Physical layer authentication

Review of physical layer authentication techniques

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Outline

1 Introduction

2 Low OSI layers security

3 Physical layer authentication

4 Superimposed-tag authentication

5 Slope authentication

6 Conclusion

Introduction
IoT

My research is about enhancing security at low OSI layers in industrial internet of things (IIoT) field.

IoT characteristics:

- Limited ressources: storage, energy, computation, ...
- Diversity in protocols and in devices
- Profit driven businesses
- Lack of related legislation

From [1, 2, 3]

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IoT characteristics:

- Limited ressources: storage, energy, computation, ...
- Diversity in protocols and in devices
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$\Rightarrow$ Security flaws

From [1, 2, 3]

Introduction

Industrial Internet of Things (IIoT)

IIoT characteristics:

- Sensors
- Controllers
- Production lines
- Used for efficiency and safety

From [1, 2, 3]

Introduction

Industrial Internet of Things (IIoT)

IIoT characteristics:

- Sensors
- Controllers
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- Used for efficiency and safety

$\Rightarrow$ We need cybersecurity !!!

From [1, 2, 3]

Why low OSI layers security ?

From [4]

Layer	Protocol data unit (PDU)
Application	Data
Presentation	Data
Session	Data
Transport	Segment, Datagram
Network	Packet
Data link	Frame
Physical	Bit, Symbol

Why low OSI layers security ?

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Why low OSI layers security ?

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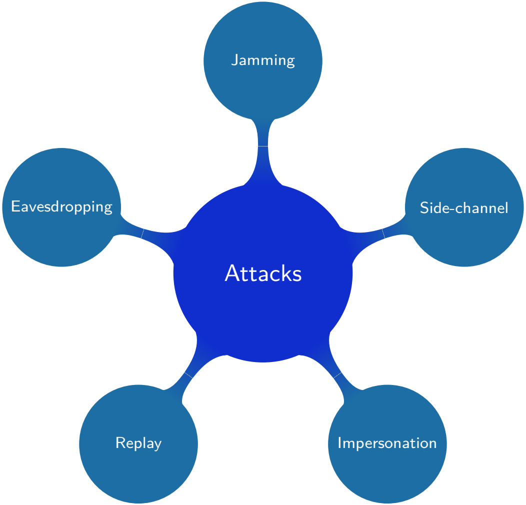
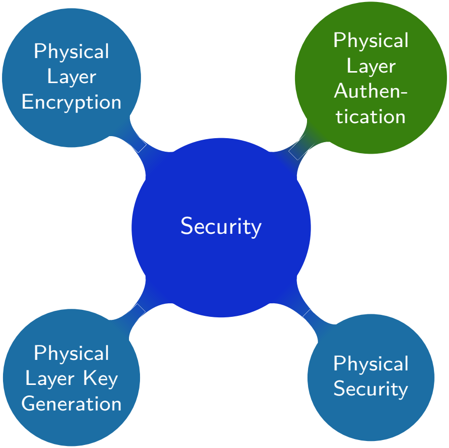
Because there are attacks on low layers ...



From [1, 2, 3]

How to defend against them in PHY layer ?



From [1, 2, 3]

What's physical layer authentication (PLA) ?

From [1]

What's physical layer authentication (PLA) ?

It allows a legitimate receiver to distinguish between a legitimate transmitter and a rogue one [1].

It enables defense against both passive (eavedropping) and active (impersonation) attacks.

It occurs at the physical layer where the unauthenticated signals can be ignored and quickly rejected.

From [1]

PLA should be robust, secure and covert

1. Robustness: The technique should be robust to channel fading and noise effects
   Channel fading: random signal attenuation due to the environment of the communication channel [5].

2. Security: The technique should be resistant to adversary attacks

3. Covertness: Unaware receiver should be able to decode signals sent from an aware transmitter

From [1]

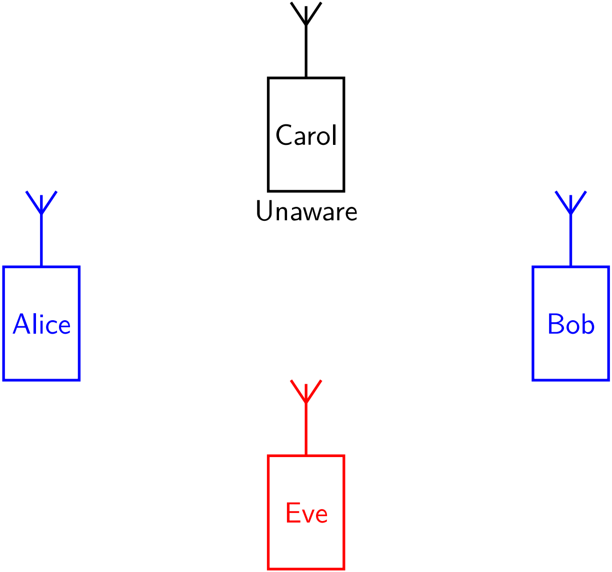
Active or passive PLA ?

1. Passives: use channel and/or device properties to authenticate a transmitter
   * Drawback: sensitive to external variables, e.g. temperature

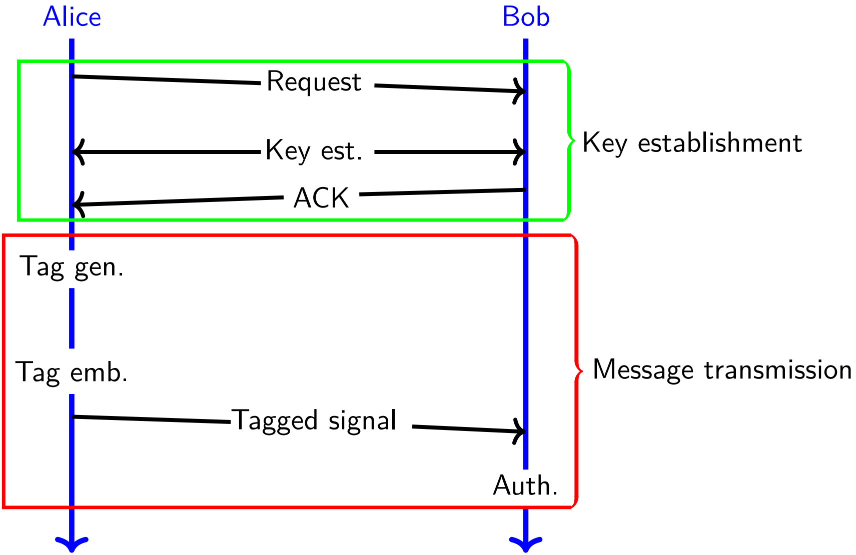
2. Actives: Embbed a "tag" to the signal to authenticate the transmitter
   * if lightweight, this should be useful in industry environment

From [1, 6, 7]

Communication scenario and roles



Key establishment and message transmission stages in active PLA



Superimposed-tag transmission (SUP method)

Idea: to send a tag signal simultaneously with the message signal

From [6]

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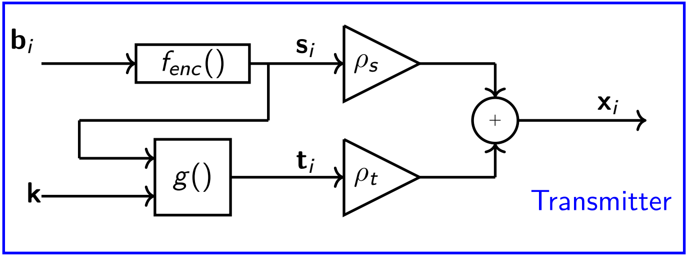

with

- $\mathbf{b}_i = \{b_1, \ldots, b_L\}_i$ block of L message symbols (i.i.d. RVs);
- $f_{enc}()$ the encoding function and $g()$ the tag generation function;
- ρ_* the energy ratio allocated to the message (ρ_s) and to the tag (ρ_t) $\Rightarrow \rho_s^2 + \rho_t^2 = 1$.

From [6]

Signal reception and estimation

Bob will receive a signal $\mathbf{y}_i$:

$$\mathbf{y}_i = h_i \mathbf{x}_i + \mathbf{n}_i$$

- $\mathbf{h}_i$: Rayleigh flat-block fading channel $h_i \sim \mathcal{CN}(0, \sigma_h^2)$
- $\mathbf{n}_i$: white gaussian noise $\mathbf{n}_i = \{n_1, \ldots, n_L\}_i$ where $\{n_k\}_i \sim \mathcal{CN}(0, \sigma_n^2)$

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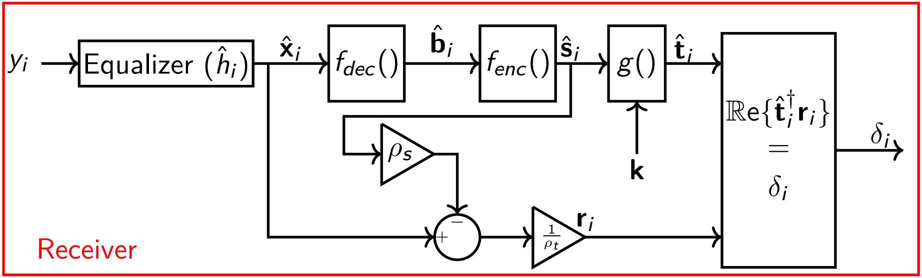

From [6]

Received signal authentication

Received signal authentication

The authentication is a threshold test with hypoteses [8]:

$$H_0: \quad \delta_i \sim \mathcal{N}\left(0, \frac{L}{2\rho_t^2\gamma_i}\right) \quad \rightarrow \mathbf{t}_i \text{ is not present in } \mathbf{r}_i$$

$$H_1: \quad \delta_i \sim \mathcal{N}\left(L, \frac{L}{2\rho_t^2\gamma_i}\right) \quad \rightarrow \mathbf{t}_i \text{ is present in } \mathbf{r}_i$$

- γ_i: instantaneous channel SNR ($= \frac{|h_i|^2}{\sigma_n^2}$)
- $\bar{\gamma}$: average SNR ($= \frac{\sigma_h^2}{\sigma_n^2}$)

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The authentication decision φ_i is then:

$$\varphi_i = \begin{cases} 1, & \delta_i \geqslant \theta_i^0 \\ 0, & \delta_i < \theta_i^0 \end{cases}$$

with θ_i^0 the optimal threshold for a fixed probability of false alarm ϵ_{FA} ($P\{H_0|H_1\}$).

Probability of authentication and simulation

The probability of detection of a randomly chosen block is [8]

$$P_D = \mathbb{E}\{Pr\{\delta_i \geqslant \theta_i^0 | H_1\}\} = \frac{1}{2}\left(1 - \mathrm{sign}(\theta^0 - L)\sqrt{\frac{(\theta^0 - L)^2 \rho_t^2 \bar{\gamma}}{L + (\theta^0 - L)^2 \rho_t^2 \bar{\gamma}}}\right)$$

Probability of authentication and simulation

The pro

$P_D =$

$$\frac{\rho_t^2\bar{\gamma}}{2\rho_t^2\bar{\gamma}}\Bigg)$$

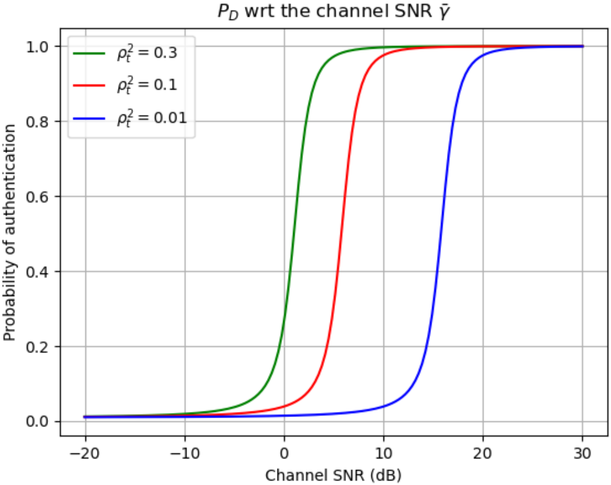


Figure: P_D versus different SNRs for $L = 64$, $\epsilon_{FA} = 0.01$, and different ρ_t^2.

Idea of slope authentication

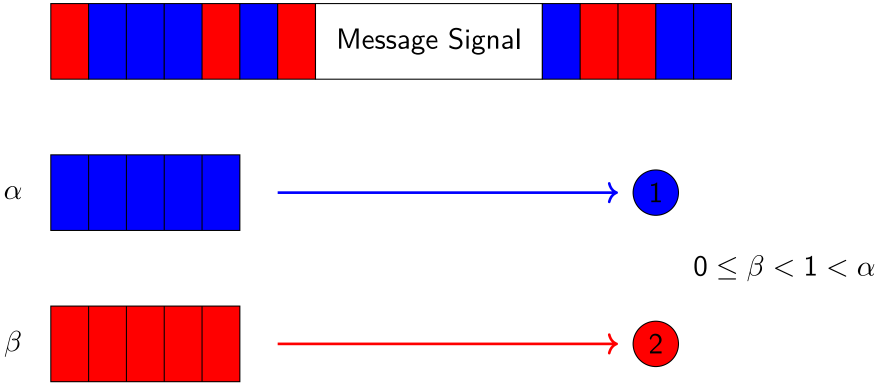
Idea: to divide the message signal into several groups and shuffle the symbols according to the secret key **k**

From [7]

Idea of slope authentication

Idea: to divide the message signal into several groups and shuffle the symbols according to the secret key **k**

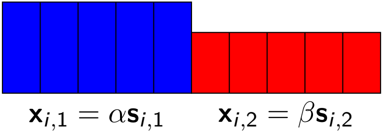
Take the case of two equal groups:



From [7]

Tagged signal transmission and reception

The tag $\mathbf{t}_i = g(\mathbf{p}_i, \mathbf{k})$ ($\mathbf{p}_i$ is the pilot signal) indicates which message signal symbol belongs to which group and is not sent. The tagged signal is constructed as



with $\mathbf{s}_{i,*}$ the message signal symbols belonging to the group $*$ and the energy allocation limitation $\frac{\alpha^2}{2} + \frac{\beta^2}{2} = 1$.

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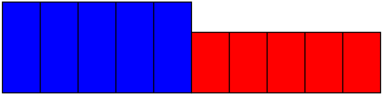

$$\mathbf{x}_{i,1} = \alpha \mathbf{s}_{i,1} \qquad \mathbf{x}_{i,2} = \beta \mathbf{s}_{i,2}$$

with $\mathbf{s}_{i,*}$ the message signal symbols belonging to the group $*$ and the energy allocation limitation $\frac{\alpha^2}{2} + \frac{\beta^2}{2} = 1$.

The received tagged signal: $\mathbf{y}_i = \mathbf{y}_{i,1} | \mathbf{y}_{i,2}$ with $\mathbf{y}_{i,*} = h_i \mathbf{x}_{i,*} + \mathbf{n}_{i,*}$.

Remark: Nakagami-m block-fading channel model [7] ($m = 0.5$, $1 \Leftrightarrow$ one-sided Gaussian distribution, Rayleigh, respectively).

From [7]

Test statistic is the slope between the groups

The hypotheses are different from the SUP method:

$$H_0: \quad \mathbf{y}_i \text{ is a normal signal}$$
$$H_1: \quad \mathbf{y}_i \text{ is a tagged signal}$$

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To decide for authtencity of a signal we will compare τ_i to a threshold θ_i as before:

$$\tau_i = \tau_{i,1} - \tau_{i,2}$$

with $\tau_{i,*} = \mathbf{y}_{i,*}^{\dagger}\mathbf{y}_{i,*}$.

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We can see a second advantage of the slope authentication compare to the SUP method: one multiplication instead of channel estimation and demodulation

From [7]

Probability of authentication

The probability of tag detection for the $i th$ block is

$$P_{i,PD} = Q_1\left(\sqrt{\frac{2T_i^2}{\sigma_n^2}}, \sqrt{2\ln\left(\frac{1}{2\epsilon_{FA}}\right)}\right) - \frac{1}{2}e^{\left(\ln\left(\frac{1}{2\epsilon_{FA}}\right) - \frac{T_i^2}{2\sigma_n^2}\right)} Q_1\left(\sqrt{\frac{T_i^2}{\sigma_n^2}}, \sqrt{4\ln\left(\frac{1}{2\epsilon_{FA}}\right)}\right)$$

with Q_1 the first order Marcum Q-function and $T_i = |h_i|^2\left(\alpha^2 - \beta^2\right)$.
Then, for a randomly chosen block, the probability of detection is

$$P_D = \int P_{i,PD} f_\gamma(\gamma) d\gamma$$

with $f_\gamma(\gamma)$ the PDF of channel SNR.

From [7]

Probability of authentication

The probabi

$P_{i,}$

with Q_1 the ... $-\beta^2)$.
Then, for a ... is

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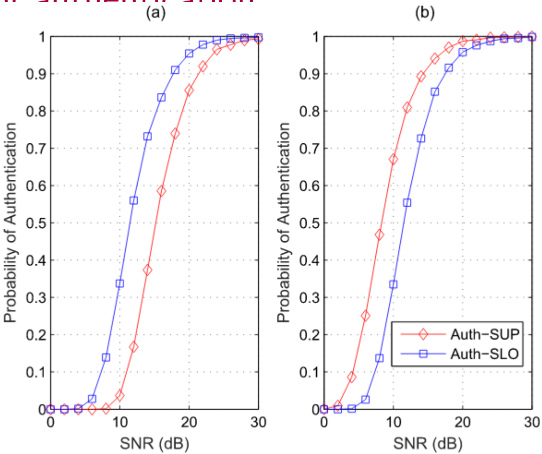

Fig. 6. Authentication probabilities of the Auth-SUP method and the proposed Auth-SLO method considering each block separately with $\varepsilon_{FA} = 0.01$, where the remaining simulation parameters are the same as those of Fig. 5 except (a) $\rho_t = 0.1$, $\beta = 0.9$; (b) $\rho_t = 0.15$, $\beta = 0.9$.

From [7]

BER and channel estimation: superiority of slope method

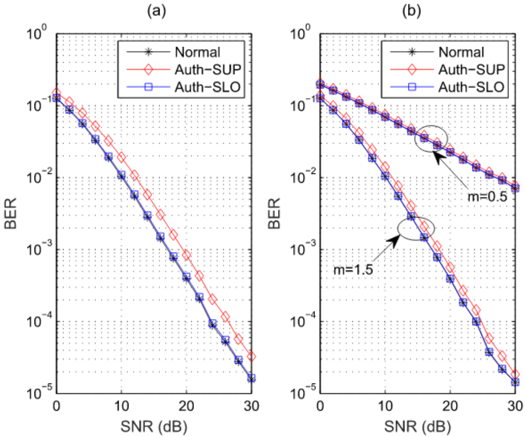

Fig. 5. BER of Carol's receiver for a normal signal, the Auth-SUP method and the proposed Auth-SLO method under Nakagami fading with $m = 1.5$, where the transmit signal is modulated with binary phase-shift keying (BPSK), $L = 2000, f_c = 2\text{GHz}$ and $d = 100\text{m}$. (a) $\rho_t^2 = 0.1$, $\beta = 0.9$; (b) $\rho_t^2 = 0.05$ and $\beta = 0.95$.

BER and channel estimation: superiority of slope method

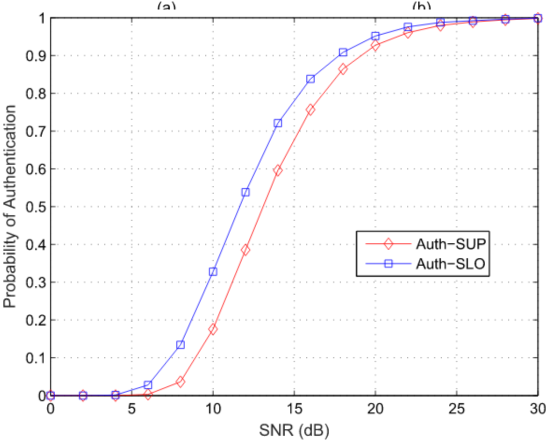

Fig. 9. Authentication probabilities of the Auth-SUP method and the proposed Auth-SLO method considering each block separately with $\varepsilon_{\mathrm{FA}} = 0.01$, where $\hat{h} = h + \tilde{h}$, $\tilde{h} \sim \mathcal{CN}\left(0, \sigma_n^2\right)$ and the remaining simulation parameters are the same as those of Fig. 6(b).

Conclusion

Two methods were presented:

1. Superimposed tag authentication
2. Slope authentication

Both methods are sensible to their parameters (ρ_t and β). Still, the slope method present advantages compared to the SUP method:

- reduced impact at the unaware receiver
- reduced computation complexity

However, I didn't recover the [7] figures. After recovering them, parameter optimization will be done for different IIoT application: simulate an industrial environment and apply PLA methods with specific standard.


CREATE SLIDES
PRESENT SLIDES
END THE PRESENTATION SUCCESSFULLY
QUESTIONS OF THE AUDIENCE

References I

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[8] N. Xie, C. Chen, and Z. Ming, "Security model of authentication at the physical layer and performance analysis over fading channels," *IEEE Transactions on Dependable and Secure Computing*, vol. 18, no. 1, pp. 253–268, jan 2021.

Superimposed-tag authentication (SUP) [6]

Definitions and transmitted tagged signal

Idea: to send a tag signal simultaneously with the message signal

Definitions:

- b_i: block of L message symbols $\{b_{i,k}\}$ idependent and identically distributed;
- f_{enc}: encoding function (channel coding, modulation and pulse shaping);
- f_{dec}: decoding function (inverse of f_{enc});
- s_i: message signal ($=f_{enc}(b_i)$);
- t_i: tag signal ($=g(s_i,\mathbf{k})$) with g the tag generation function, e.g. hash function;
- ρ_*: energy allocation for the signal (s) or the tag (t) $\rightarrow \rho_s^2 + \rho_t^2 = 1$.

Alice sends the signal x_i to Bob:

$$x_i = \rho_s s_i + \rho_t t_i$$

Assumptions: $\mathbb{E}\{M_{i,k}\} = 0$; $\mathbb{E}\{|x_{i,k}|^2\} = 1$; $\mathbb{E}\{|M_i|^2\} = L$; $\mathbb{E}\{s_i^\dagger t_i\} = 0$; where M denotes s, t or x; $k = \{1, \ldots, L\}$.

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Superimposed-tag authentication (SUP) [6]

Tagged signal and detection

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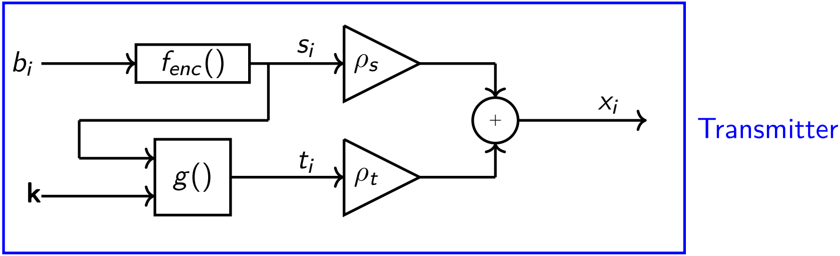
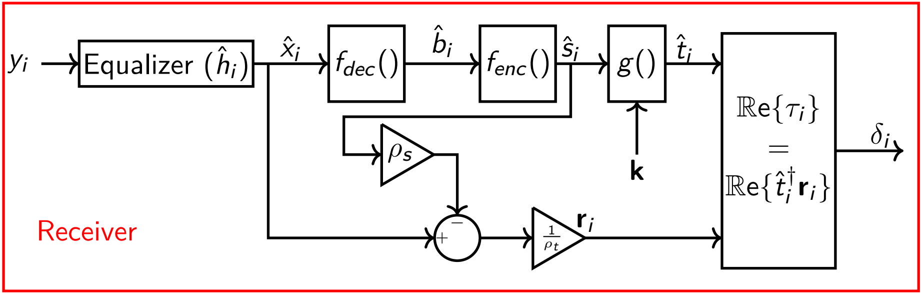
Bob will compare the estimated tag $\hat{t}_i$ and a computed residual signal $\mathbf{r}_i = \frac{1}{\rho_t}(\hat{x}_i - \rho_s \hat{s}_i)$.

Superimposed-tag authentication (SUP) [6]

Transmission, reception and authentication block diagrams





Slope authentication [7]

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The received tagged signal is then:

$$y_{i,1} = h_i x_{i,1} + n_{i,1}$$
$$y_{i,2} = h_i x_{i,2} + n_{i,2}$$

[7] considers Nakagami-m block-fading channel. The Nakagami-m PDF is

$$f_x(x) = \frac{2m^m x^{2m-1}}{\Gamma(m)} e^{(-mx^2)}$$

Slope authentication [7]

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The probability of tag detection for the i*th* block is

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Then, for a randomly chosen block, the probability of detection is

$$P_D = \int P_{i,PD} f_\gamma(\gamma) d\gamma$$

with $f_\gamma(\gamma) = \frac{1}{\gamma\Gamma(m)}\left(\frac{m\gamma}{\bar{\gamma}}\right)^m e^{\left(-\frac{m\gamma}{\bar{\gamma}}\right)}$, $\gamma \geq 0$.

Slope authentication [7]

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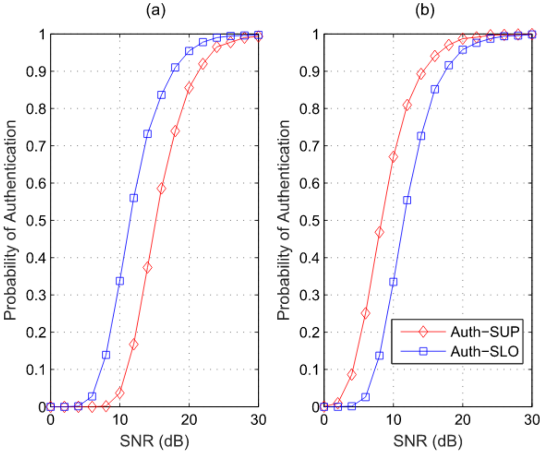
Then, for a ... is



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