GNSS Interoperability

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GNSS Interoperability

Contents

- Definition of Interoperability
- Signal Design for Interoperability
- Quantitative Evaluation Algorithm

Definition

Refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system.

Definition

1. Provide ***better*** services for the user level;
2. Interoperability benefits ***outweigh*** its cost;
3. ***High-performance*** interoperability signal;
4. Coordinate reference frame of each system ***close to*** ITRF;
5. The system time of each system ***trace to*** UTC;

Definition

7.***Broadcast*** **interoperability messages.**

8.***Cost-effective*** **interoperability receiver;**

9.***Enhanced*** **sharing of system resources.**

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Interoperability Signal

Interoperability Signal design focus on

- ✓Carrier frequency
- ✓Modulation
- ✓Code
- ✓Message

Interoperability Signal

Interoperability carrier frequency

1、Same carrier frequency

2、Frequency offset is a few kHz

3、Completely different frequency

Expected but should think about the interference

Interoperability Signal

On the assumption that: C/N_o=46dBHz, BW=20MHz

Wanted Signal	GPS Signals	Single signal	12 GPS visible satellites signals	
MBOC(6,1,1/11)	BPSK（1）	0.0037@43.8364 dBHz;	0.0448@ 43.8098dBHz	0.1529@ 43.3821dBHz
	BPSK（10）	0.0021@43.9072 dBHz	0.0247@ 43.8939dBHz	
	BOC（10,5）	1.2221e-4@43.9941dBHz	0.0015@ 43.9936dBHz	
	MBOC(6,1)	0.0068@43.7029 dBHz	0.0819@ 43.6580dBHz	

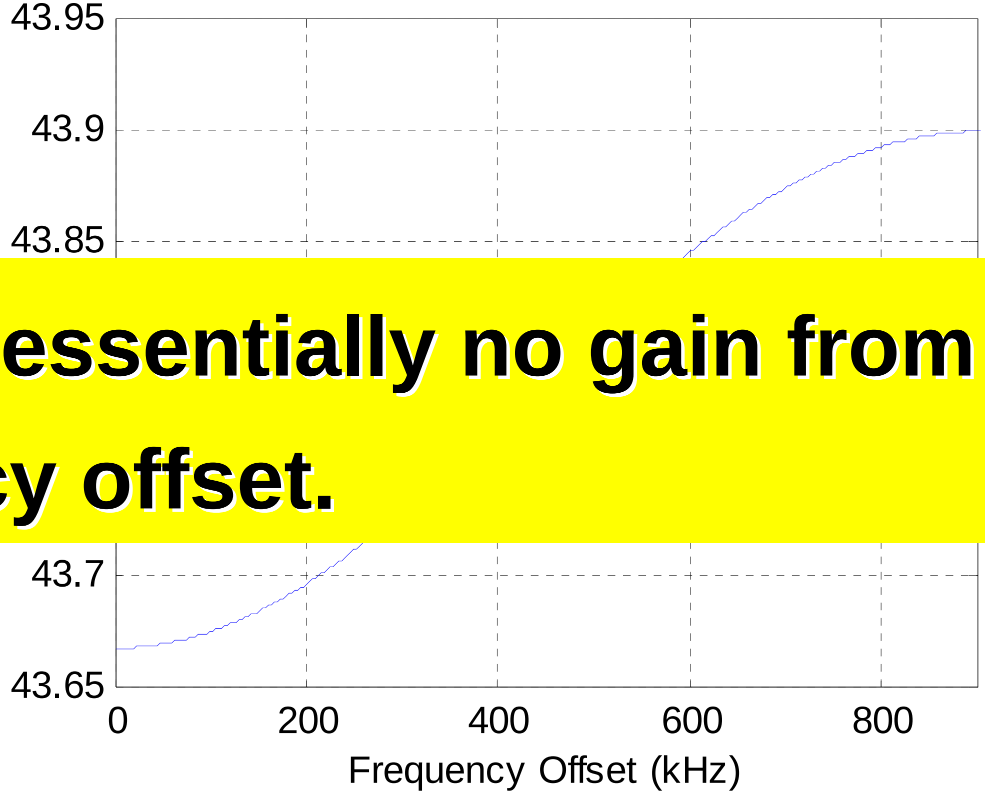
Interoperability Signal

On the assumption that: C/N_o=46dBHz, BW=20MHz

Wanted Signal	Galileo Signals	Single signal	12 Galileo E1 signals	
L1 MBOC(6,1,1/11)	BOCcos（15,2.5）	9.3256e-7@44.00dBHz	1.1191e-5/@44.00 dBHz	0.0819 @ 43.6580 dBHz
	CBOC	0.0068@43.675dBHz	0.0819@ 43.6580dBHz	

Wanted signal	Galileo signal	Single signal	12 Galileo E5a signals
E5a:QPSK(10)	QPSK(10)	0.0026@43.99 dBHz	0.03 @43.86 dBHz

Interoperability Signal



There is essentially no gain from a large frequency offset.

The interference of CBOC(6,1,1/11) to TMBOC(6,1,4/33), when Frequency offset is within [1kHz, 900kHz].

Interoperability Signal

Modulation

- ✓The correlation curve
- ✓Acquisition
- ✓Tracking
- ✓Multi-path performance

Interoperability Signal

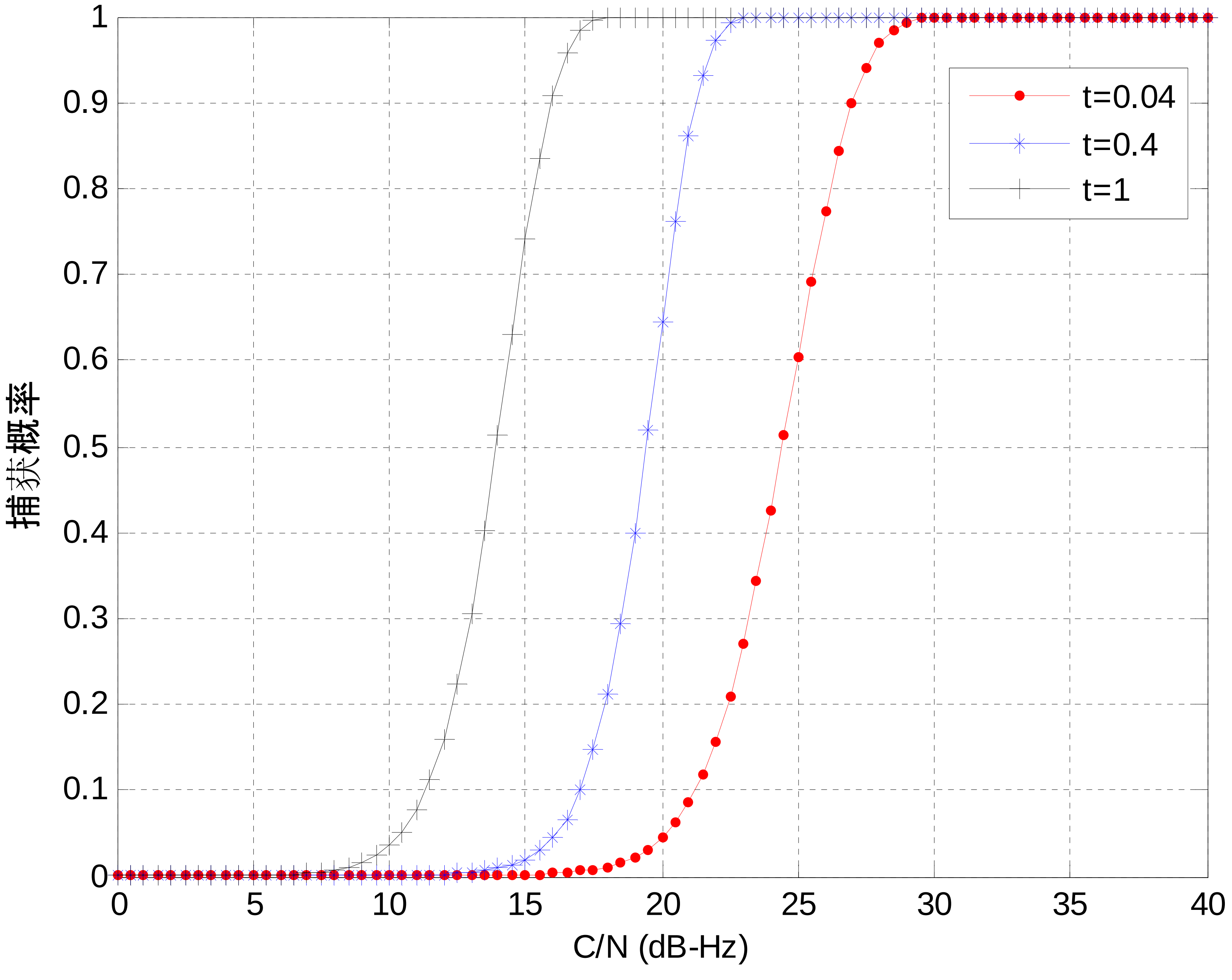
The correlation curve

A ***Sharp*** correlation peak will be proposed which can ***reduce*** the number of side lobes and the probability of false lock.

Interoperability Signal

Acquisition performance

Longer **code period and** ***lower*** **message rate ensure enough integration time to effectively** ***enhance*** **acquisition performance.**

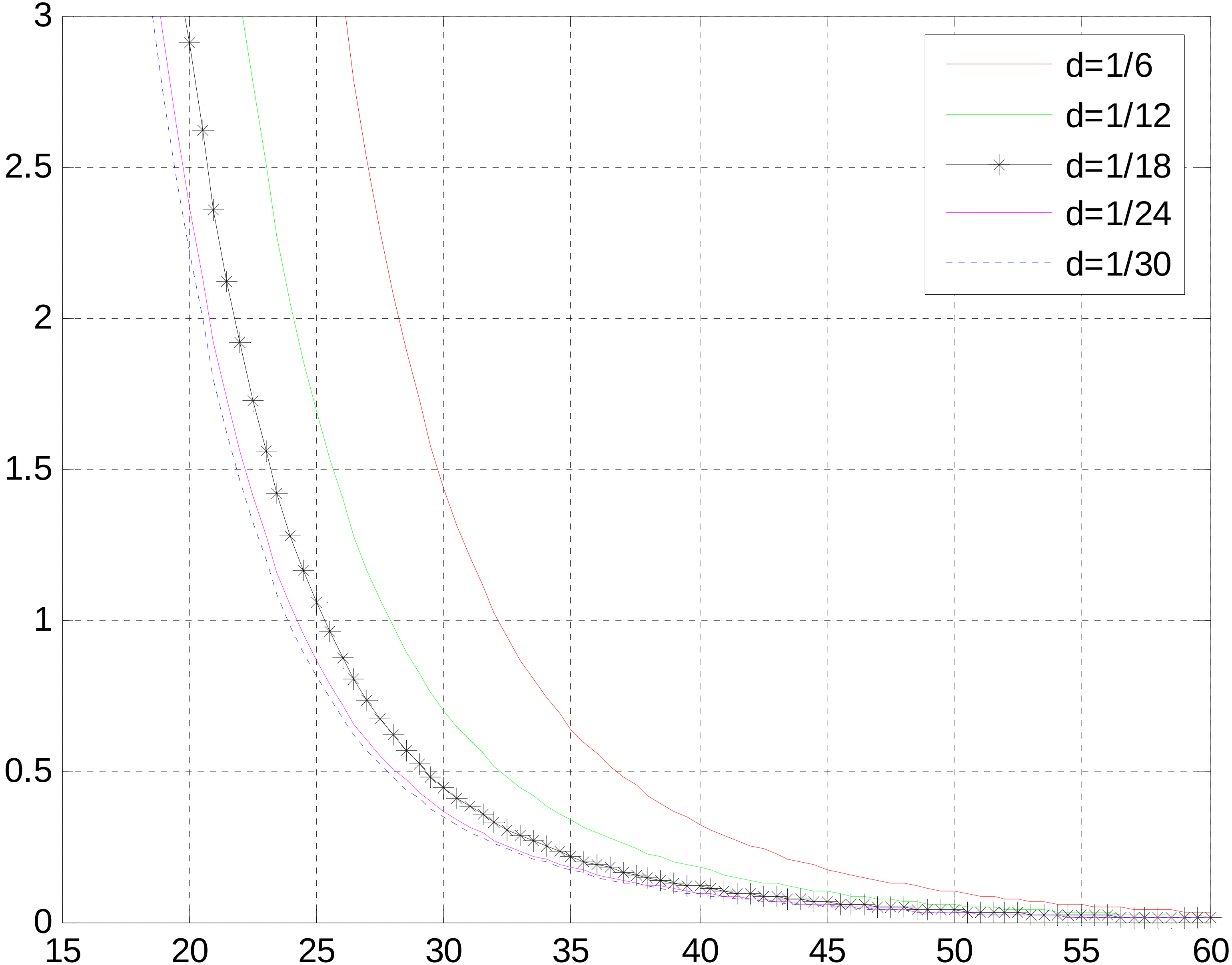


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
C/N (dB-Hz)
捕获概率
t=0.04
t=0.4
t=1

Interoperability Signal

Tracking performance

A ***high*** chip rate and ***long*** integration time to effectively ***reduce the receiver's tracking error***.

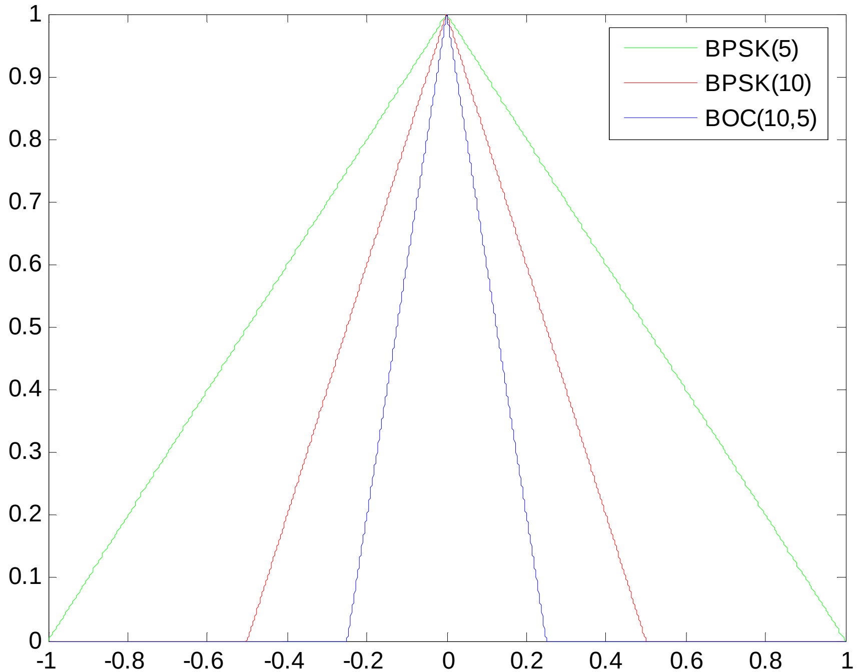


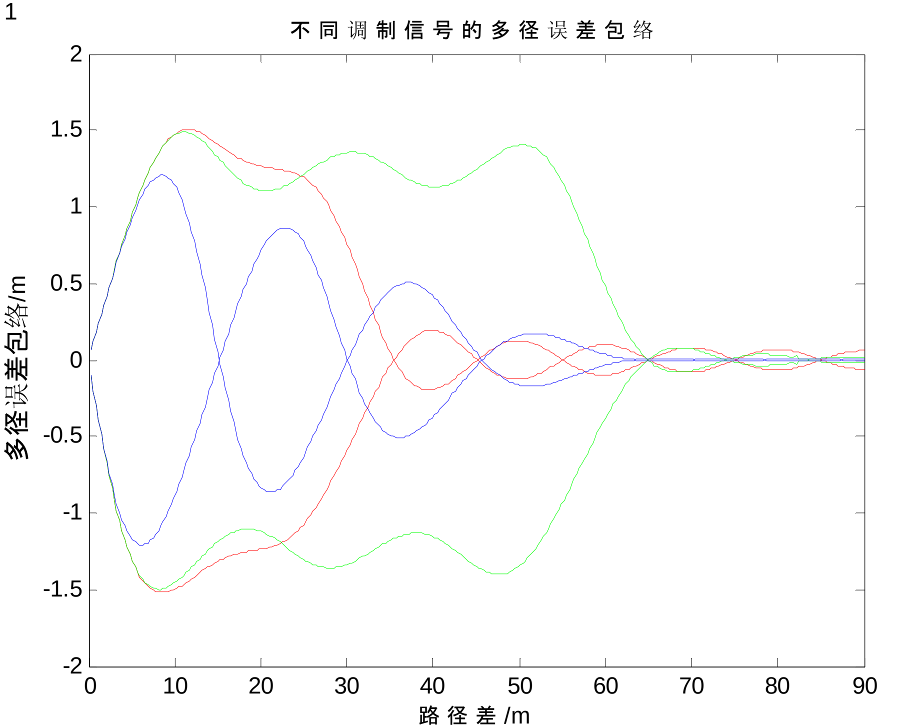
3
2.5
2
1.5
1
0.5
0
15
20
25
30
35
40
45
50
55
60
d=1/6
d=1/12
d=1/18
d=1/24
d=1/30

Interoperability Signal

Multi-path performance

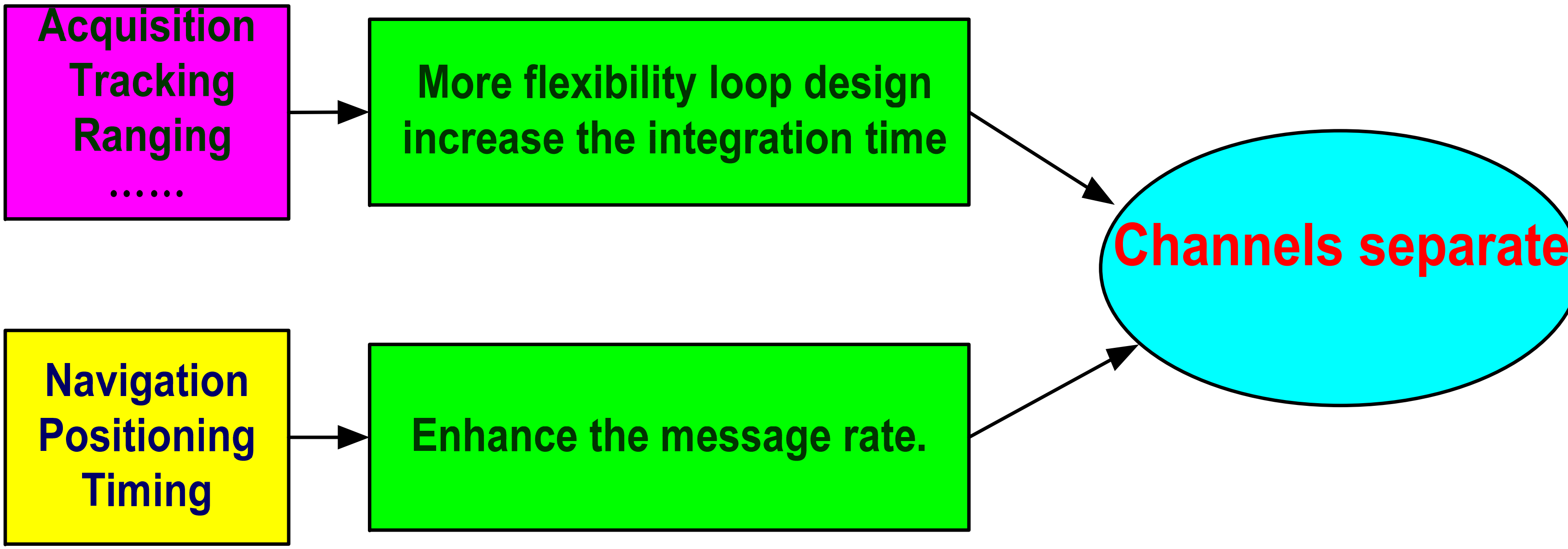
Correlation peak, main peak curve and TC, TS (chip rate (1/TC) or sub-carrier rate (1/TS)) are relevant. When TC, TS become ***smaller***, the correlation peak becomes more ***sharp*** and the multi-path errors are ***smaller*** .


BPSK(5)
BPSK(10)
BOC(10,5)


不 同 调 制 信 号 的 多 径 误 差 包 络
多径误差包络/m
路 径 差 /m

Interoperability Signal

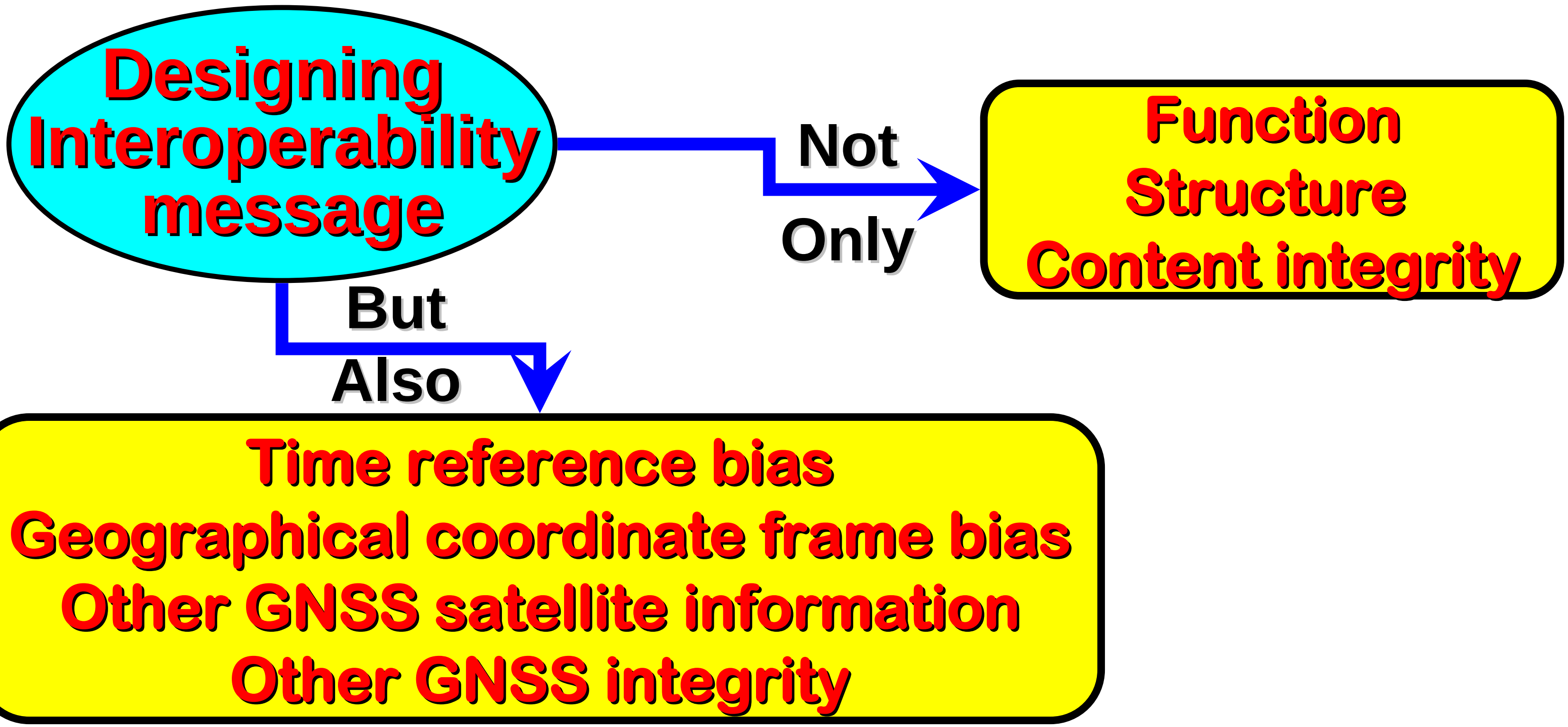
Channels Design



Separate pilot and data channel will bring the signal design greater flexibility.

Interoperability Signal

Message



The first time-to-fix, the system information itself and additional information content shall be considered.

GNSS Interoperability

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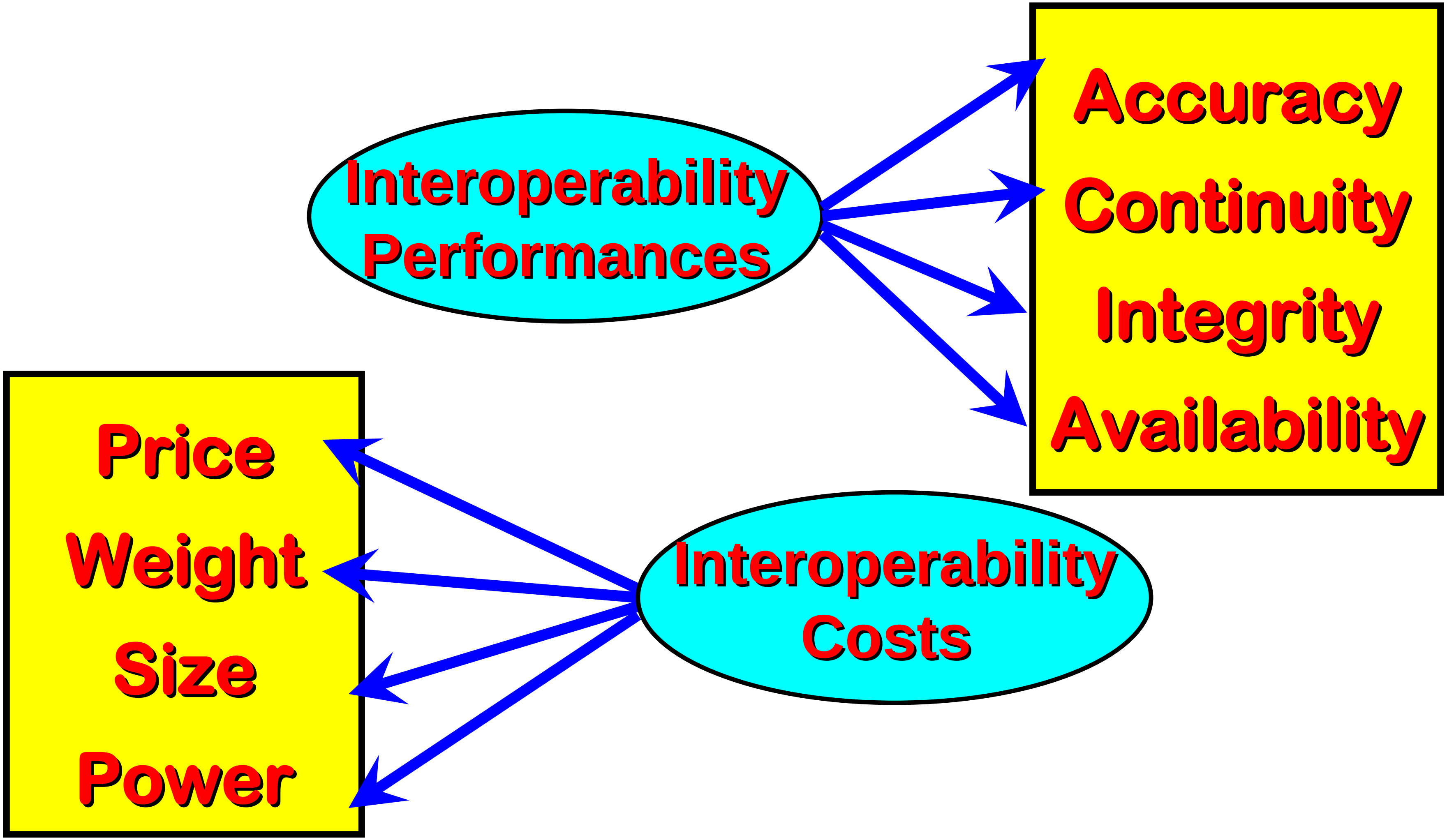
Evaluation Algorithm

Performances and Cost of GNSS are two main items to evaluation interoperability .

Evaluation Algorithm



Evaluation Algorithm

Mathematical Modeling

$$\begin{cases} \dfrac{dx}{dt} = \alpha x\left(1-\dfrac{x}{M}\right) - \beta y \\ \dfrac{dy}{dt} = \gamma y\left(-1+\dfrac{y}{N}\right) - \delta x \end{cases}$$

$$Z(t) = \frac{x(t)}{y(t)}$$

***Z*(*t*)**: **Performance Cost Rate**

From Logistic model.

Performance will be increasing with a upper bound.

Cost will be decreasing with a lower bound.

Notice: $\{(x,y) \mid x \in [0,M], y \in [0,N]\}$

$x(t)$: the magnitude of system performance

$y(t)$: cost

M: limitation of performance increasing

N: limitation of cost decreasing

α: self-increasing rate of performance

β: influence factor of cost to performance

γ: self-increasing rate of cost

Non-linear influence

δ: influence factor of performance to cost

Evaluation Algorithm

Mathematical Modeling

System have

4 Equilibria

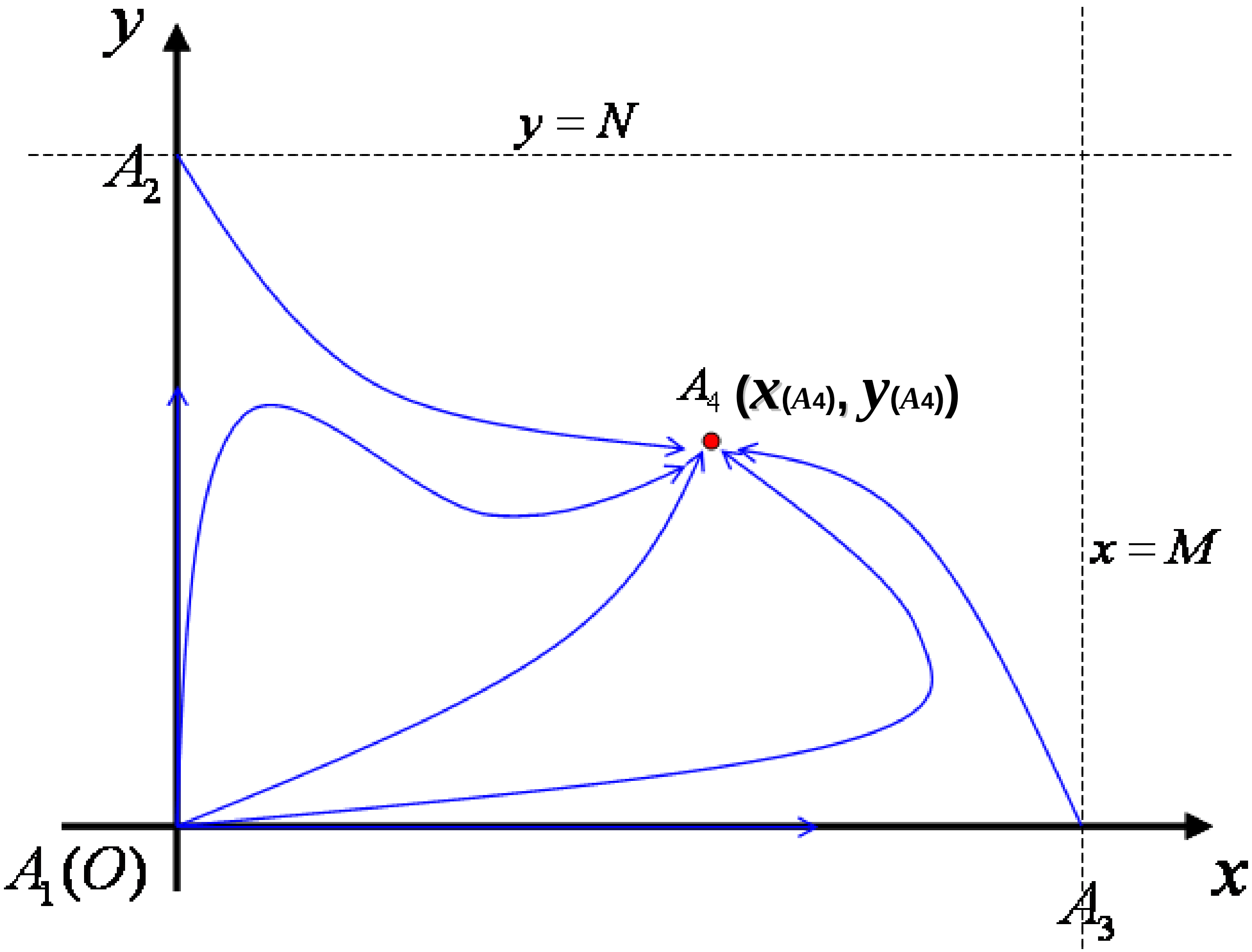
$$A_1\ (0,0),\ A_2(0,N),\ A_3(M,0),$$

$$A_4\left(\frac{M(1-N\beta)}{1+NM\beta\delta},\frac{N(1+M\delta)}{1+N\beta M\delta}\right).$$

Positive Equilibrium with practical significance.

Evaluation Algorithm

Mathematical Modeling



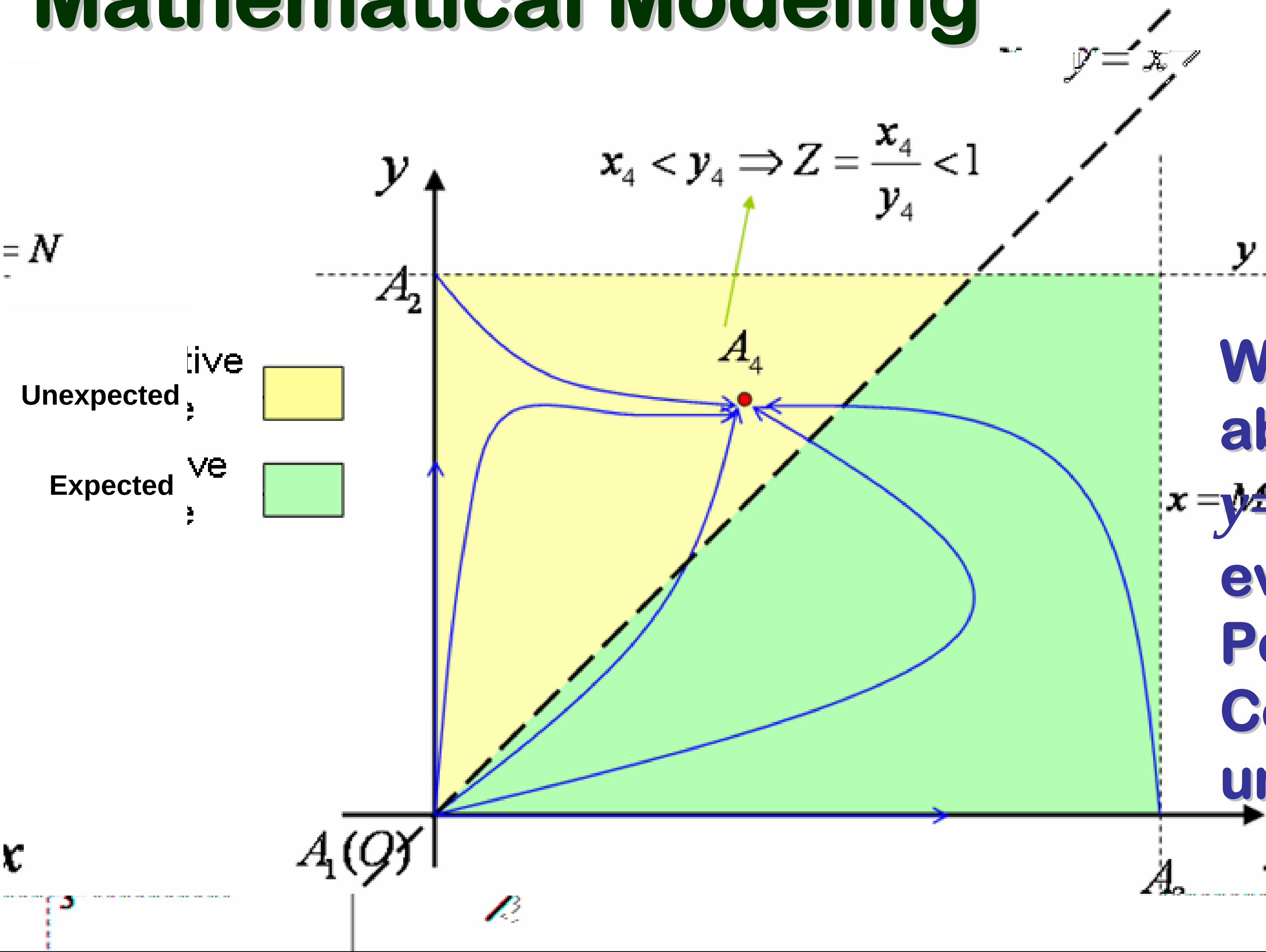
Equilibria A_1, A_2, A_3 do not have practical significance; and they are unstable.

Positive Equilibrium A_4 have practical significance.

$x_{(A_4)}$ to $y_{(A_4)}$ reflect the Performance Cost Rate.

Evaluation Algorithm

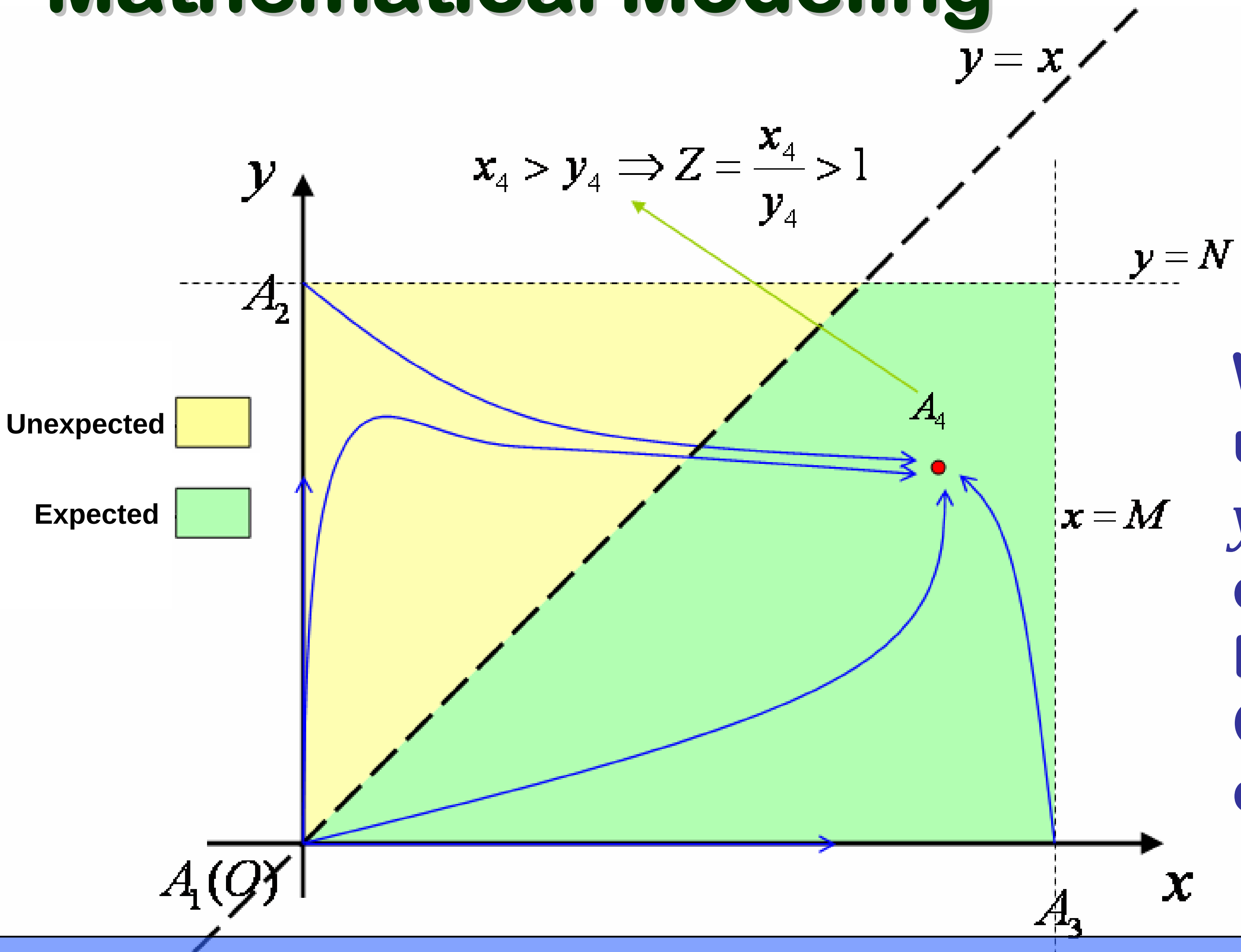
Mathematical Modeling



When A_4 is above the line $y=x$, the evaluation of Performance Cost Rate is unexpected.

Evaluation Algorithm

Mathematical Modeling



When A_4 is under the line $y=x$, the evaluation of Performance Cost Rate is expected.

Evaluation Algorithm

Evaluate GPS/Galileo Interoperability

Investigate 7 receivers: 3 of single GNSS; *4 of GPS/Galileo Interoperability*.

		One GNSS	Interoperability	Maximum	M or N
Performa	Accuracy	0.795	-0.596	1.391	1.488
	Continuity	0.468	-0.351	0.819	
	Availability	-1.069	0.802	1.871	
	Power	-0.740	0.555	1.295	

A_4: (1.38, 0.72).

In this example, the Performance Cost Rate is 1.907.

The result is *expected*.

NOTICE: All data have been averaged and standardized.

Evaluation Algorithm

Evaluate different Interoperability ways

Different Interoperability ways:

	Positive Equilibrium	P&C Rate	Order
All the same	(0.318,0.166)	1.916	1
Different carrier wave frequency	(0.542,0.415)	1.307	6
Different Modulation	(0.423,0.277)	1.527	5
Different frequency Spectrum	(0.431,0.273)	1.577	4
Different receiver power	(0.389,0.234)	1.661	3
Different message	(0.366,0.195)	1.878	2

Summary

Interoperability Signal

- **Viewpoint on Frequency Choice, Message, Modulation & Channels Design**

Quantitative Evaluation Algorithm

- **Evaluate different Interoperability ways**

Thank You !

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