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M2M: System Control via PLC

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烽火台 Beacon Tower

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現代的烽火台

The ancient tower meets radio-tech.

something has changed

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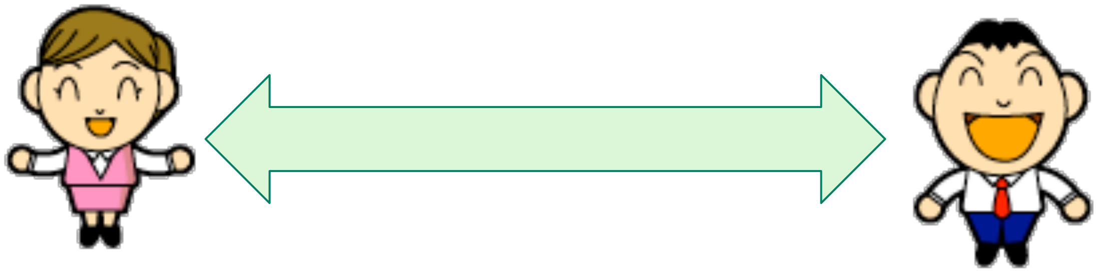
No Change… for thousands years

1000 – 2000 years ago

two days ago



Human to Human

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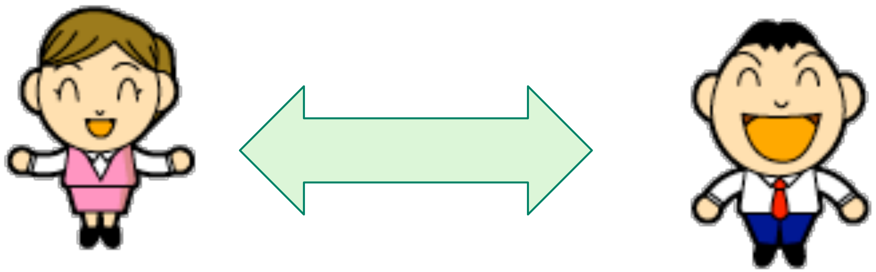
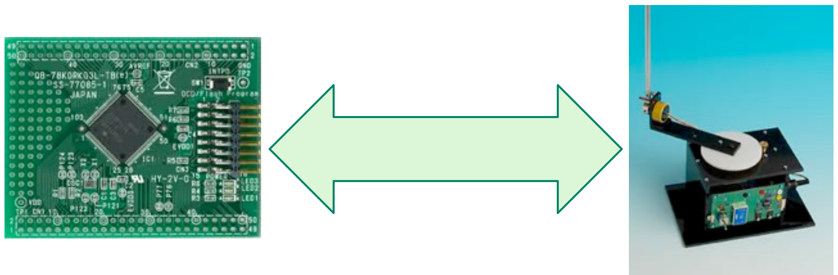
M2M or Cyber Physical Systems

- Comm. users for thousands years



Conventional Users

- New Users



M 2 M Communications

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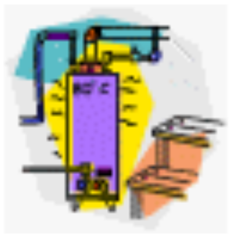
M2M: Old and also very New field of research

- Industrial Machines   Automatic cranes, Robotic arms.
- Robots / Humanoid
- Intelligent Transportation System
- Home/Building/Community
  Energy Management
- Smart Grid and Smart Community



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Smart Grids

- Two way flow of Energy and Information
  - Information Collection：Sensor Networks
  - System Control: Control Communications
- Features
  - Scale
    - larger than conventional control/sensor networks
  - Security
    - Information is highly private
  - Reliability and Robustness
    - Error in Communication results in social problem
    - Possibility of Intentional Attacks
  - M2M Communication

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Control of distributed machines / plants in a wide area is a key to sustainable society.

Wireless* Control is needed

* PLC is wireless technology that uses lines!

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Control of distributed machines in a wide area is a key to sustainable society.

Wireless* is not Reliable!

↓

Robust Reliable Radio is needed

* PLC is wireless technology that uses lines!

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reliable/robustness was important
also in traditional wireless communications

Is there any difference?

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Measures of Wireless Systems

Wireless Engineers' Favorites are

- Top (Best Case) Data Rate
- Throughput = Average Data Rate
- Average Bit Error Rate

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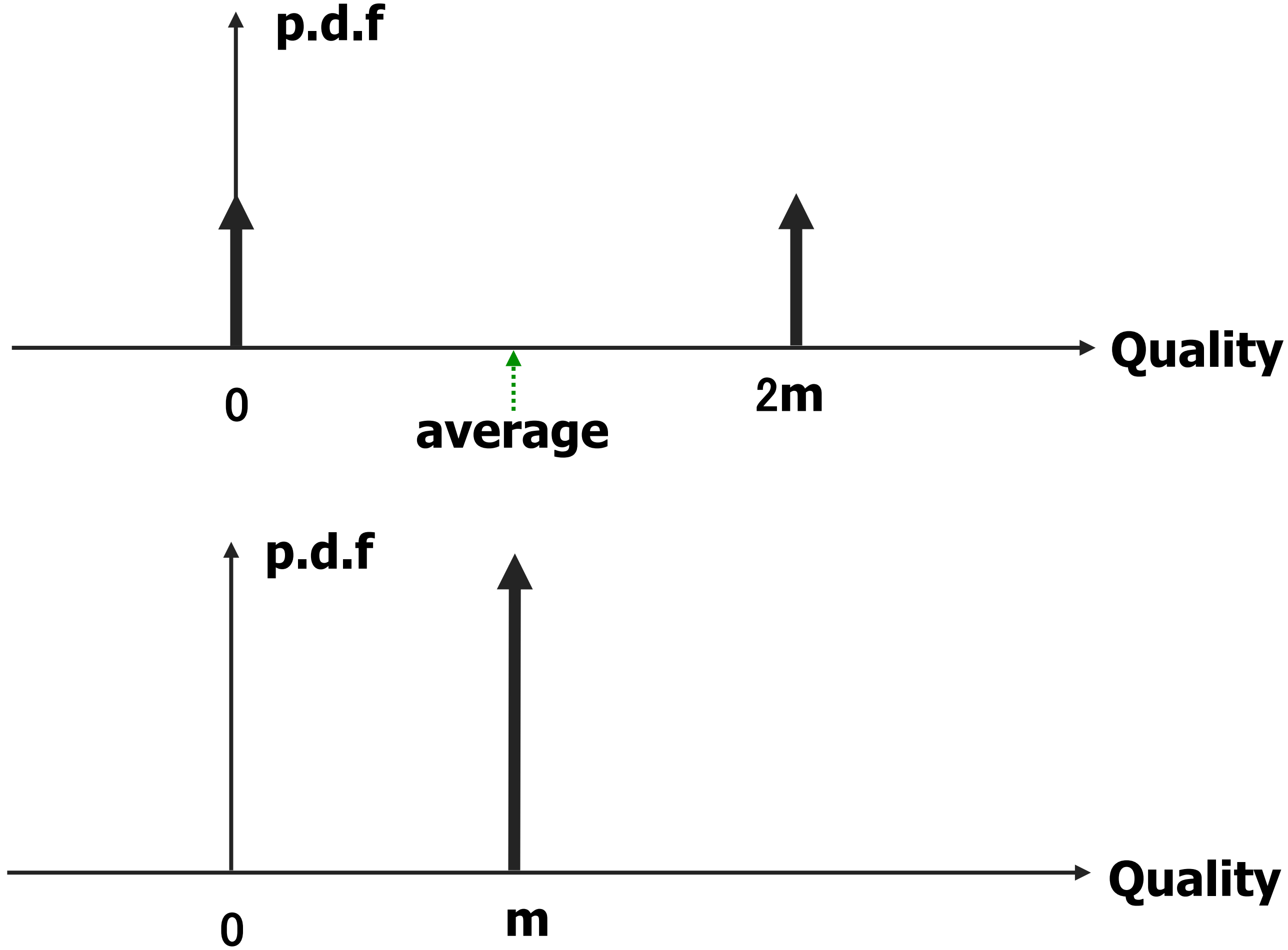
Averages are the same, but …



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Average/Worst Delay

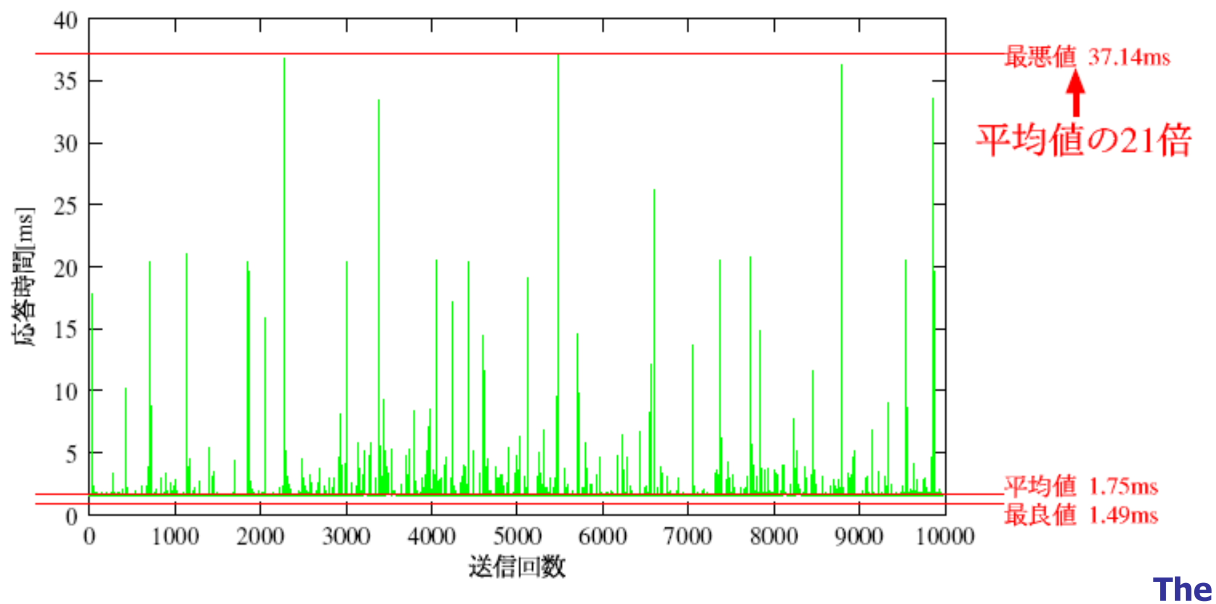

図 1: パケット送信に対する応答時間

The data is provided by Prof. Hirayama@NIT

Wireless LAN: 802.11g (64bytes/packet)
Propagation: 10 meters LOS
Transmission: 100packets, 1ms after ACK
Location: Indoor @ University Building (10 x 20 m^2)

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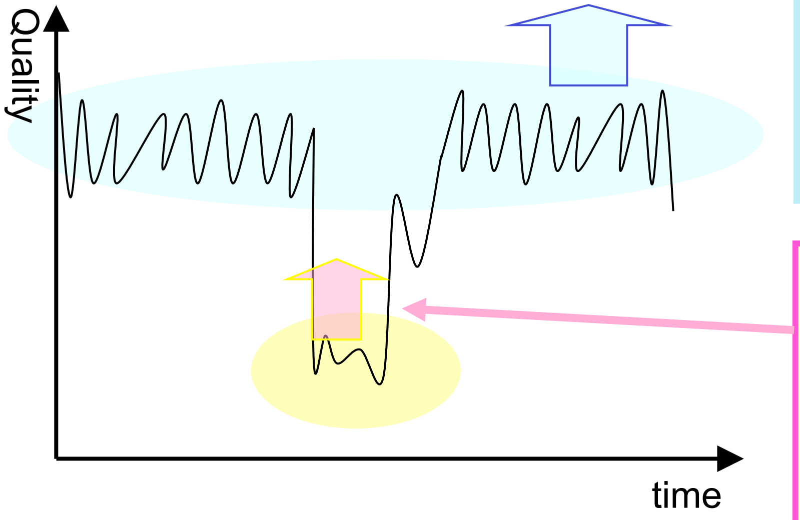
Guaranteed Quality than Average High Speed



- Conventional Radio
  - High Speed & Capacity
  - Focuses on
    Max Quality and Average Quality

- Wireless Control
  - Small Amount of Control Data
    in particular time delay
  - Focuses on Worst Quality

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reliable/robustness was important
also in traditional wireless communications

Is there any difference?

⇩

Human: focus on Average and provide Best Effort

M2M : focus on Worst Case and provide Guaranteed

Just in Time than Real Time

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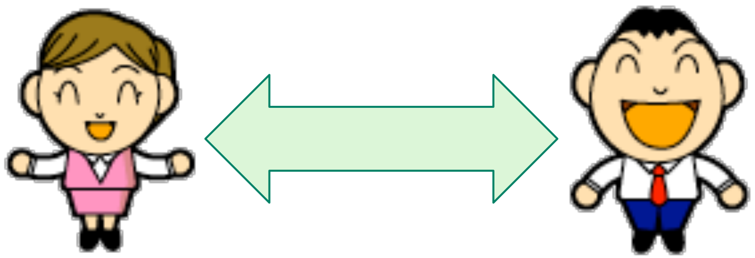
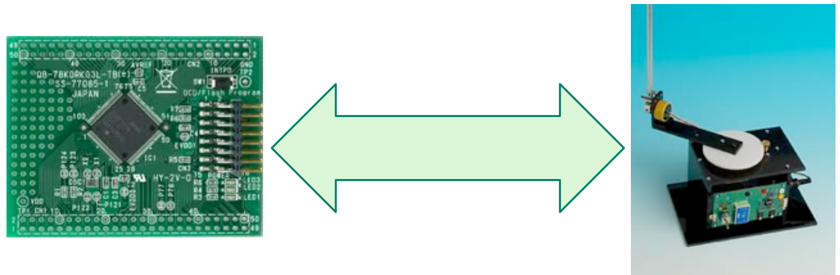
Upper Layers of Conventional Systems

- Human Communications
  - Complicated
  - Highly intelligent
  - Difficult to have a math model

than Control's M2M communications



Conventional Users



M 2 M Communications

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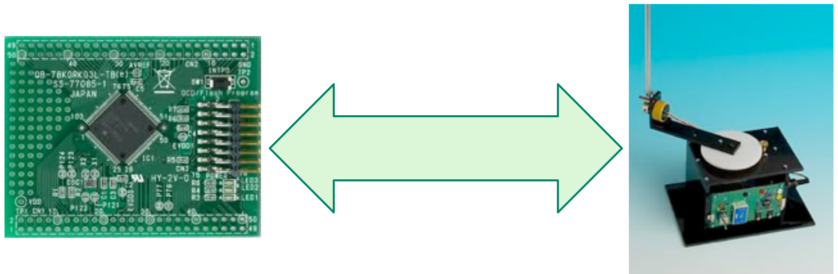
Upper Layers of Control Systems

- Physical System (Machines) are
  - Not so Complicated as human
  - Not so Intelligent as human
  - possible to represent and evaluate with mathematics.



M 2 M Communications

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reliable/robustness was important
also in traditional wireless communications

Is there any difference?

Human: focus on Average and provide Best Effort
M2M : focus on Worst Case and provide Guaranteed

Evaluation by QoS of upper (control) Layer is possible and necessary

Reliable Robust Radio Control !!

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What is Reliable Robust Radio Control?

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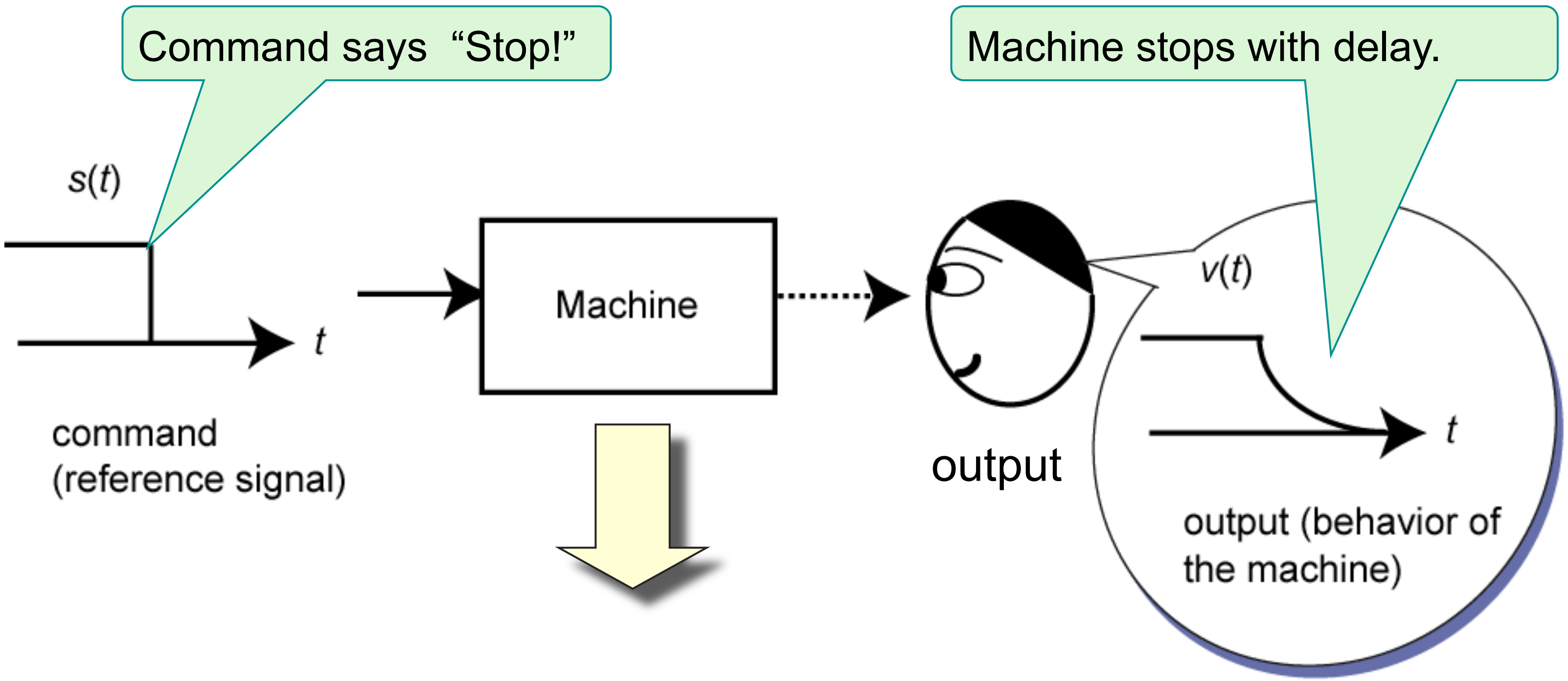
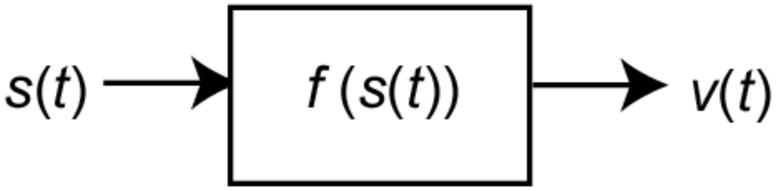
Control System





Error in Control System :

$\varepsilon_M(t) = v(t) - s(t)$

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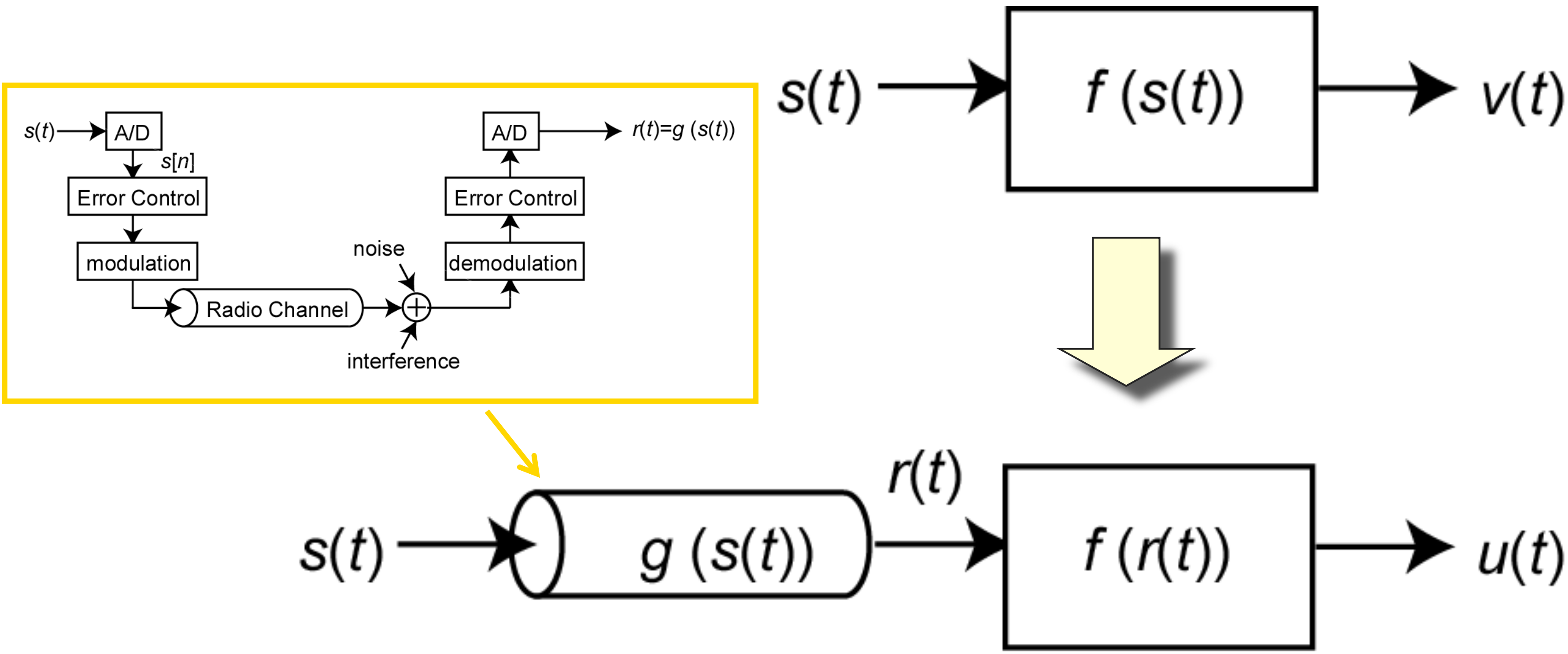
Radio Control System



Error in Wireless Comm：

$\varepsilon_C(t) = r(t) - s(t)$

Overall Errors：

$\varepsilon_S(t) = u(t) - s(t)$

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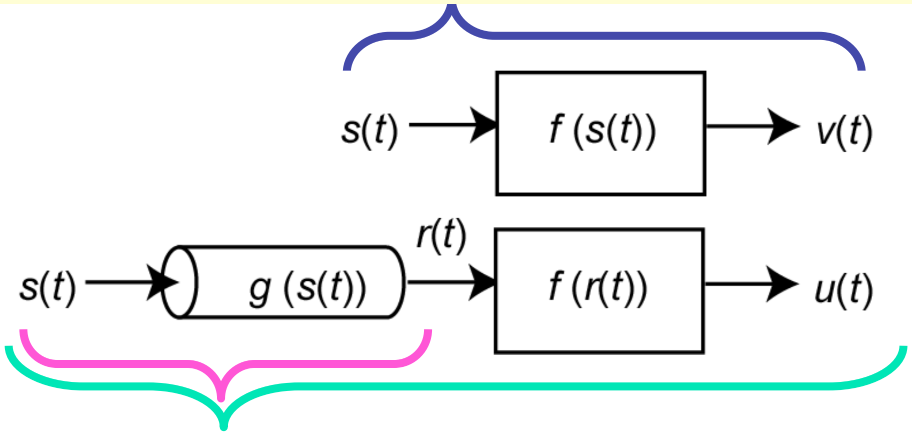
Radio Control System: Probabilistic System

Deterministic System: s(t) determines v(t)



Stochastic System: s(t) defines probability of r(t), u(t)

In Radio Control System
even if input is determined still output is stochastic/random

Measure of Quality based on Stochastic behavior of the system is needed.

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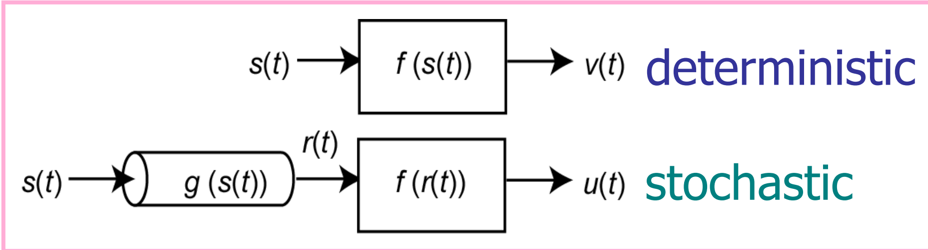
Examples of Performance Measures



- System
  - Machine $f(\cdot)$
  - Command $s(t)$
  - Channel Prob($r(t)$| $s(t)$)

- Measures [based on Stochastic behavior of $\varepsilon(t)=u(t)-v(t)$]
  - MSE --------------- $E[\varepsilon^2(t)]$
  - worst case -------- $\max|\varepsilon(t)|$
  - outage prob.------ Prob($\Theta<|\varepsilon(t)|$)
  - delay

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What is Reliable Robust Radio Control?

- Optimization of QoS
  at Control (Application) Layer

- QoS measures
  considering its stochastic behavior

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Chronological Review of our works on Reliable Robust Wireless Control

Papers are at
http://www.katayama.nuee.nagoya-u.ac.jp/dbase/search-e.php

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List of our Works on RRRC [1999-2010]

Proposal: Radio Control as a new research topic (1999)

Radio for Control… Improvement of Systems
- Propagation measurement[focusing on worst cases]
- Space Diversity with Repeater-Cloud

Evaluation by QoS of Control
- Trade-off between Control Rate and Error Rate (2006～)

第４回無線分散ネットワークに関するワークショップ，June 27, 2008.

Inverted Rotary Pendulum as an Example (2008～)

- 制御のための無線通信の信頼性に関する考察

Control of Multiple Machines and their Synchronization (2010～)

- 協調動作のための無線制御方式における伝送誤りの影響と特性改善手法
  WBS 2010年6月

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List of our Works on RRRC [2010-]

- 特 … 年7月
- 礼 … 学会 基礎・ 境 …
- 礼 … 選択性が受 付 … 付 …
- 協 … 信学技報 …
- 無線 … の影響 信 …
- A … gnals IC …
- Po … ve Motion Co … IE …
- 無線フィードバック制御システムにおける伝送量削減の影響 信学技 …
- In … led rotary in … 信 …
- Ev … he control qu …
- 無 … 信 …

cont.
Control of Multiple Machines and their Synchronization (2010～)

Reduction of Control Data for Frequency Efficiency (2011.3～)

Control through non-stationary channels (2011～)
Error Control for Control Communications (2011～)

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Ex. Evaluation by QoS at Control Layer

- Trade-off between Data Transmission Rate and Data Loss Rate
- Optimum Data Transmission Rate

R. Uchida: Reliable Wireless Communications for Control/Sensing based on Diversity Concepts
doctoral thesis, March, 2008.

R. Uchida, H. Okada, T. Yamazato, M. Katayama :
Influence of Characteristics of Wireless Channels on Quality of Wireless Control Systems,
IEICE Transactions on Fundamentals, vol.J89-A, no.12, pp.1104-1107 Dec. 2006

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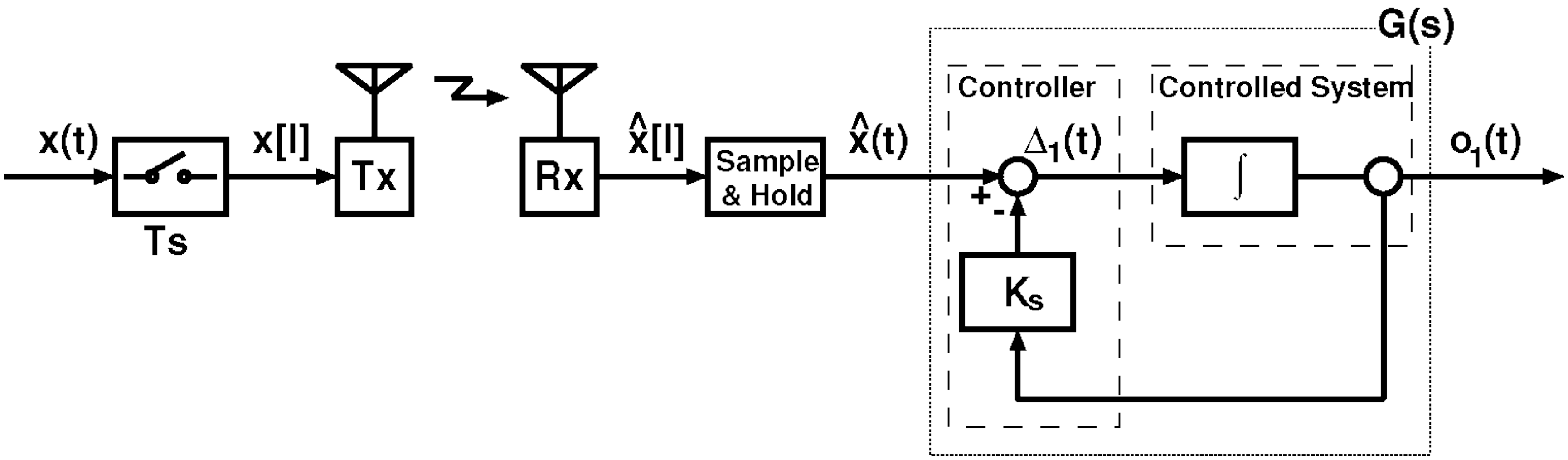
Control through a Radio Channel

- Control Commands are sent through radio channel.



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Feature of Radio System

- In order to achieve
  good control performance…
  - Decrease Data Loss Rate
  - Increase Data Transmission Rate

↓

Both require

increase of Transmission Power

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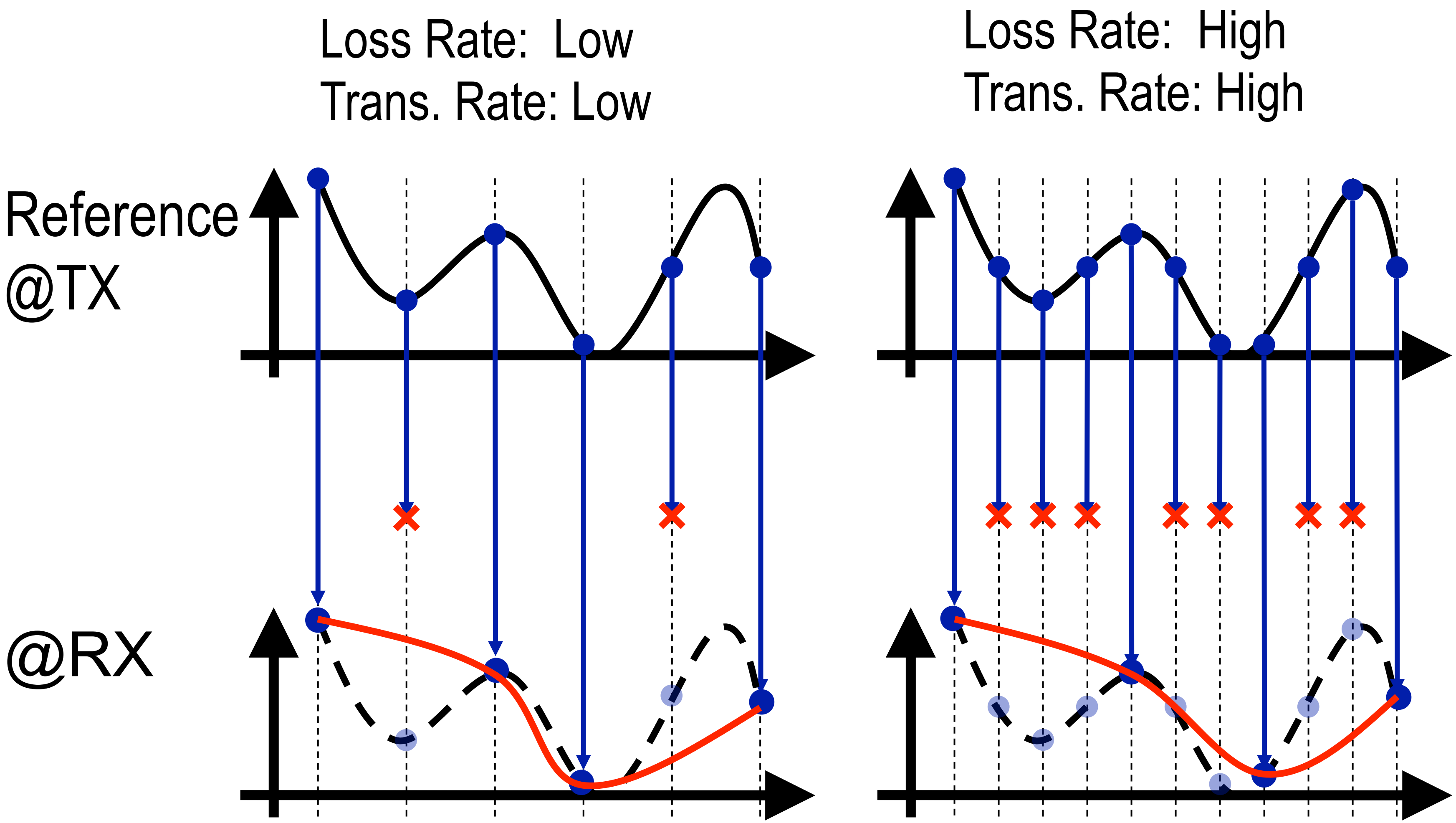
Loss Rate & Transmission Rate



Which gives better Control Quality ??

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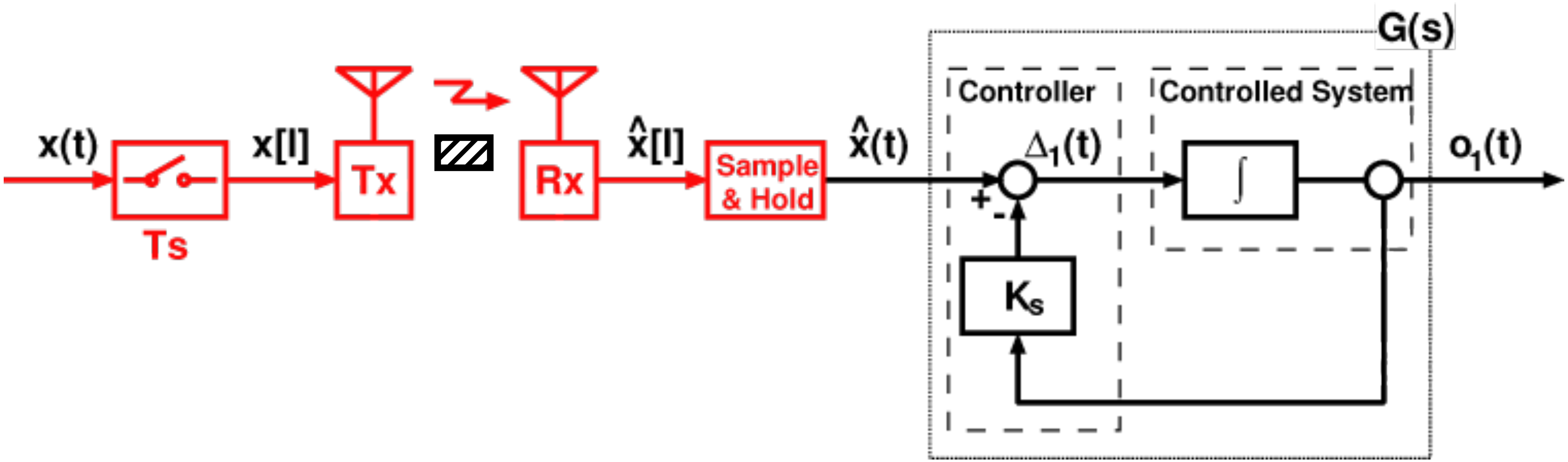
System Model (Radio Part)



- Reference : $x(t) = \sin(2\pi f_m t + \phi)$, $f_m = 1/4$ [Hz]
- Trans. Rate : $1/T_s$ [packets/s]
- Packet Size : 512 [bits]
- Modulation: BPSK
- Rayleigh Fading (Doppler Freq. $10f_m$ [Hz])
- D/C : 0th order hold
  (if a packet is lost, its previous held sample is used.)

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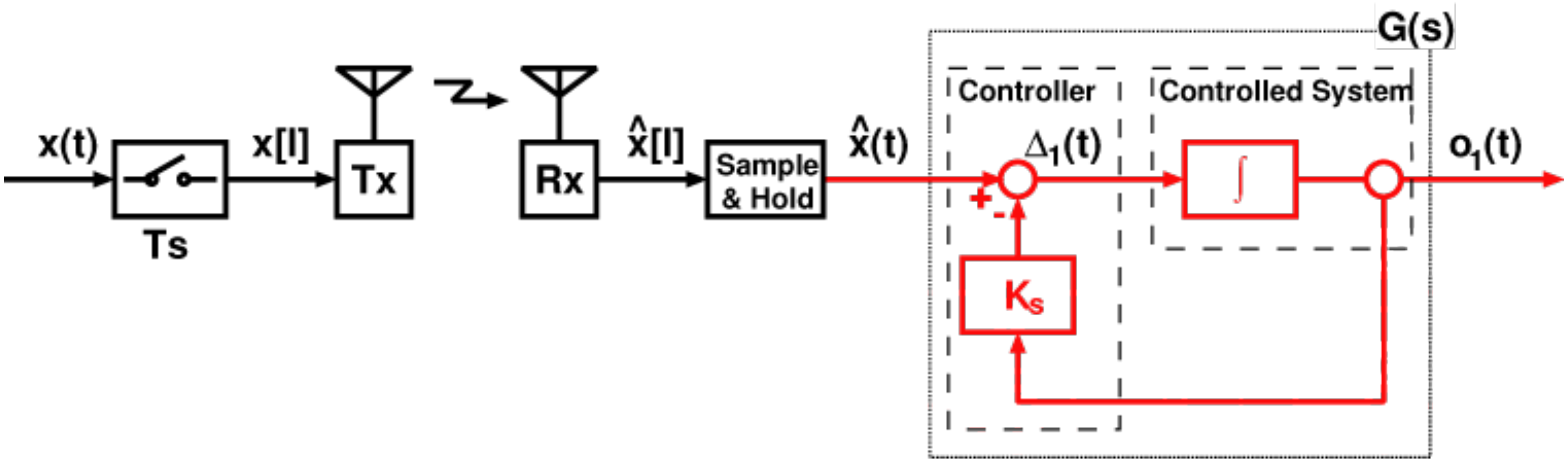
System Model (Radio Part)



- 1st order feedback system：$K_s = \pi$（cutoff：1/2 [Hz]）
- (ideal) stationary state： $x(t) \cong \hat{x}(t) \cong \hat{o}(t) = o(t)$

($o(t)$: ideal output with enough high trans. late and low loss rate)

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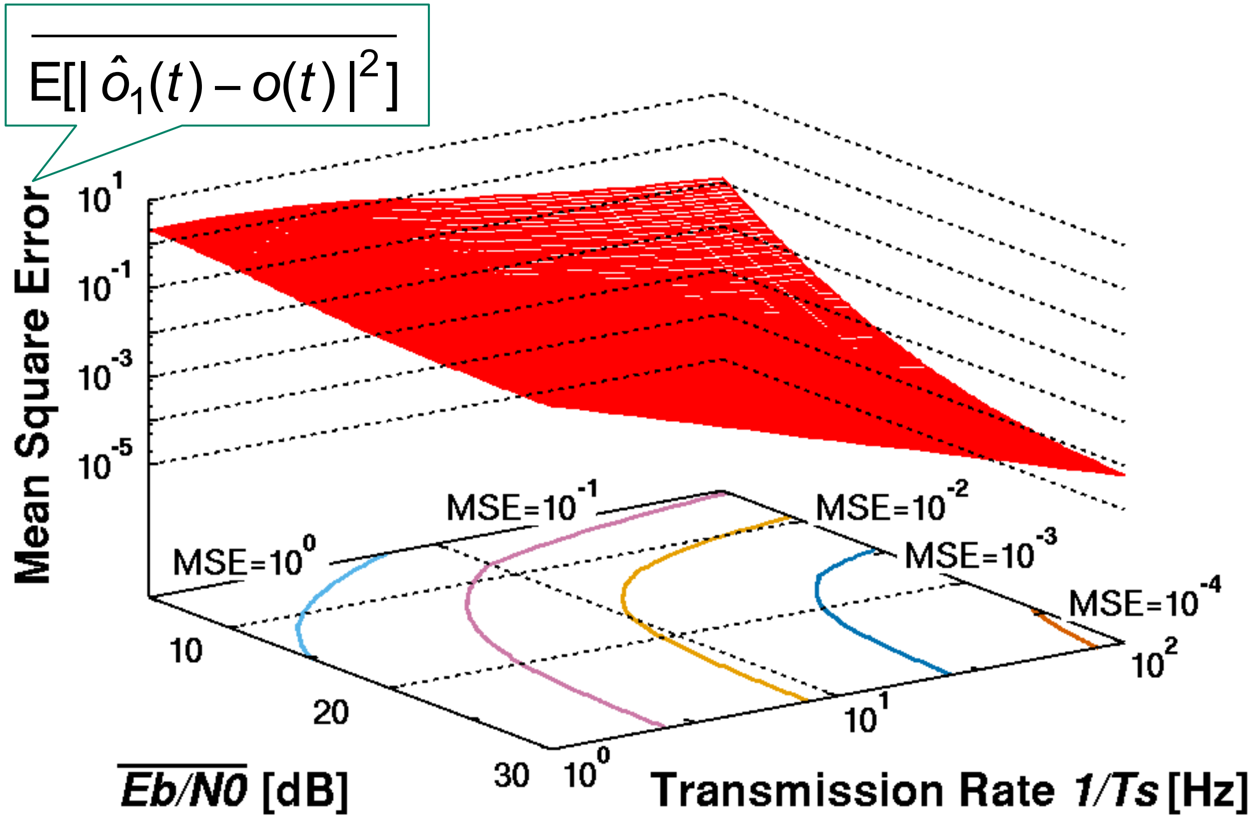
Mean Square Error of the Output of the Control System



- Control Performance can be Improved by the improvement of both $\overline{Eb/N0}$ (Error Rate), $1/T_s$(Trans. Rate)

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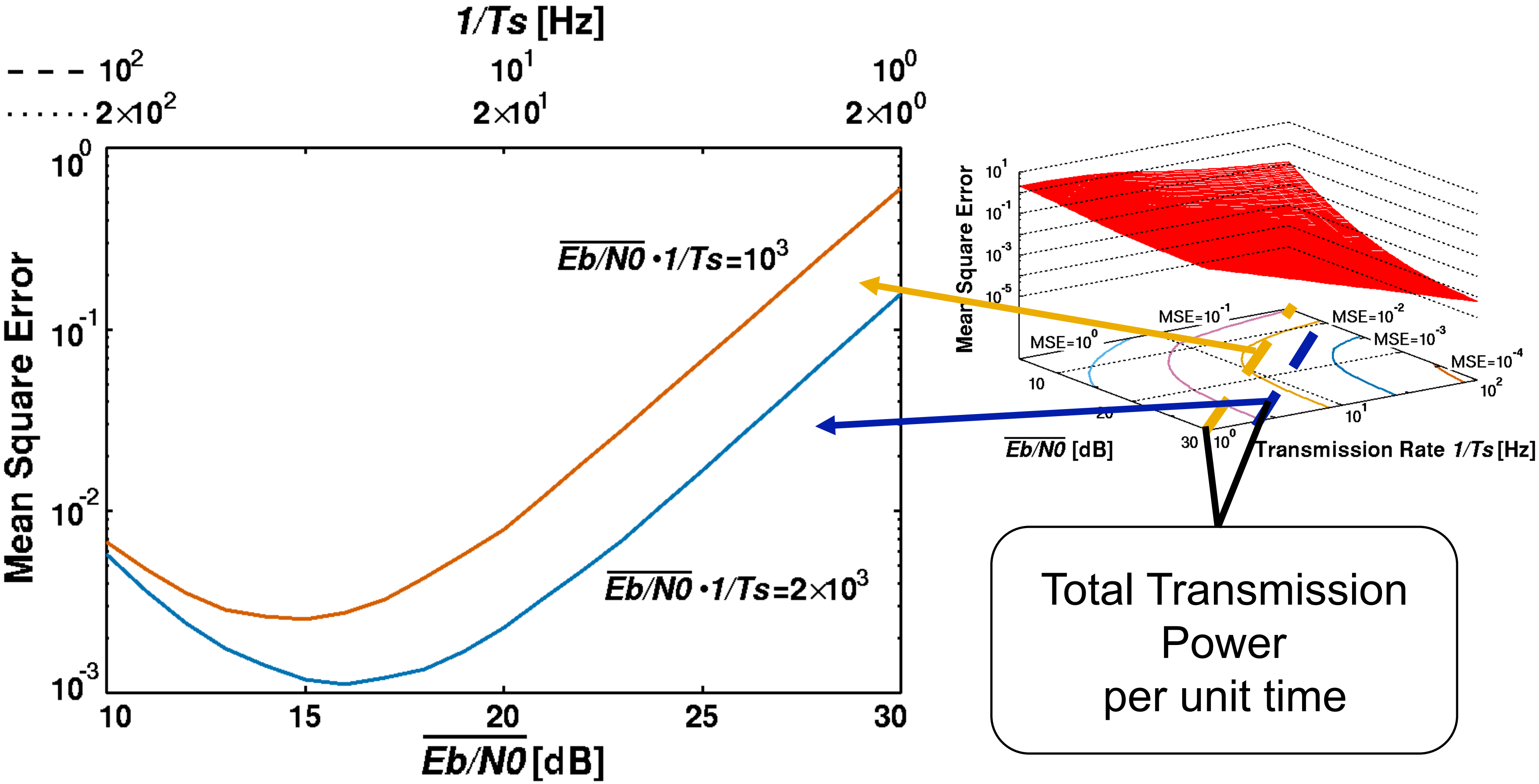
Performance of a Control System



- There are optimum transmission rates.
- The optimum rates depend on total transmission power.

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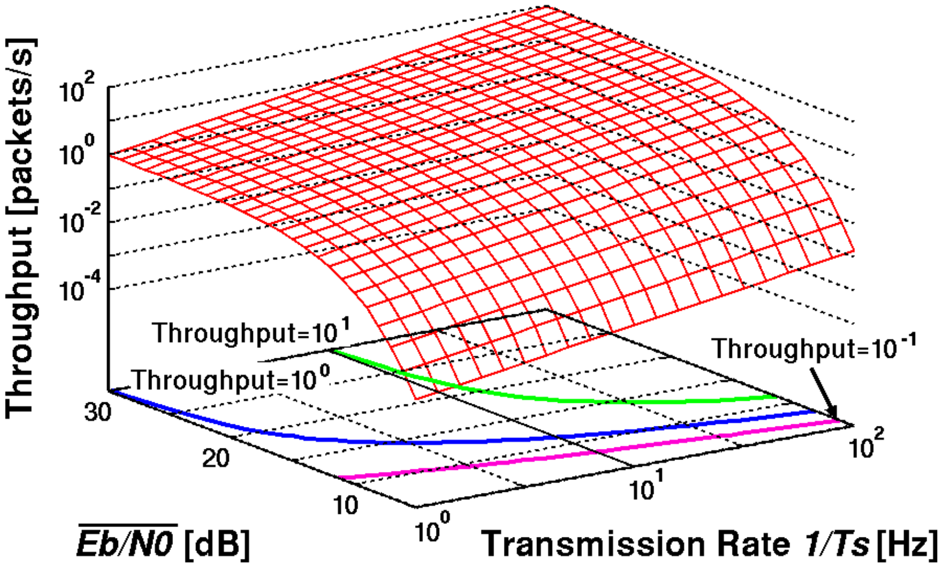
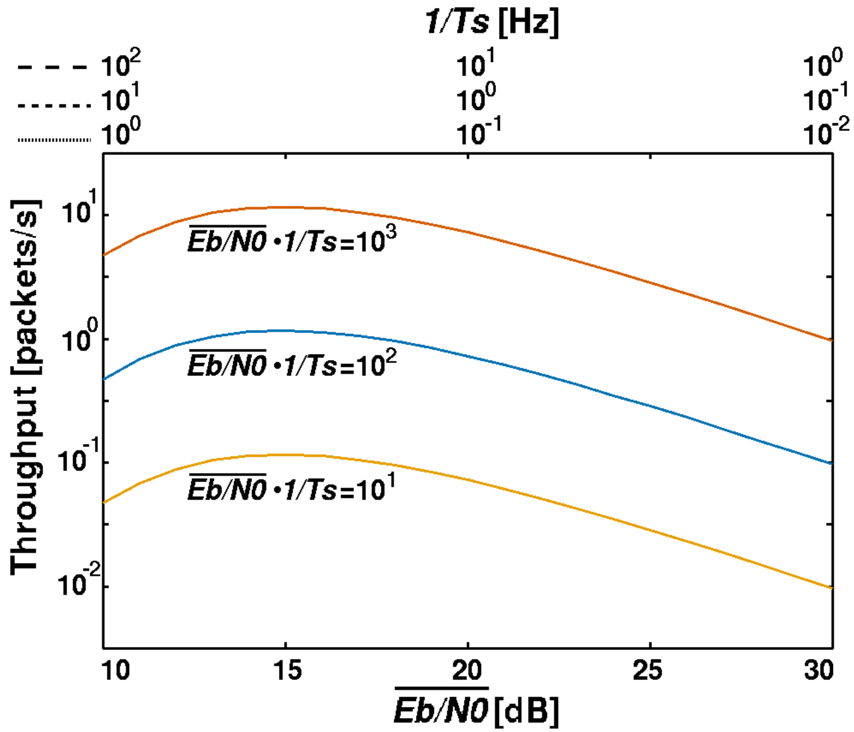
Performance of a Radio System





- There is an optimum transmission rate.
- The optimum rate does not depend on total transmission power.
- Throughput (Comm) optimum does not ensure MSE (Control) optimum

Throughput:

$$\frac{1 - \text{Average Packet Loss Rate}}{T_s}$$

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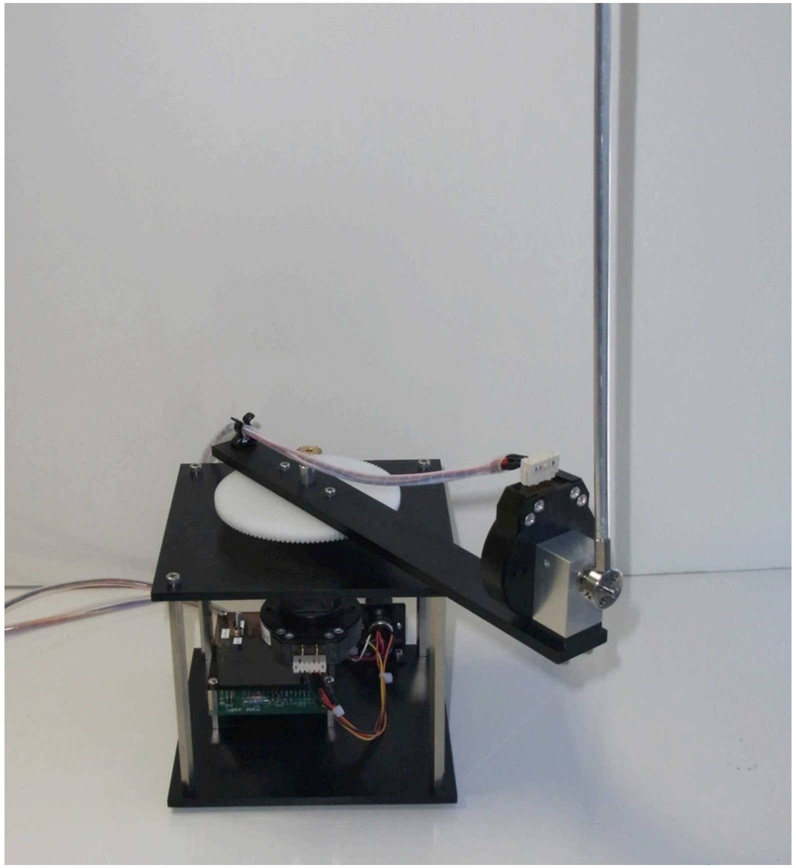
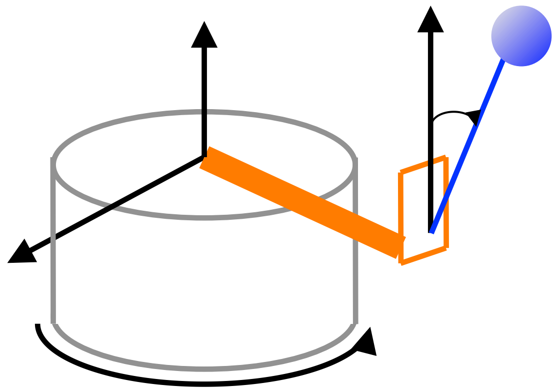
Rotary Inverted Pendulum





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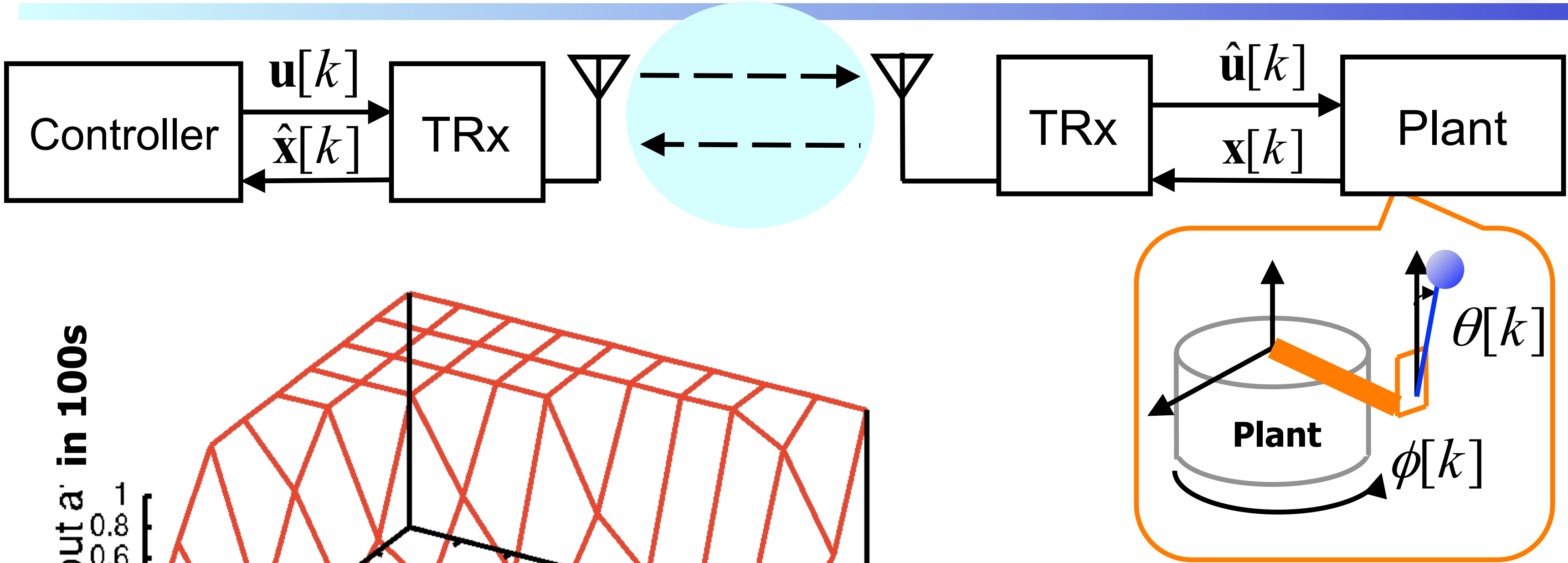
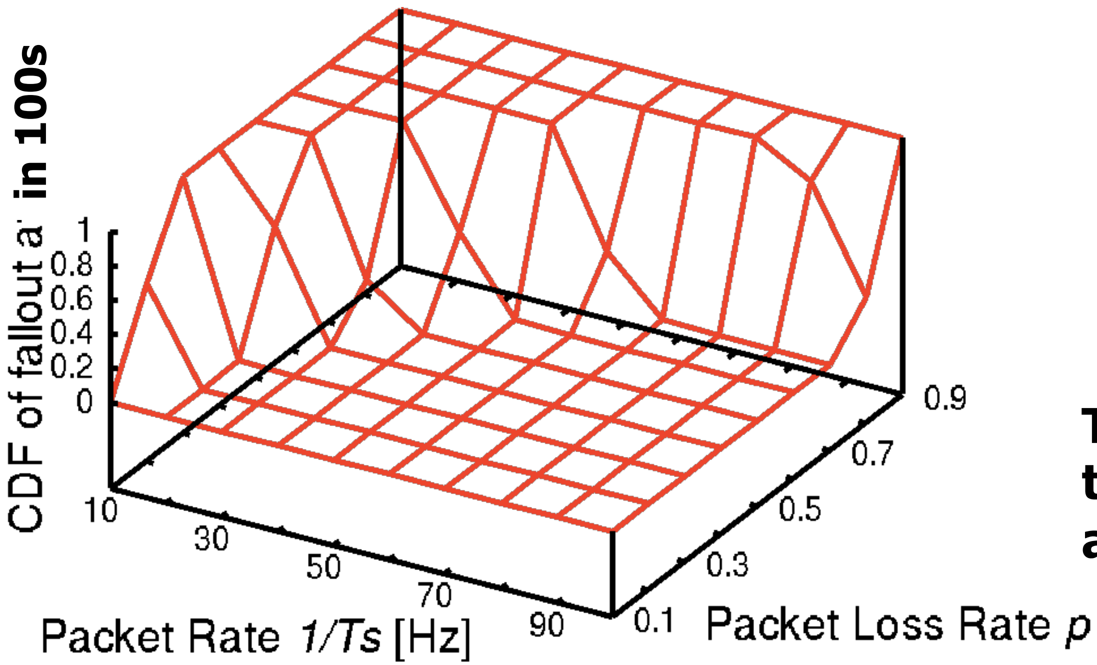
Transmission Rate / Loss Rate





Trade-off between the packet transmission rate and the packet loss rate [1]

[1] R.Kohinata,T.Yamazato and M.Katayama,
"Influence of channel errors on a wireless-controlled rotary inverted pendulum"

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Feedback Control through PLC Cyclic Channel

C. Carrizo, K. Kobayashi, H. Okada, M. Katayama "Influence of cyclostationary noise on the behavior of a powerline-controlled rotary inverted pendulum," Technical Report of IEICE, RRRC2011-6, pp.19-24 Jun. 2011

C. Carrizo, K. Kobayashi, H. Okada, M. Katayama, "Control Quality of a Feedback Control System Under Cyclostationary Noise in Power Line Communication," IEICE Transactions on Fundamentals, vol.E95-A, no.4, 2012.

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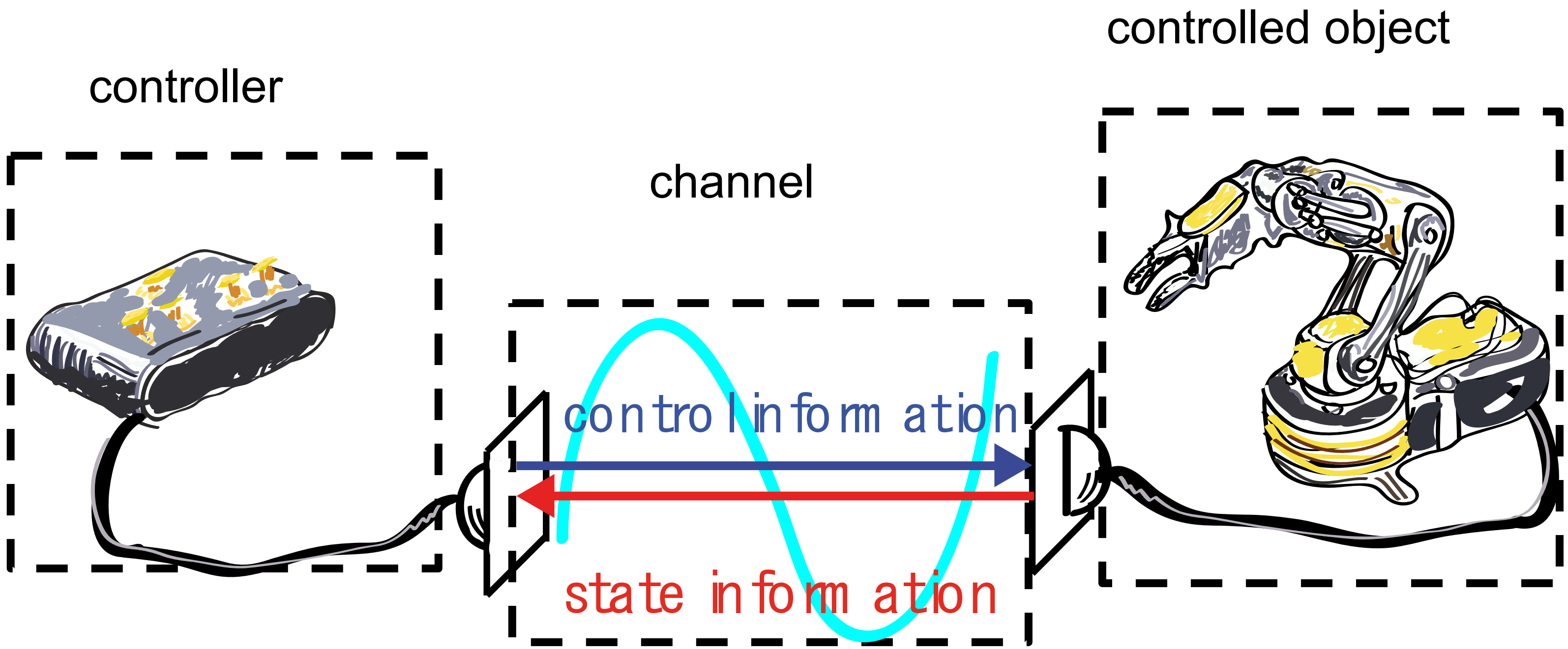
System model

- Feedback system that employs a power line as its feedback loop



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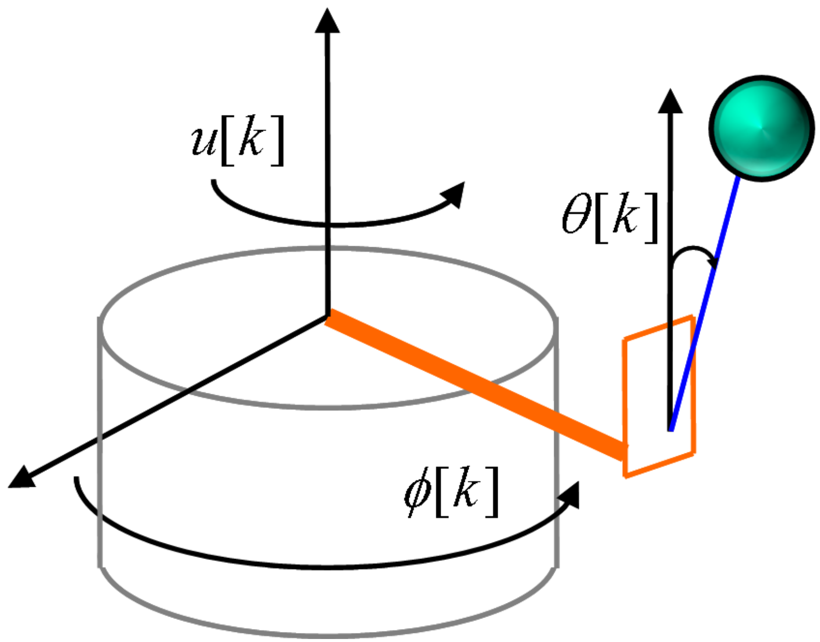
Pendulum's physical parameters



Pendulum's mass	0.004 [kg]
Pendulum rod's mass	0.025 [kg]
Pendulum rod's length	0.241 [m]
Arm's length	0.152 [m]
Arm's moment of inertia	0.00121 [kgm^2]
Gravitational acceleration	9.81 [m/s^2]

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Simulation parameters

Modulation scheme	BPSK
Packet length	40 bits
Digital sampling rate	1024 Hz
Mains voltage frequency	60 Hz
Simulation duration	100 s
Number of simulation trials	100 and 1000 times
Pendulum angle target value	0 [rad]
Period of arm motion	10 s
Arm target value	0⇔π
Upright region	±π/6 [rad]

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Simulation parameters

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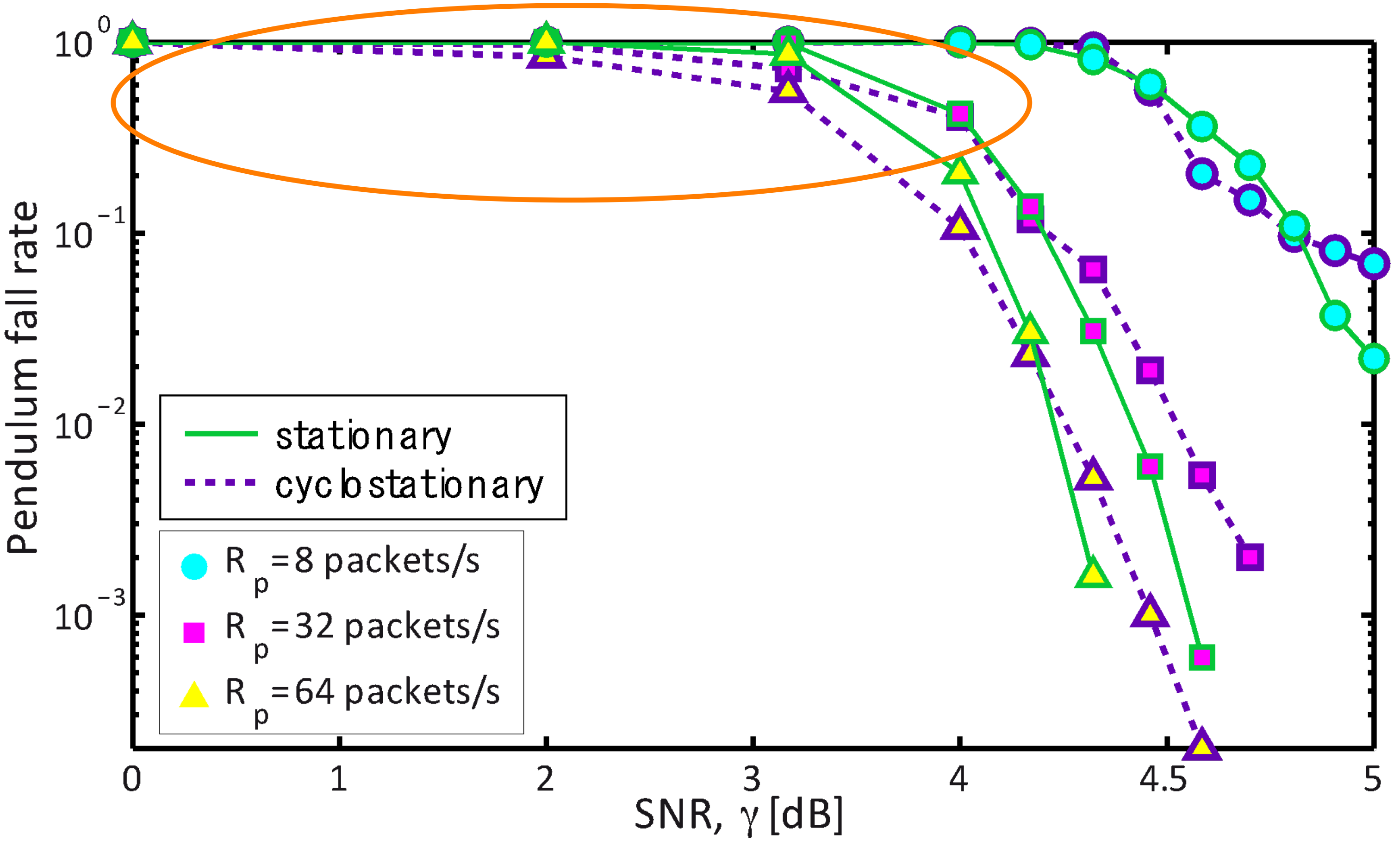
Evaluation of the average SNR vs the control quality



the cyclostationary noise case shows
a better performance at the lower SNR region

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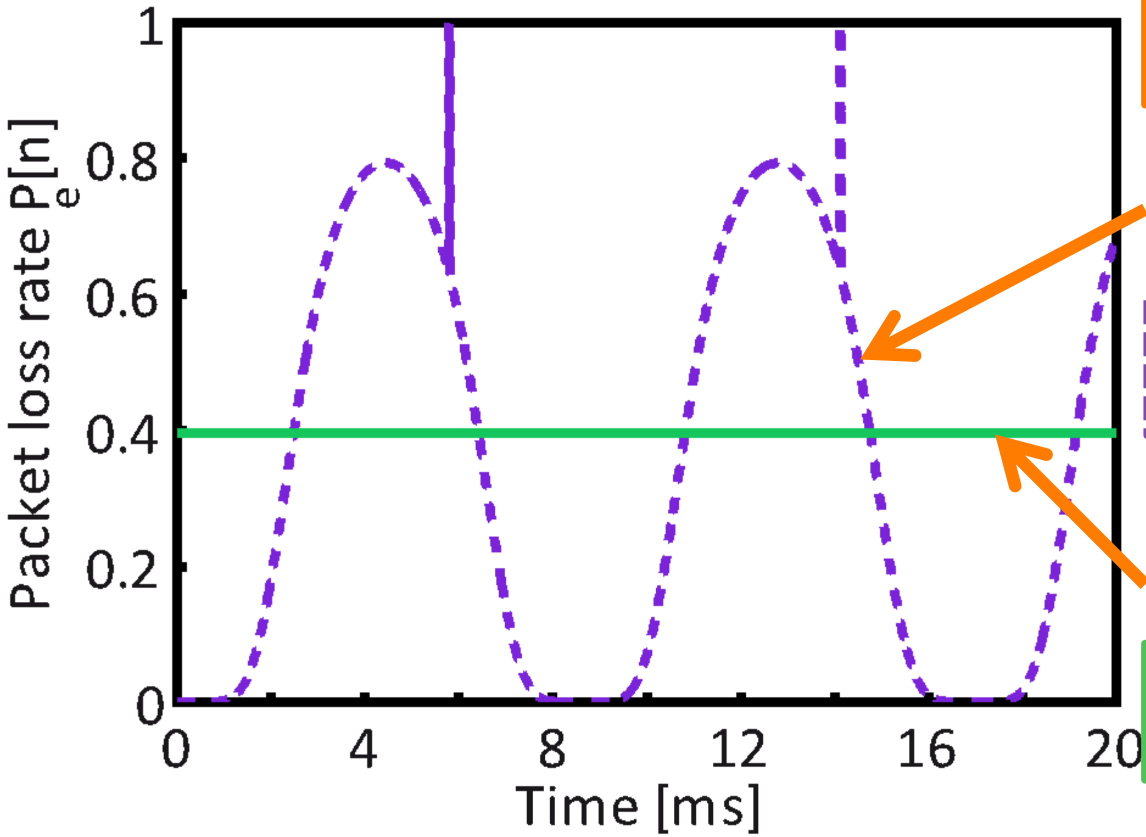
Packet loss rate behavior

SNR γ=4 dB
packet length : 40 bits
modulation scheme : BPSK



cyclostationary noise case

stationary noise case

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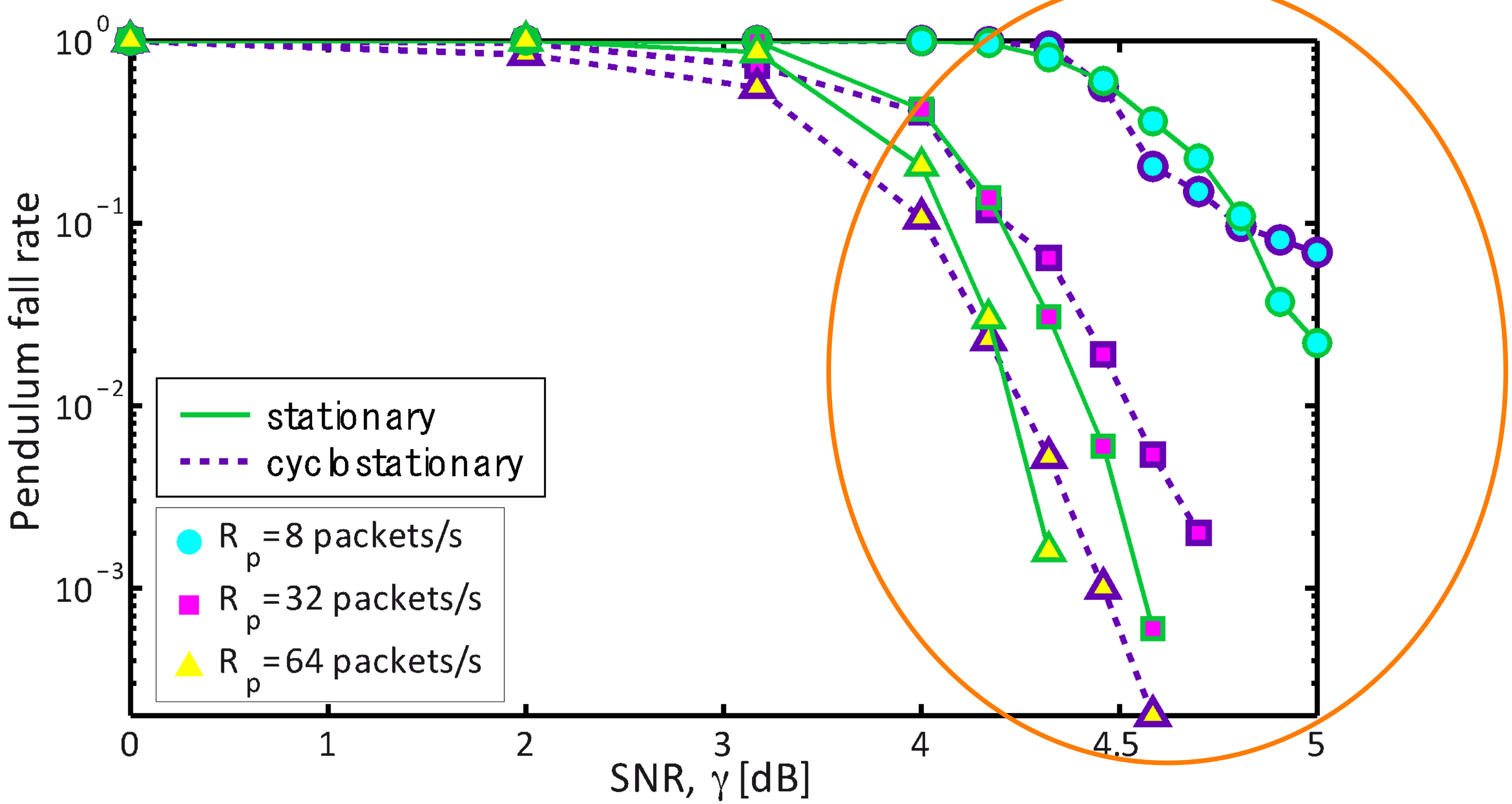
Evaluation of the average SNR vs the control quality



however, the stationary noise case shows a slightly better performance at the higher SNR region

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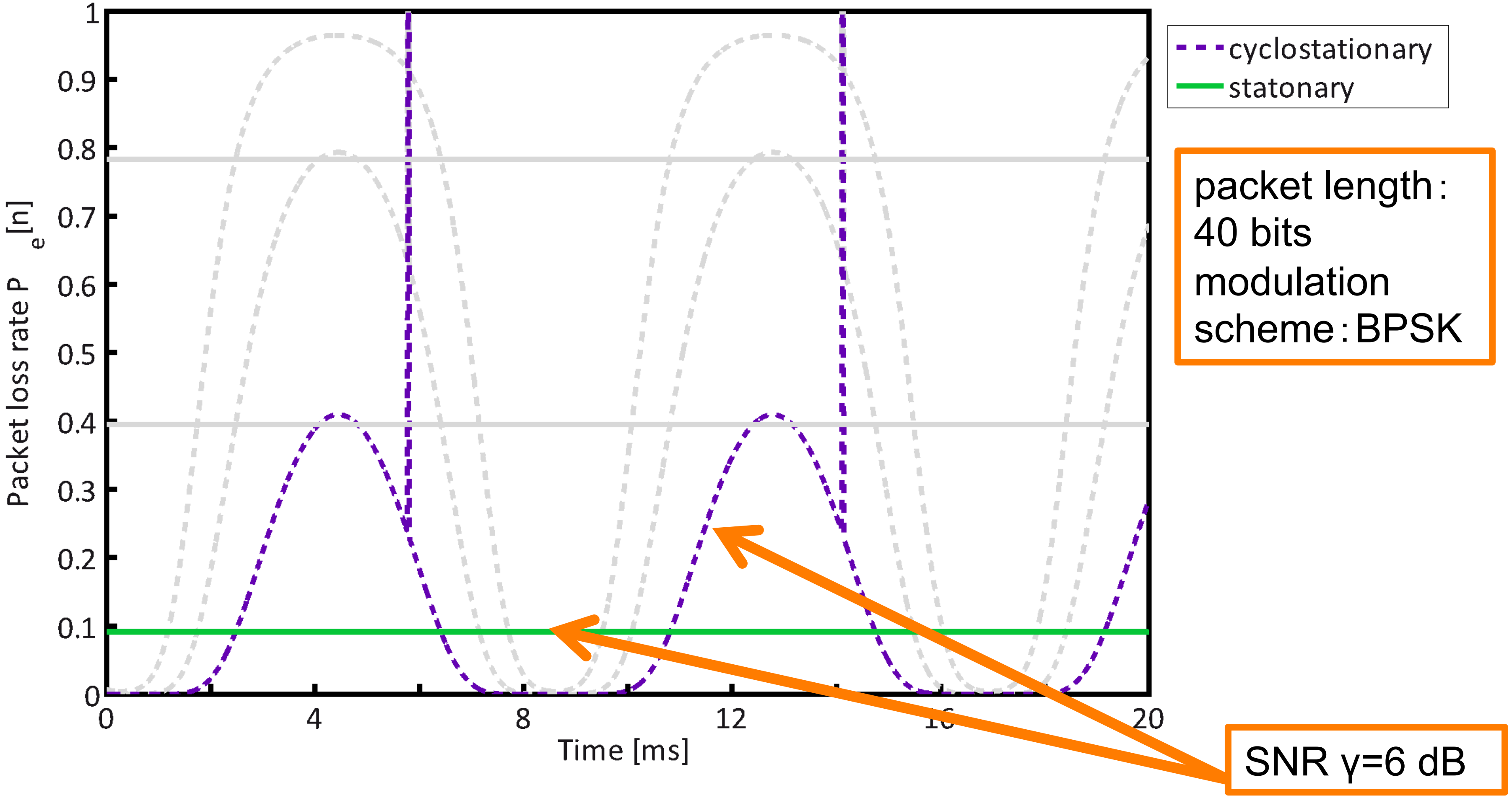
Packet loss rate behavior



packet length : 40 bits
modulation scheme : BPSK

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Feedback Control with PLC

- Time variant（Cyclo-stationary）Channel
  - Example of the system where
    - average and worst error rates (comm. quality measures) are not good measure of control quality, and
    - the cyclic “good-states” dominate overall control quality.

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Synchronous Move of Multiple Plants

(Allow me skip contents and focus on the main idea)

T. Kondo, K. Kobayashi, M. Katayama, “A Wireless Control System with Mutual Use of Control Signals for Cooperative Machines,” IEICE Transactions on Fundamentals, vol.E95-A, no.4, 2012

F. Minamiyama, , K. Kobayashi, M. Katayama, “Power Supply Overlaid Communication with Common Clock Delivery for Cooperative Motion Control,” IEICE Transactions on Fundamentals, vol.E94-A, no.12, 2011.

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Latency

The concert
with 10 minutes delay

and the music is great!

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Synchronization

The concert with

1 second of random delay

of each player

confirms

central limit theorem.

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Synchronization is often more important than latency.

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Invitation to M2M Research

- Importance of Radio/PLC Control is increasing
  - Control of Smart Grid --- Typical Cyber-Physical System

- Radio/PLC Control is interesting for Control People
  - Behavior of systems become stochastic
  - Control of multiple distributed plants

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Invitation to M2M Research

- Radio/PLC Control is new and interesting application for Communication People
  - Conventional measures of quality are not sufficient.
  - Total optimization including application layer is possible/necessary.
  - There exists new concepts/viewpoints such as synchronous move and common clock delivery.
  - meanings of bits change : needs new theory

In Classic Comm. Theory
Bits can be canned or stored/compressed taking time

In Control Communications
Bits have to be fresh!

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