The effect analysis of the GNSS interference to the Infrastructure sectors

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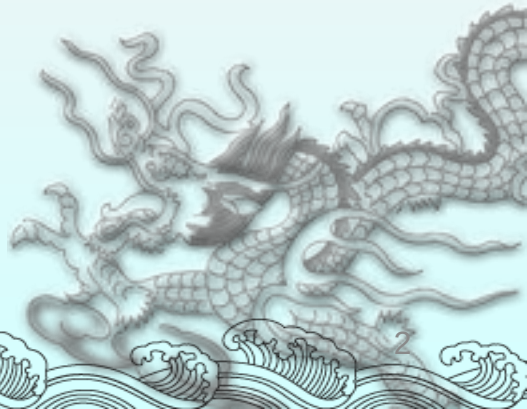
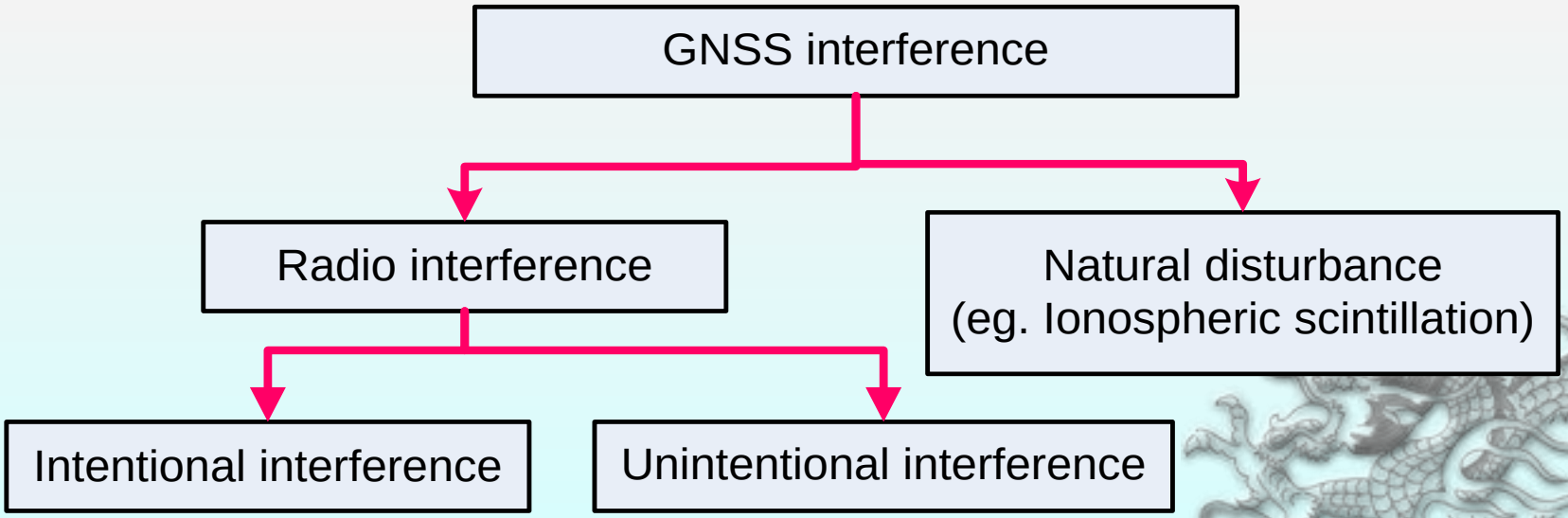


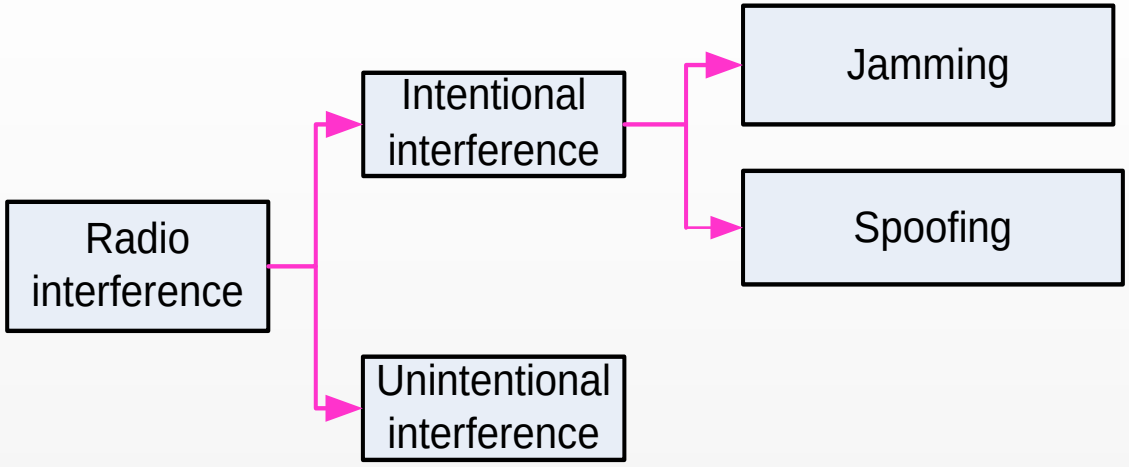
1、GNSS interference and the impact on GNSS receivers

GNSS interference classification

GNSS Interference---- classified in ICG-7

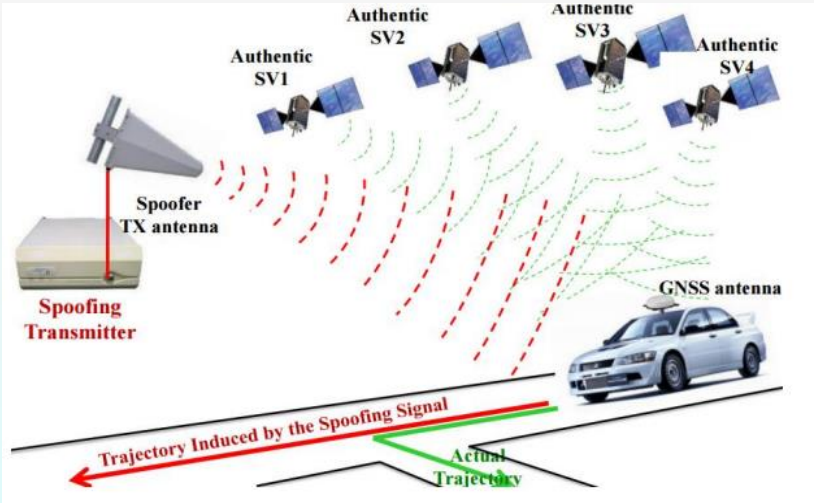
- **Radio interference (Interference from radio systems)**
  - *Intentional interference*
  - *Unintentional interference*
- **Natural Disturbance (mainly ionospheric scintillation)**





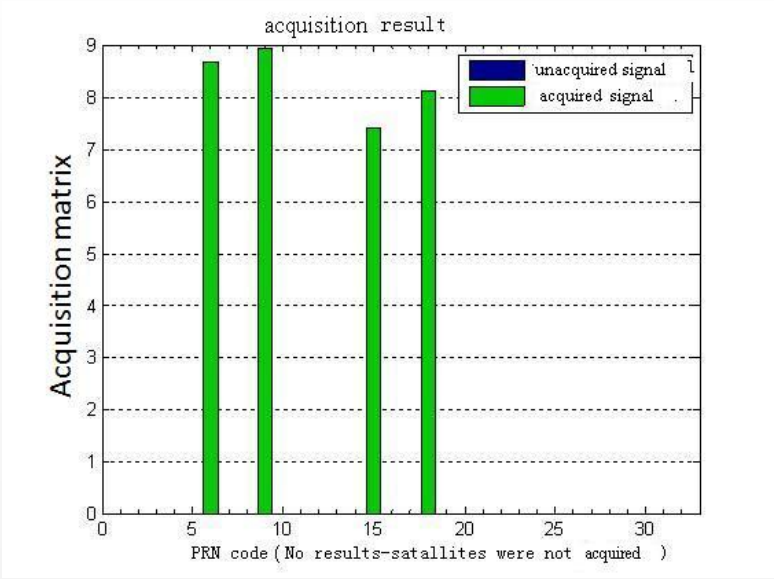
Jamming

Unintentional Interference

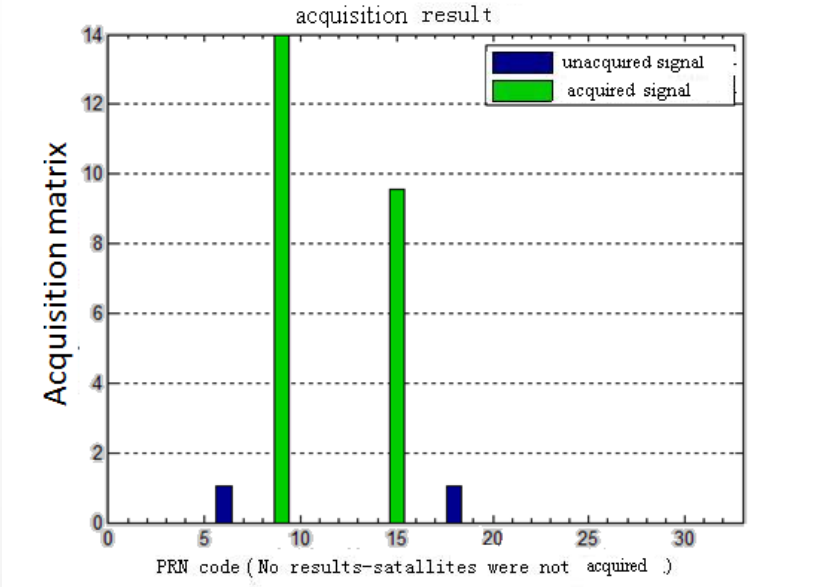


Spoofing Interference

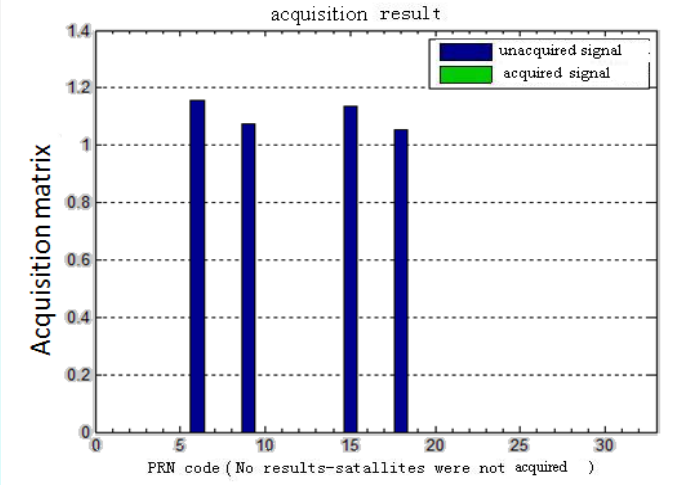
Acquisition effect of RF interference on the GNSS receiver



Acquisition result with no interference



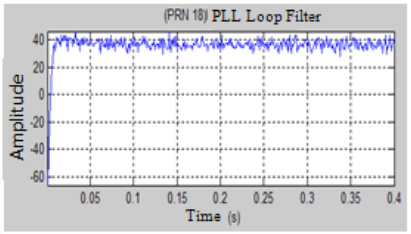
Acquisition result with single frequency RF interference （Pj=-111dBm）

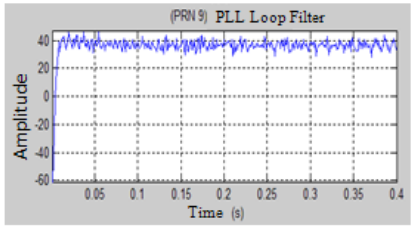


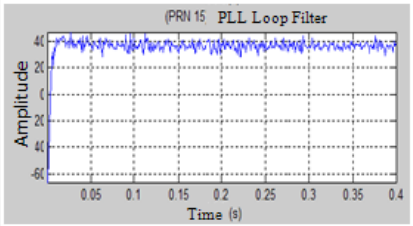
Acquisition result with single frequency RF interference （Pj=-106dBm）

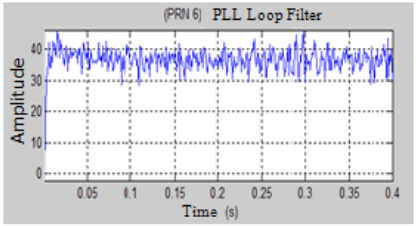
When the single frequency RF interference power increases to a certain value, the receive could not acquire some of the satellites.
If the interference continues to increase, the receiver could not acquire any satellites.

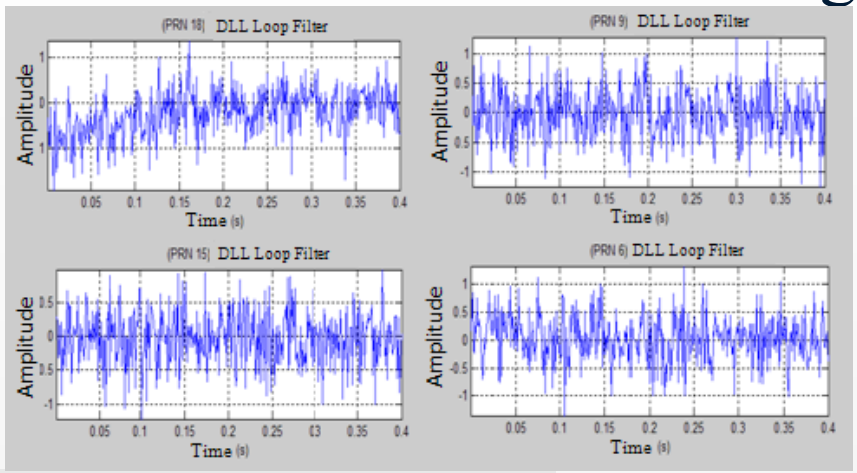
Effect of the RF interference to the GNSS receiver's tracking



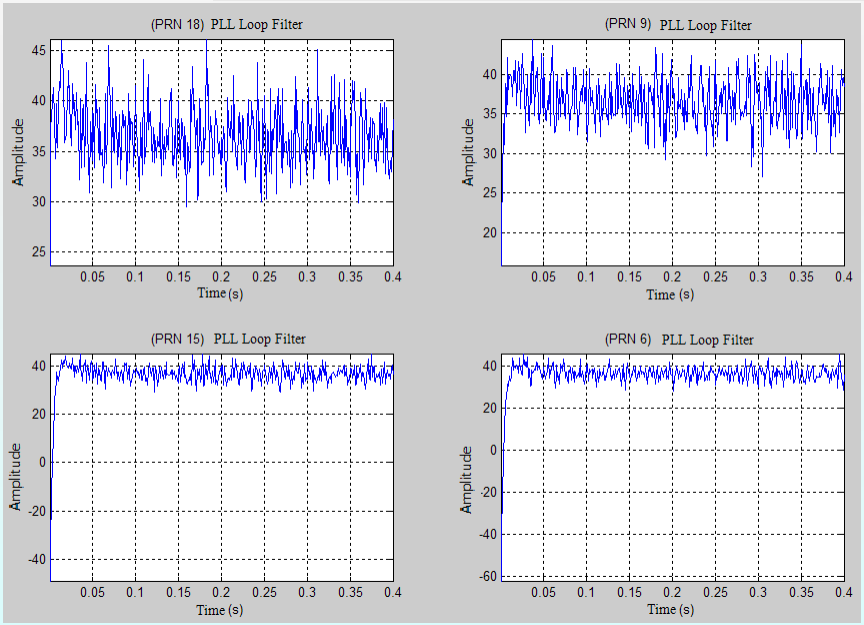


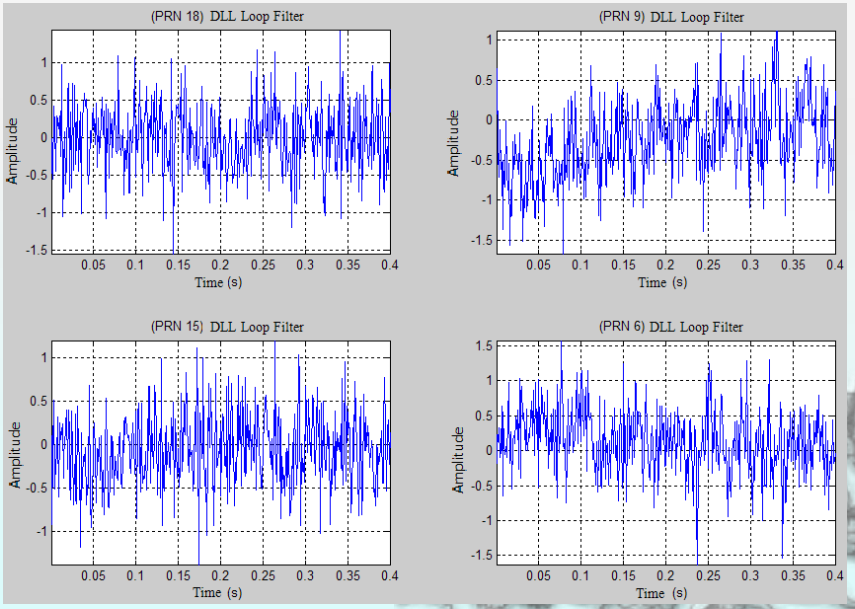






Result of PLL and DLL output with no interference





Result of PLL and DLL output with single frequency RF interference （Pj=-106dBm）

2. The effect analysis of the GNSS interference to the infrastructure sectors

(1)General introduction to the GNSS application in infrastructure sectors and interference situation.

(2)GNSS interference to the communication sector.

(3) GNSS interference to transportation sector.

(4) GNSS interference to the electricity sector.

(5)GNSS interference to the agriculture sector.

(1)General introduction to the GNSS application in infrastructure sectors and interference situation

- The key infrastructure sectors depend highly on the GNSS to keep working and cooperating. The weakness of the GNSS is ignored sometimes.
- High probability of GNSS being destroyed exists in the infrastructure sectors. This may caused by the RF interference(unintentional, jamming and spoofing interference) and natural disturbance, which we have discussed above.

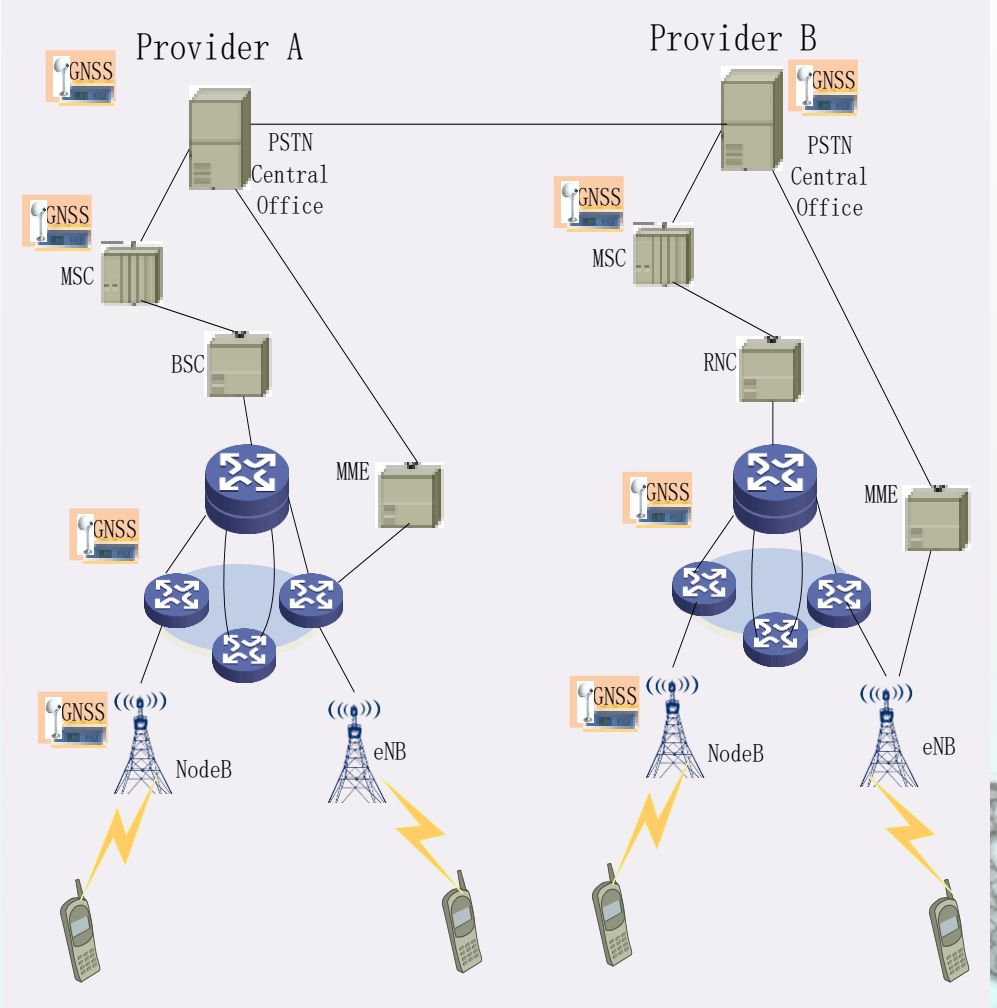
(2)GNSS interference to the communication sector

GNSS application in the communication

In communication sector, GNSS is mainly used for timing service.

1） Synchronization source of communication network.

2） Synchronization source of communication base station.



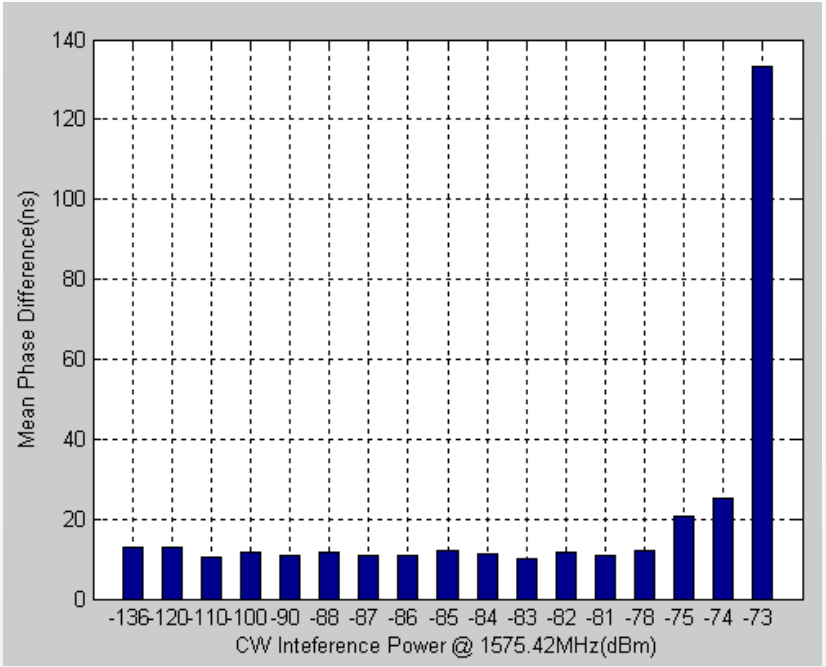
Communication time precision requirement and quantity of GNSS module used in communication cellular networks

The time synchronization requirement differs in different cellular network：

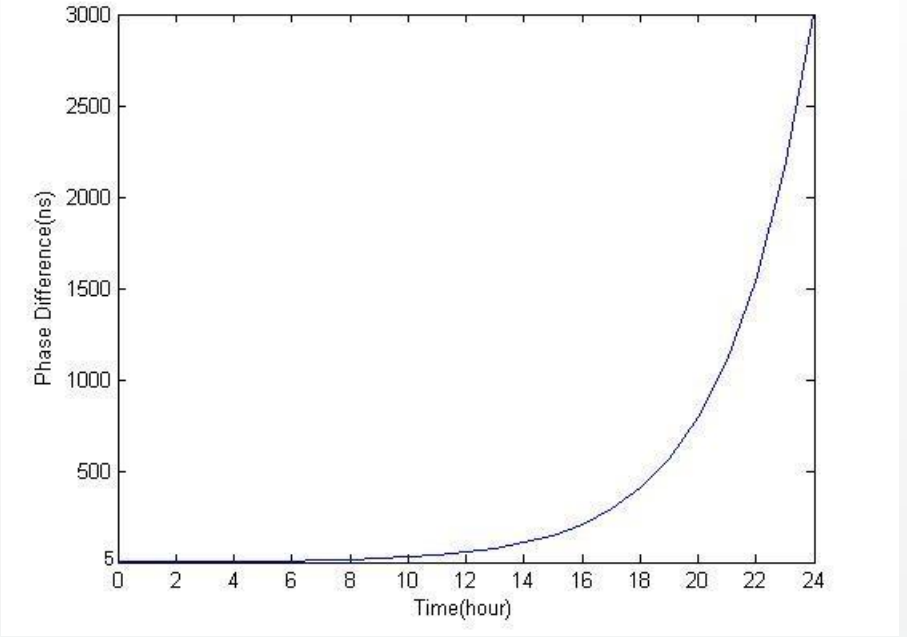
mode		Frequency accuracy	Time synchronization requirement
GSM（2G）		±50ppb	N.A
WCDMA（3G）		±50ppb	N.A
TD-SCDMA（3G）		±50ppb	≤±3*us*
CDMA2000(3G)		±50ppb	≤±3*us*
(4G)	TD-LTE	±50ppb	≤±3*us*
	LTE-FDD	±50ppb	4*us*

According to the statistic data, the number of GNSS module used in communication cellular networks is about 300000000 at the end of 2014 all around the world

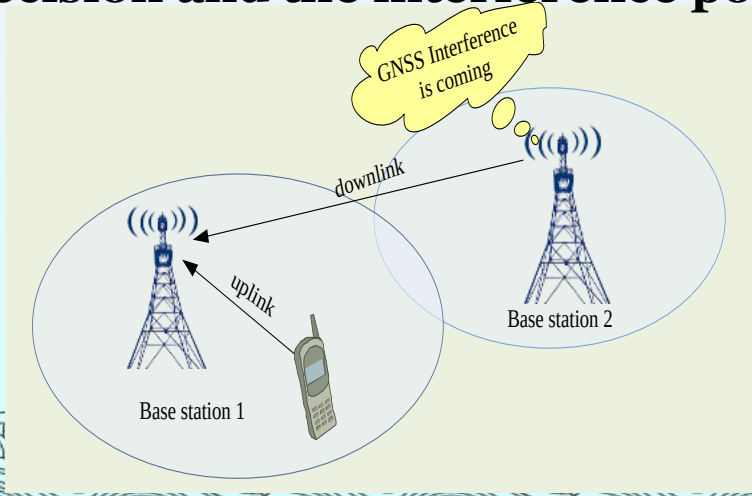
Threat to the communication sector after GNSS being interfered



Relationship between the GNSS timing precision and the interference power



Precision changes of the crystal timing after the GNSS lost lock



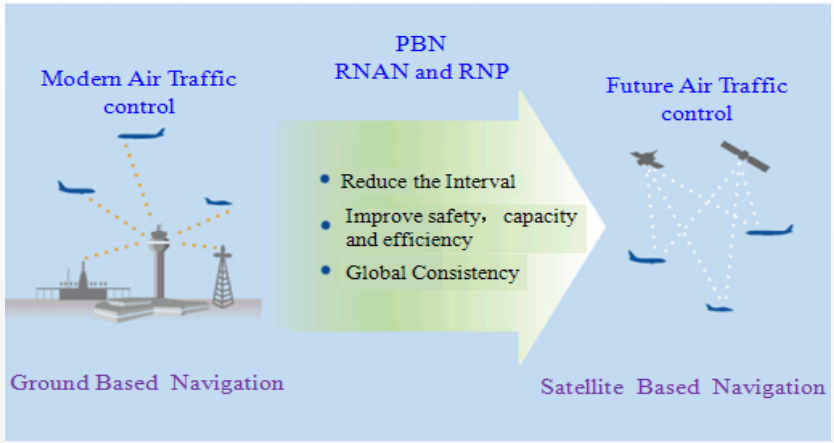
If the GNSS is interfered and the GNSS receiver lost lock, the crystal on the timing board could last a period of time at most of 24 hours. The communication would be blocked after that time.

GNSS interference events in the communication sector

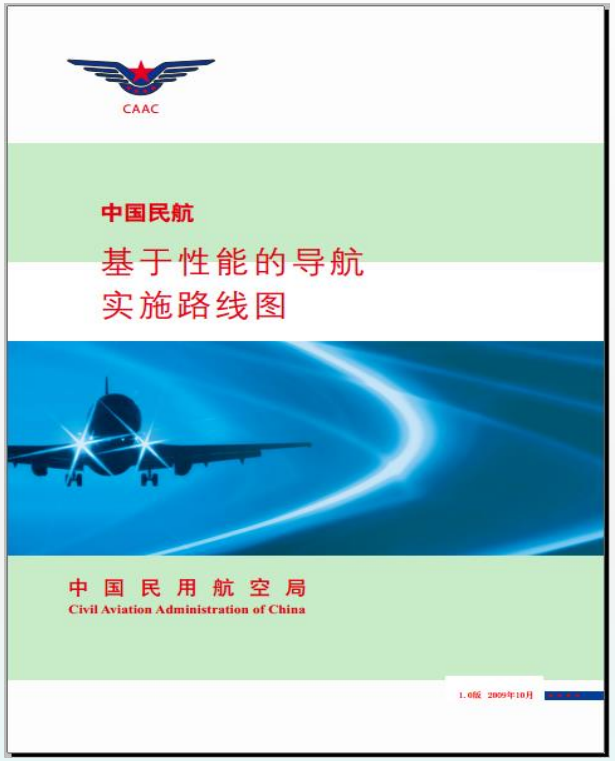
- In 2007, due to the GPS software updates, over 100 base stations in U.S. were affected, and the communication services were cut off.
- In 2007, a place of American, the GNSS interference caused two local base stations closed, 150 stations nearby were affected
- In Aug. 2015, GPS time service station in xiangfan city of China was interfered, and the communication was blocked
- .....

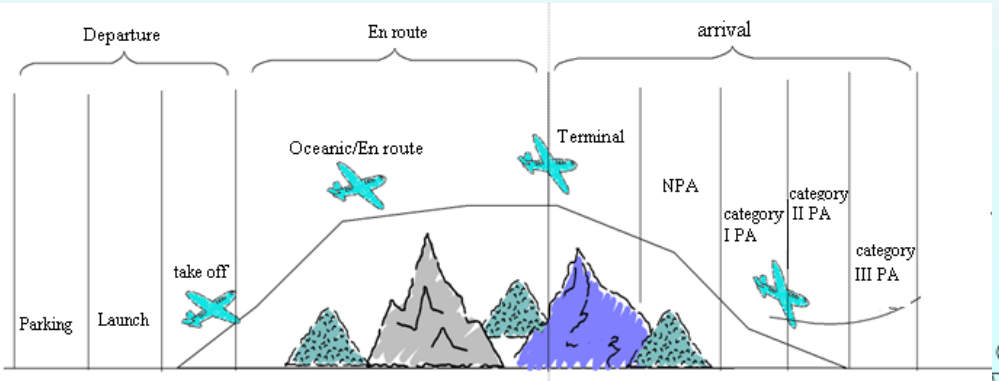
（3）effect of GNSS interference to the transportation sector

GNSS applications in aviation



ICAO proposed the PBN（performance based navigation），clarify that in the future, the aviation will mainly depend on the GNSS, and the ground based navigation only assist.





In 2009, China published the above volume, the long-range plan(2017-2025) points out to use GNSS as the main navigation facility.

Integrity alert limit and alert time of different flying phase

Typical operation	Alert limit		Alert time
	Horizontal	Vertical	
En-route(oceanic)	7.4km	N/A	5min
En-route(continental)	3.7km	N/A	5min
NPA	1.85km	N/A	10s
APV-I	556m	50m	10s
APV-II	40m	20m	6s
CAT1	40m	15~10m	6s

interference threshold of each kind of interference

The accuracy requirement of GNSS application in aviation is very high, so the FAA gives GNSS interference threshold of each kind of interference as following table.

Continuous wave interference

Frequency range f_i of the interference signal	Interference thresholds for receivers used for precision approach phase of flight
$f_i \leq 1\,315$ MHz	−4.5 dBW
1 315 MHz < $f_i \leq$ 1 525 MHz	Linearly decreasing from −4.5 dBW to −42 dBW
1 525 MHz < $f_i \leq$ 1 565.42 MHz	Linearly decreasing from −42 dBW to −150.5 dBW
1 565.42 MHz < $f_i \leq$ 1 585.42 MHz	−150.5 dBW
1 585.42 MHz < $f_i \leq$ 1 610 MHz	Linearly increasing from −150.5 dBW to −60 dBW
1 610 MHz < $f_i \leq$ 1 618 MHz	Linearly increasing from −60 dBW to −42 dBW*
1 618 MHz < $f_i \leq$ 2 000 MHz	Linearly increasing from −42 dBW to −8.5 dBW*
1 610 MHz < $f_i \leq$ 1 626.5 MHz	Linearly increasing from −60 dBW to −22 dBW**
1 626.5 MHz < $f_i \leq$ 2 000 MHz	Linearly increasing from −22 dBW to −8.5 dBW**
$f_i >$ 2 000 MHz	−8.5 dBW

* Applies to aircraft installations where there are no on-board satellite communications.
** Applies to aircraft installations where there is on-board satellite communications.

Band-limted interference

Interference bandwidth	Interference threshold
0 Hz < $Bw_i \leq$ 700 Hz	−150.5 dBW
700 Hz < $Bw_i \leq$ 10 kHz	$-150.5 + 6 \log_{10}(BW/700)$ dBW
10 kHz < $Bw_i \leq$ 100 kHz	$-143.5 + 3 \log_{10}(BW/10000)$ dBW
100 kHz < $Bw_i \leq$ 1 MHz	−140.5 dBW
1 MHz < $Bw_i \leq$ 20 MHz	Linearly increasing from −140.5 to −127.5 dBW*
20 MHz < $Bw_i \leq$ 30 MHz	Linearly increasing from −127.5 to −121.1 dBW*
30 MHz < $Bw_i \leq$ 40 MHz	Linearly increasing from −121.1 to −119.5 dBW*
40 MHz < Bw_i	−119.5 dBW*

* The interference threshold is not to exceed −140.5 dBW/MHz in the frequency range 1 575.42 ±10 MHz.

Pulse interference

	GPS and SBAS	GLONASS
Frequency range	1 575.42 MHz ± 10 MHz	1 592.9525 MHz to 1 609.36 MHz
Interference threshold (Pulse peak power)	−20 dBW	−20 dBW
Pulse width	≤125 μs	≤250 μs
Pulse duty cycle	≤1%	≤1%

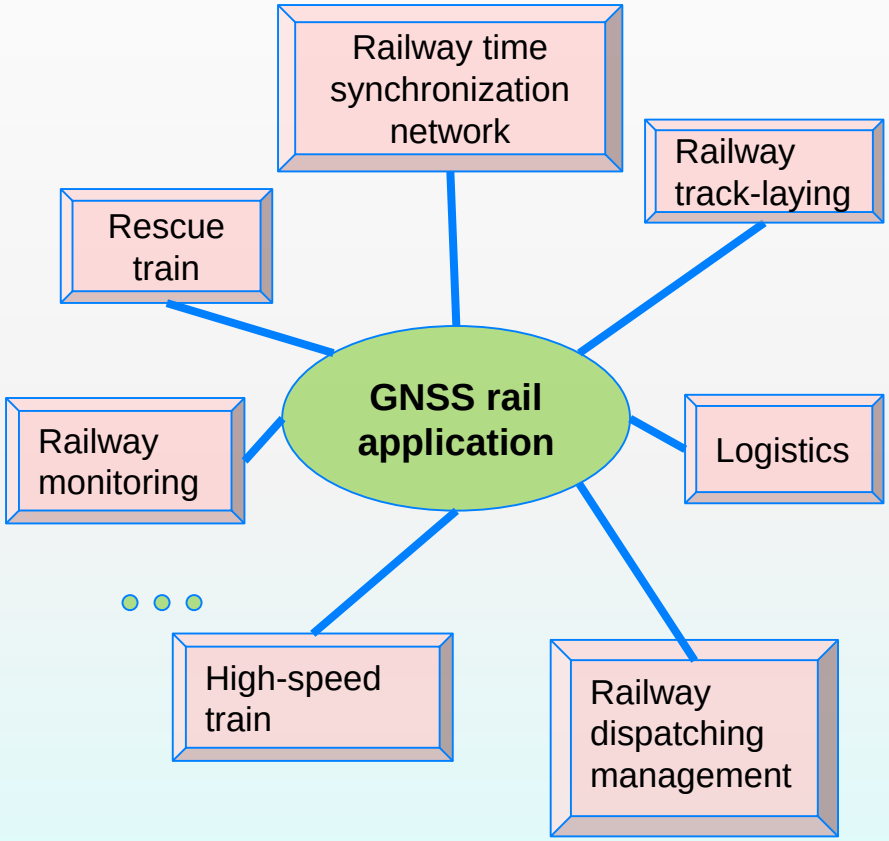
Threat to the aviation after GNSS being interfered

1. If GNSS is interfered and can not meet the positioning demand of aviation（both GNSS interference threshold and integrity alert limit and alert time），but the traffic controllers do not give a warning and still only dependent on GNSS, it may lead to a catastrophe.
2. Even if GNSS interference is detected, air traffic controllers would act swiftly to change flight approaches and utilize legacy ground-based navigation aids, the capacity, efficiency, and survelliance could be affected.

GNSS interference events in the aviation subsector

- After GPS is applied to the airplane navigation, FAA has found many interference sources that may affect the GPS work, like VHF air-to-ground communication transceiver, DME and emergency positioning ELFs, analog broadcasting and television
- In 1997, the GPS at Lugarno airport in Switzerland was interfered. The interference signal came from the permanent transceiver of the Italian army.
- In Dec. 2015, navigation system at the Nanyang airport in Yancheng, Jiangsu was interfered, which caused the signal can not be received at the 3 to 7 kilometers on the extension line of the runway.
- ……

The application of GNSS on the land transportation



GNSS highway application		
Vehicle Navigation		
Intelligent traffic	General Requirement (Vehicle management, traffic command, speed management and information search)	
	High-precision requirement	Lane level monitoring
		Vehicle collision alarm
		Vehicle accident survey
		Vehicle automated driving
Road Engineering	Engineering measurement	
	Precision control of construction machine	
	Deformation monitoring	
	Highway maintenance	

Threat to the land transportation after the GNSS being interfered

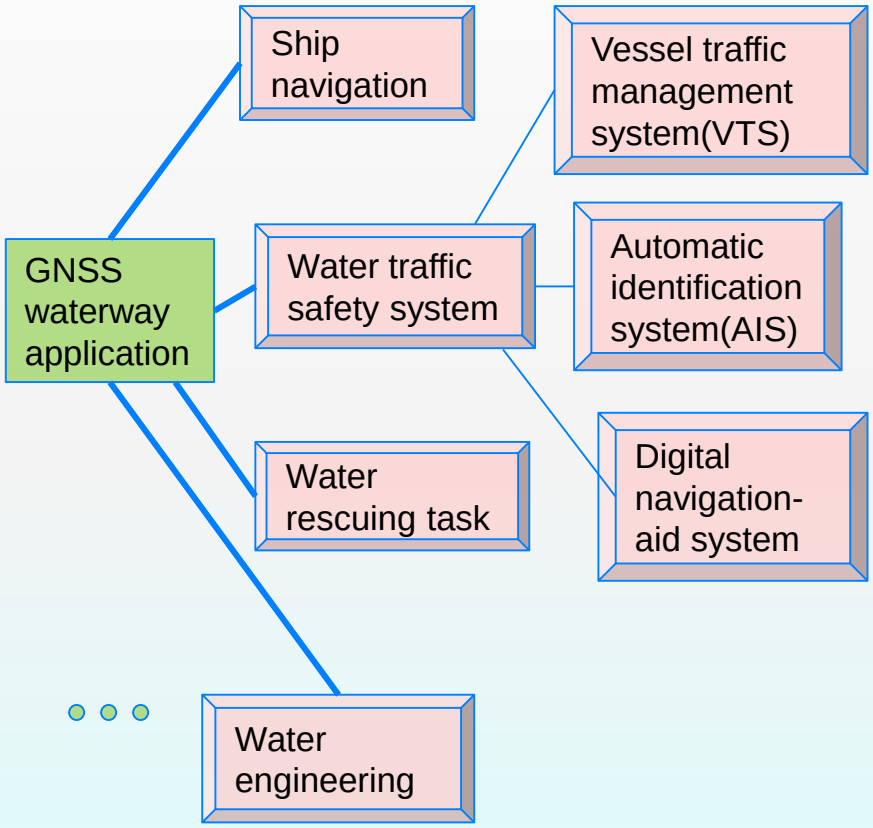
- Through testing and investigation , it is found that the most mobile interference happens on the road and the highways.
- The damage of this kind of interference is usually serious and mobile, which influences the navigation on roads and traffic control.
- For the railway, if the timing synchronization system is interfered, chaos would happen in the dispatch system or would lead to railway accident.

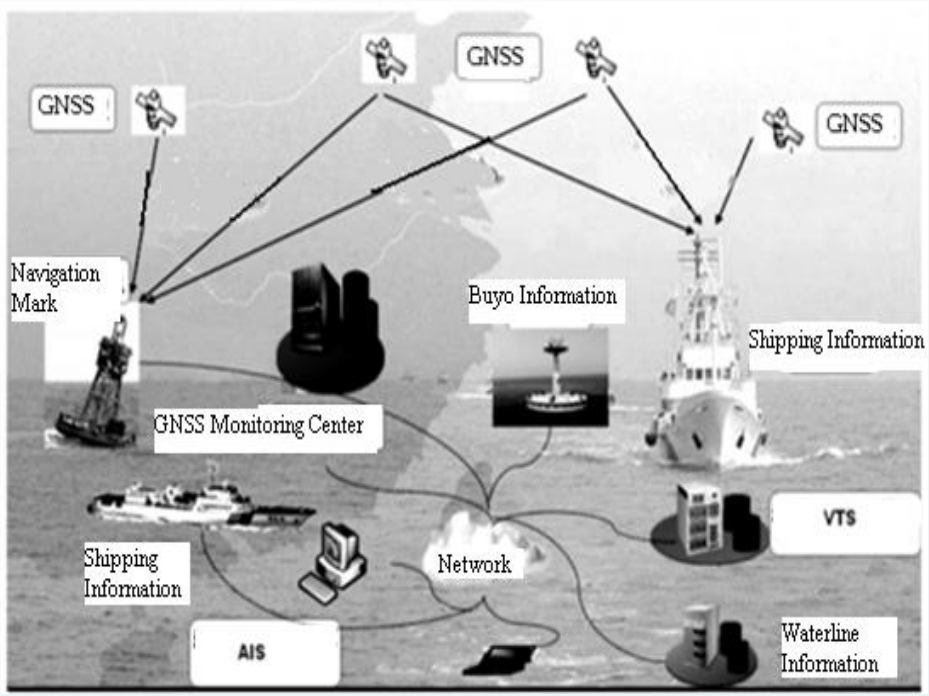
GNSS interference events in the land transportation subsector

- In Apr. 2014, a long-distance coach in Luzhou used GPS jammer to escape from the monitoring ;
- In Feb. 2015, an driver school in Peizhou city claims that their GPS system was destroyed badly, which caused the cease of the driving test of over 1000 people.
- ……

Note:Due to the most users on the roads are the separate individuals, and they do not need the time services to be very precise. And the railway is a track transportations with high security, so the interference cases in the land transportations are relatively rare reported. But the damage and its popularity are very obvious .

GNSS application on the waterway transportation



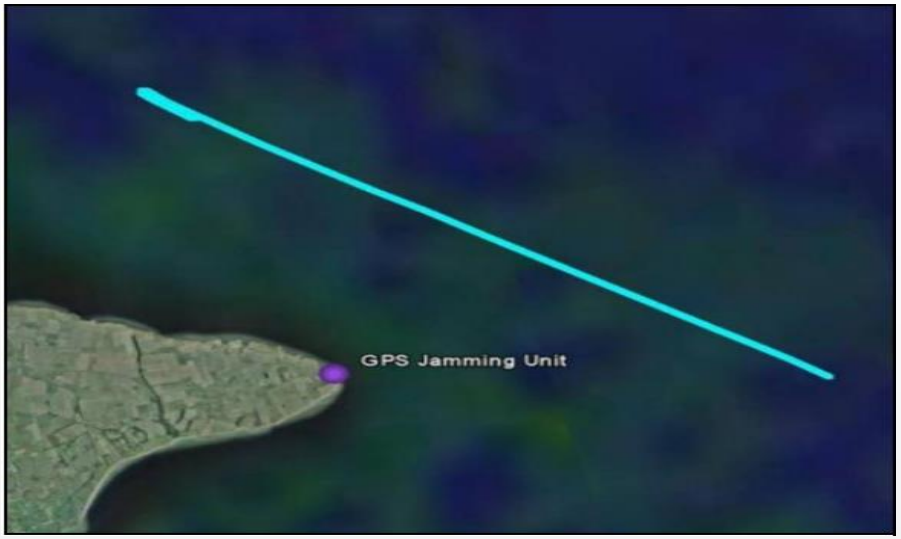


The water traffic safety system

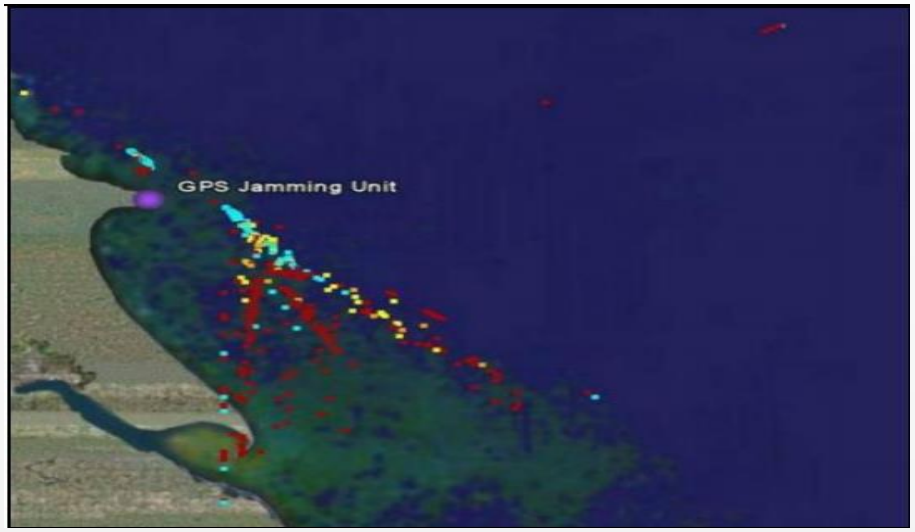
Threat to the waterway transportation after GNSS being interfered

The Taxes University used a notebook, a small antenna and a GPS cheating machine to mislead the huge ocean linear White Rose of Drachs off its route with the captain could not aware it at all.

Threat to the waterway transportation after GNSS being interfered



With GNSS interference equipment off, the position and speed of the boat under the aids of GNSS.(blue lines show the speed <15knts)



With GPS interference equipment on, the position and speed of the boat(Blue <15knts yellow< 50knts, orange<100knts ,red>100knts)

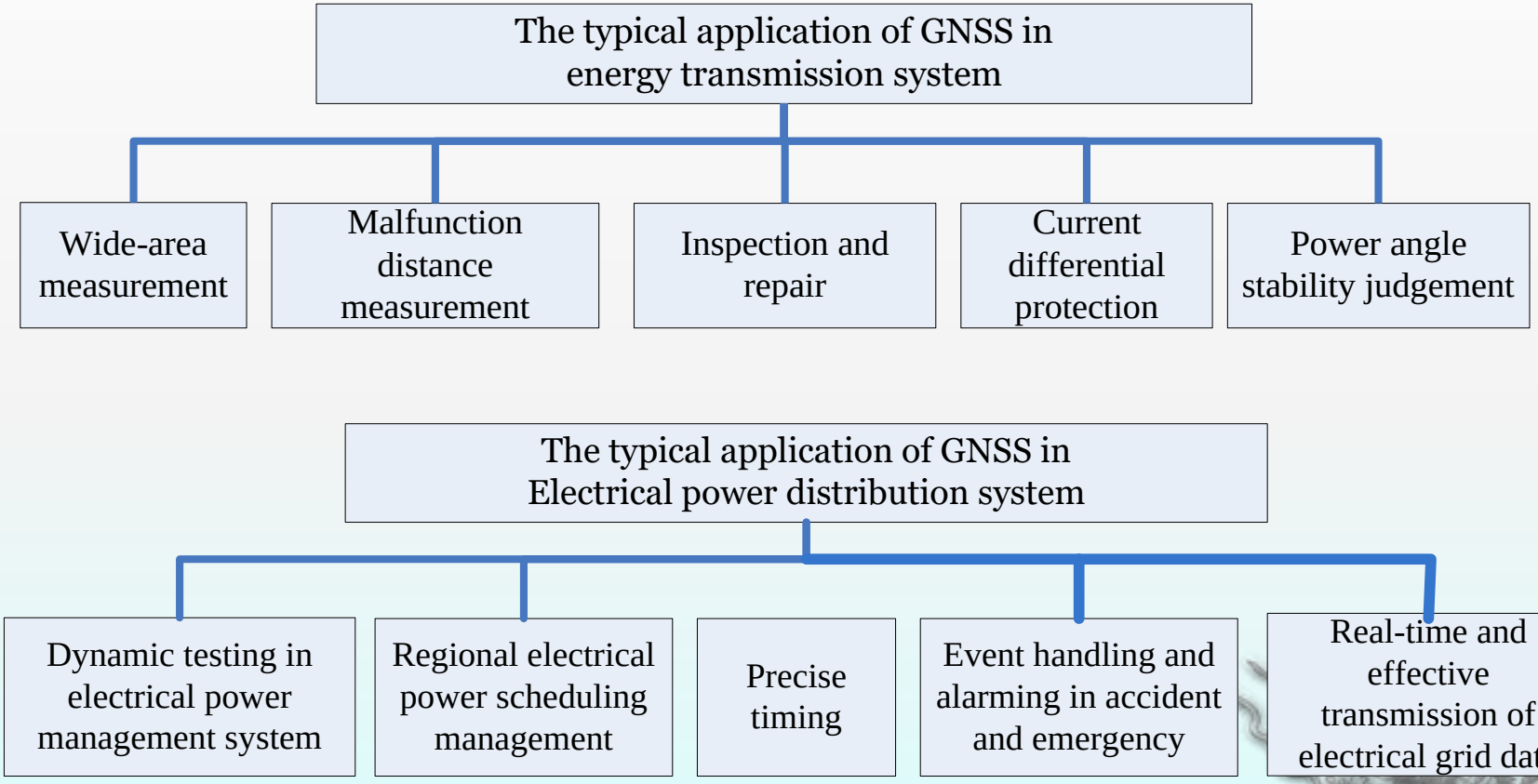
After the interference, the boat with the aid of the GNSS will make huge mistakes in its direction and speed without acknowledgement of the crew, which is very dangerous.

GNSS interference events in the waterway transportation subsector

- In April 2001, the GPS signal at Moss Landing port in U.S. was interfered which affect the traffic orders in that port.
- In the English Channel, there once happened several disasters caused by GPS interfered. And the “Tricolor” sank in an accident caused by interference, and two other ships crashed into the leftovers of the “Tricolor” also caused by the interference.
- in Jan. 2007. the GPS in Santiago port suffers an unintentional interference, which stopped the work of navigation facilities, and cut off the communications in the port.
- ……

(4)Effect analysis of GNSS interference to the electricity sector

GNSS application in the electricity sector

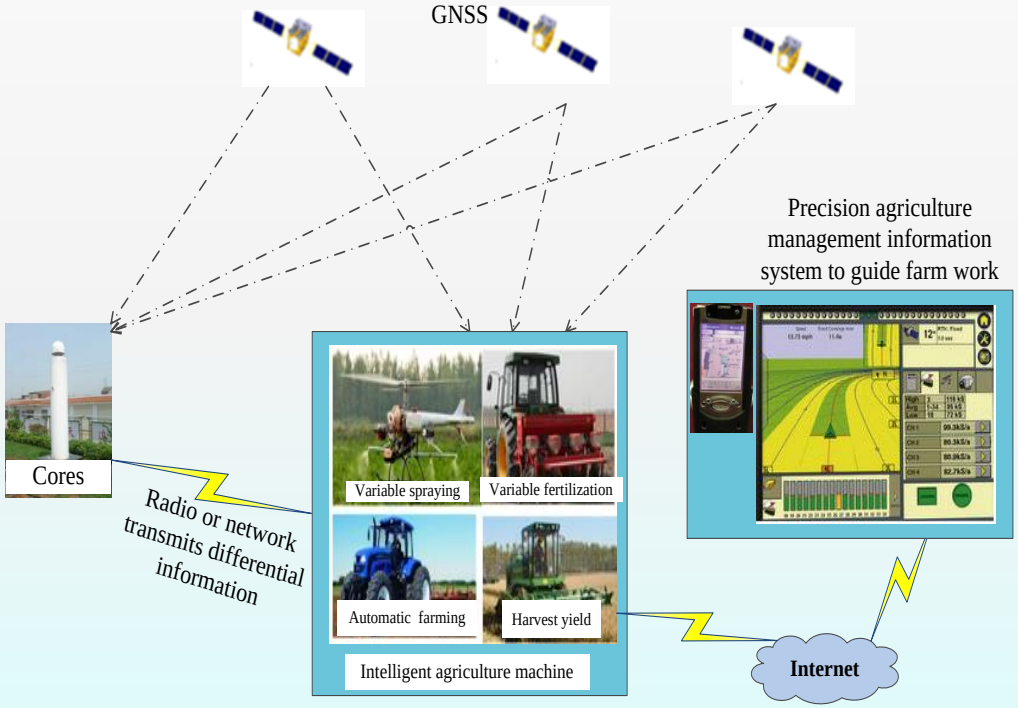


Threat to the electricity sector industry after the GNSS being interfered

- GNSS interference could cause the abnormality of the electrical power system. In a digitalized transformer substations, the measured data of power and power factors often exceeded the limitation, which proves to result from the time synchronism.
- The power industry adopts the IEEE1588 web as the GNSS backups, but this way can only be used in time services of small-scale electronic wire netting. And to the large-scale like a province or the whole country, the time services must depend on the GNSS, which make it urgent to monitoring the GNSS interference.

(5) Effect analysis of GNSS interference in the agriculture sector

GNSS applications in precision agriculture



GNSS application in agriculture is mainly in precision agriculture:

- large irrigation machine(direction control in 20 cm)
- unmanned seeding machine(8cm)
- unmanned transplanting machine(10cm)
- seeding bed machine(5cm)
- extensive spray pesticide(10cm)
- Spray herbicide(1 m).

Threat to the precision agriculture after the GNSS being interfered

- The GNSS interference mainly affects the working process of the automatic farming machinery.
- Now, the smart farming machinery usually use backups besides the GNSS like machinery arm, machinery view or laser sensors, so less attentions have been paid in the monitoring for GNSS interference .
- With the development of modern farming, large-scale and smart equipment will be applied, so the GNSS will play a much more important role, and much attentions should be paid in the monitoring for GNSS interference .

3.conclusion

1) GNSS signal is weak and can be easily disturbed. The GNSS interference commonly exists, and due to the appearance of the intentional interference unit, it is increased rapidly .

2) The interference damage could lead to serious problems, like economical loss, lower trust from the users and time delay of the main task, etc.

3）The effect of GNSS interference on certain infrastructure is different

- *The damage in the communication sector is usually temporary because it will use constant temperature crystal to keep a period time for the timing requirement. However, the long-time GNSS being interfered over 24 hours or longer will cause the lower service quality.*
- *Energy department(especially for the power department) has the defend ability to the GNSS interference, but the multi-target GNSS cheating may also cause the large-scale cutoff of the power supply. Besides, with the development of the newly PMU used in the smart electronic netting, the outcome will be more and more serious if the GNSS being interfered.*
- *In short term, the transportation department will not suffer from large-scale decrease or being cut off the services. However, in the long prospect, the transportation department will use more and more GNSS facilities, the outcome of interference will be worsened. So, the transportation department should develop more backup system to reduce the dependence on GNSS.*
- *Now, the farming department mainly uses the backup systems, so the threaten to GNSS being interfered is not obvious. But the outcome will be much worse with the GNSS popular use in the farming industry in the future.*

Thank you