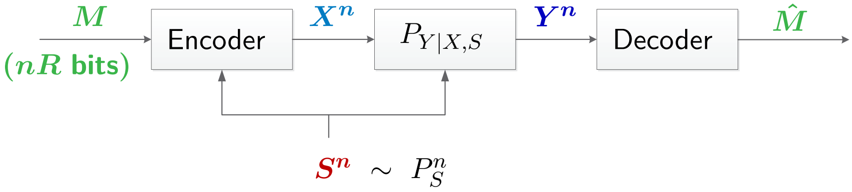

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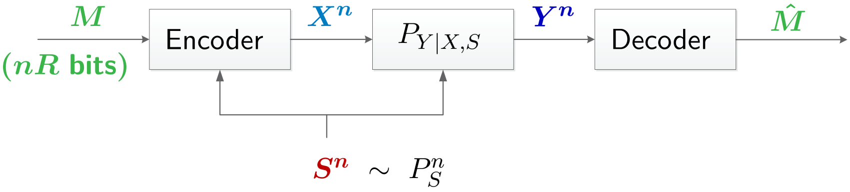

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State S_t	1	1	0	1	0	0	...
SNR at time t	Low						

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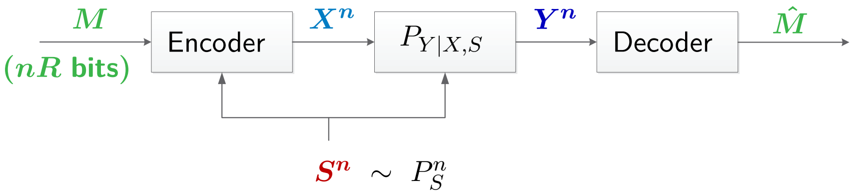

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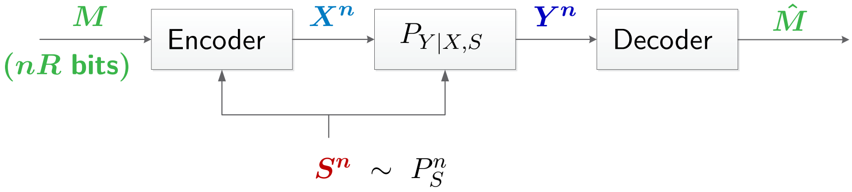

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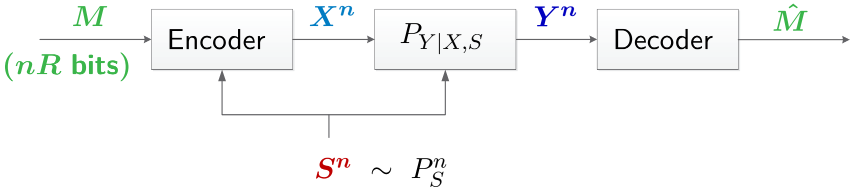

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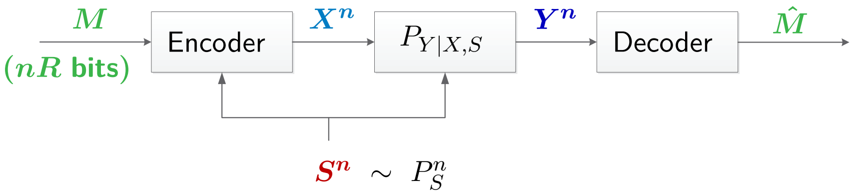

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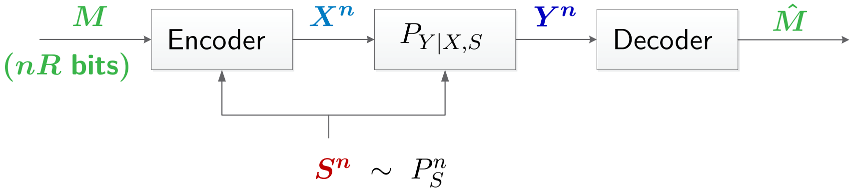

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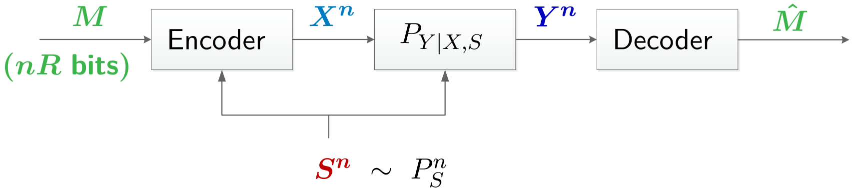

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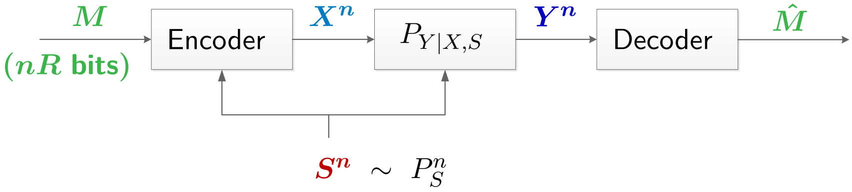

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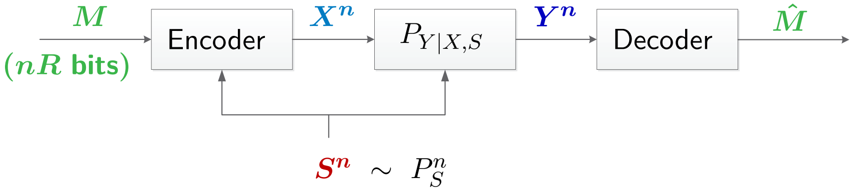

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Theorem (Gelfand-Pinsker 1980)

$$\mathsf{C}_{\mathsf{GP}} = \max_{P_{U,X|S}} \Big[I(U;Y) - I(U;S) \Big]$$

Joint distribution: $P_{U,X|S} P_{Y|X,S}$

The Gelfand-Pinsker Channel - Encoding

- Pad nR **message bits** with $n\tilde{R}$ **redundancy bits**.

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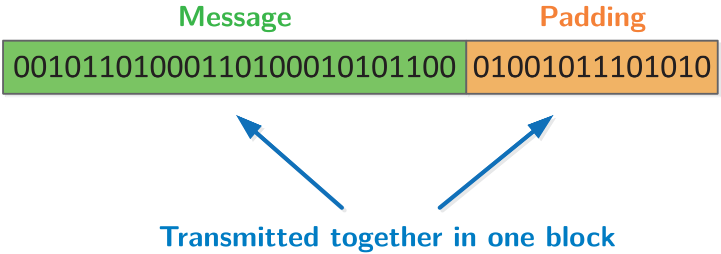

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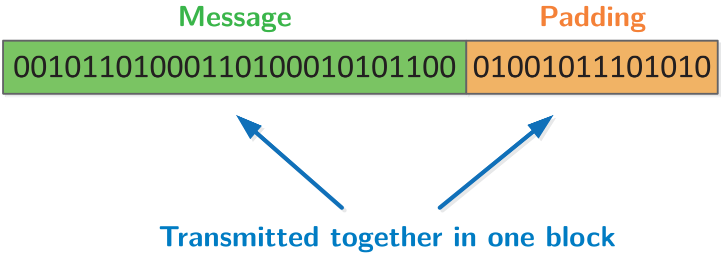

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Message	Padding
00101101000110100010101100	01001011101010

Transmitted together in one block

- **Codebook:** (**Message**, **Padding**) $\rightarrow$ Codeword $\boldsymbol{U^n}$.
- **Correlating $\boldsymbol{U^n}$ with $\boldsymbol{S^n}$:** $\tilde{R} > \boldsymbol{I(U;S)}$.

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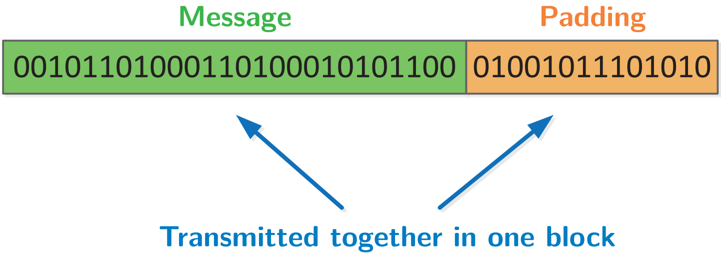

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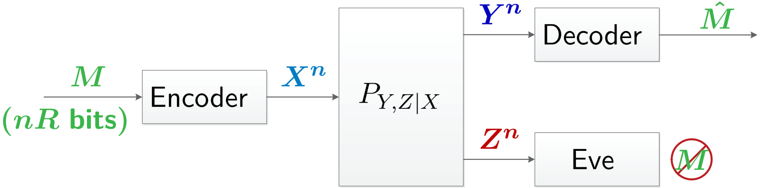
- **Reliability:** $R + \tilde{R} < \boldsymbol{I(U;Y)}$.

Wiretap Channels

Degraded [Wyner 1975], General [Csiszár-Körner 1978]



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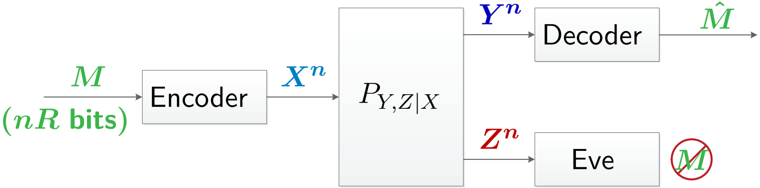

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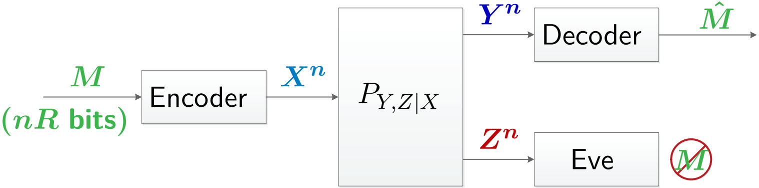

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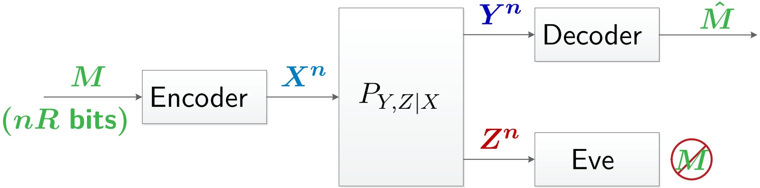

Secrecy-Capacity:

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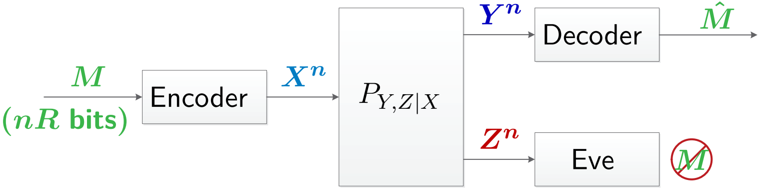
- Z^n contains no information about M.

Wiretap Channels

Degraded [Wyner 1975], General [Csiszár-Körner 1978]



Secrecy-Capacity:

- Reliable Communication.
- Z^n contains no information about M.

Theorem (Csiszár-Körner 1978)

$$\mathsf{C}_{\mathsf{WTC}} = \max_{P_{U,X}} \Big[I(U;Y) - I(U;Z) \Big]$$

Joint distribution: $P_{U,X} P_{Y,Z|X}$

Wiretap Channels - Encoding

- Pad nR **message bits** with $n\tilde{R}$ **redundancy bits**.

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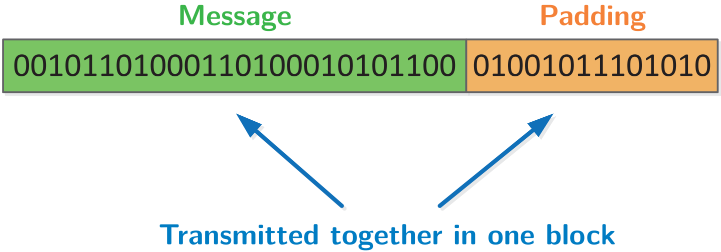

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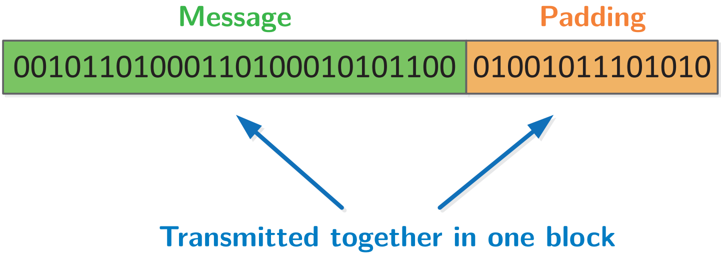

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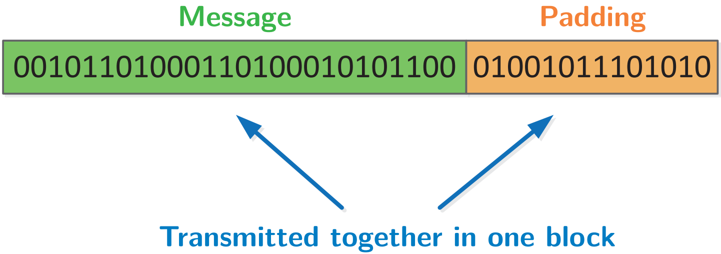

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- **Security:** $\tilde{R} > I(U;Z)$.

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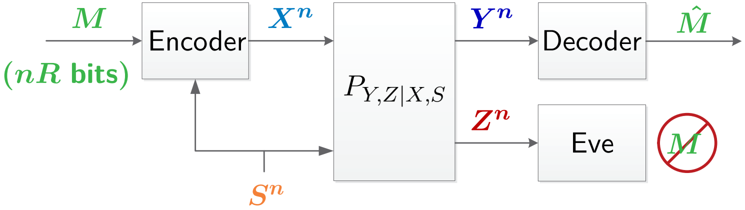
Message	Padding
00101101000110100010101100	01001011101010

Transmitted together in one block

- **Codebook:** (**Message**, **Padding**) $\rightarrow$ Codeword U^n.
- **Security:** $\tilde{R} > I(U;Z)$.
- **Reliability:** $R + \tilde{R} < I(U;Y)$.

The Gelfand-Pinsker Wiretap Channel



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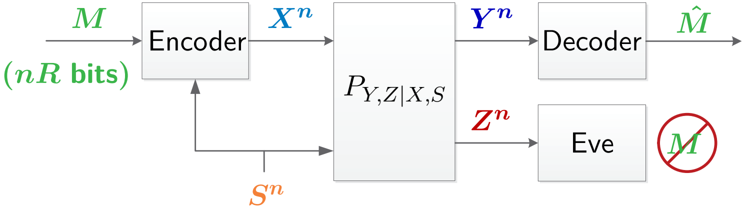

Secrecy Capacity: Reliable and Secure Communication.

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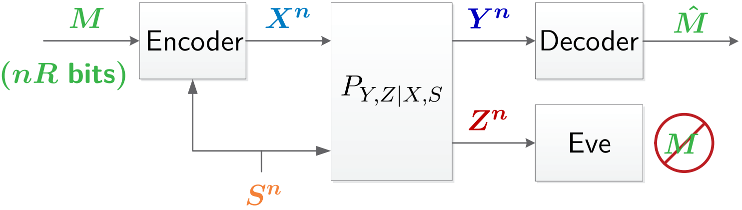

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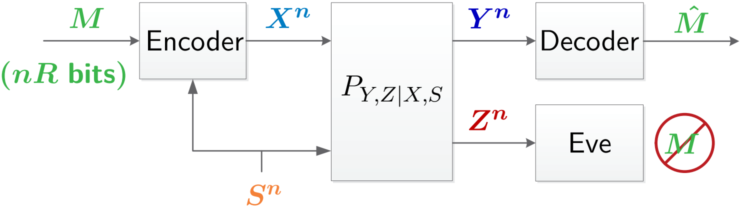

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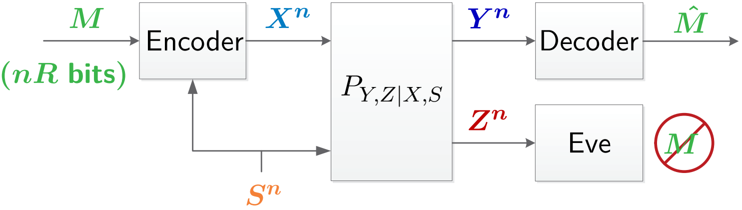

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- Enhance **reliable** communication rate (coherent transmission).
- Boost **security** performance (e.g., via secret key agreement).

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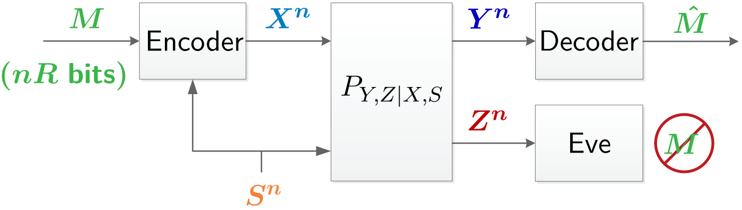
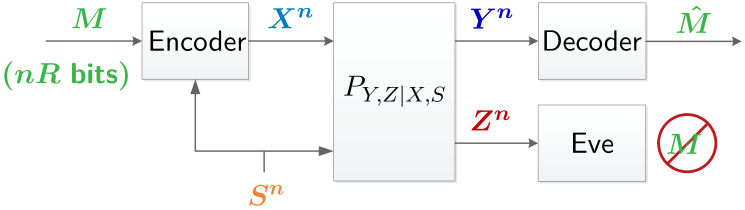


Naive Approach:

The Gelfand-Pinsker Wiretap Channel



Naive Approach: Combine **wiretap coding** with **GP coding**.

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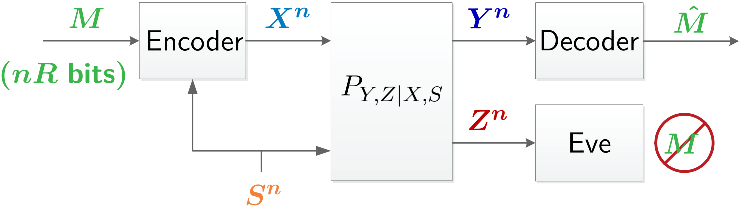

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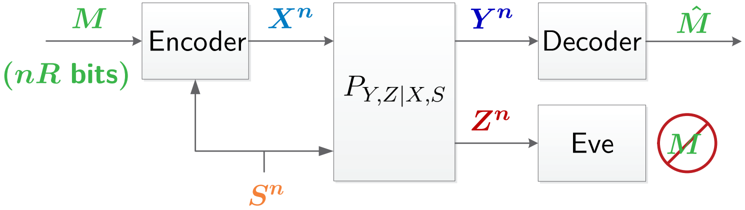

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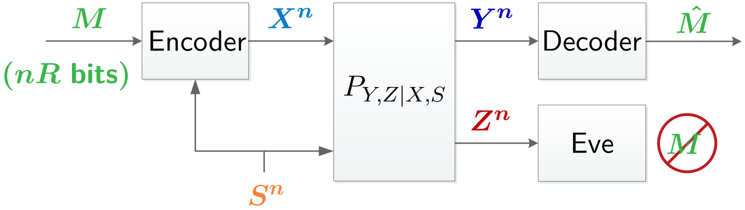

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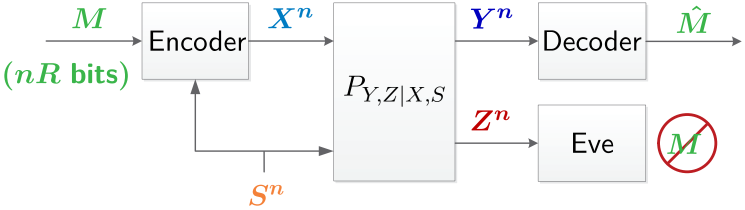

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★ Always preforms **wiretap coding** $\Longrightarrow$ Suboptimal vs. **strong Eve**

Improved Two-Layered Coding Scheme

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Strict Improvement: Explicit example & Analytic derivation.

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