

Universidade de Vigo

AtlantTIC

Research Center for
Information & Communication Technologies



Link Adaptation in Mobile Satellite Links: Field Trial Results

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Contributions and Novelty

- **Implementation of a Mobile SatCom standard:**
 - **ETSI TS 102 704** (S-UMTS family SL) → BGAN (Inmarsat)
- **Use of Software Defined Radio (SDR) technology**
 - Physical layer hosted by an ARM Cortex A9 667 MHz dual-core processor
- **Deployment of a SatCom link** using an S-band MEO satellite
- **Experimental test of novel link adaptation algorithms**
 - **Land Mobile Satellite channel:** car
 - **Aeronautical channel:** fixed-wing Unmanned Aerial Vehicle (UAV)

The SatUAV project

- **Project coordination:** AtlantTIC
- **Partners**



Technological center



Satellite operator (USA)



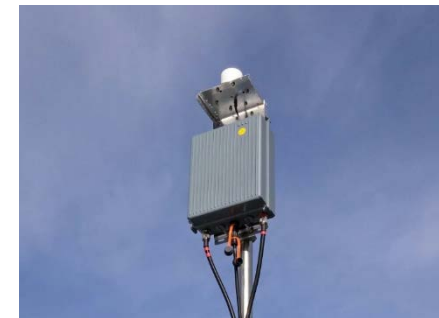
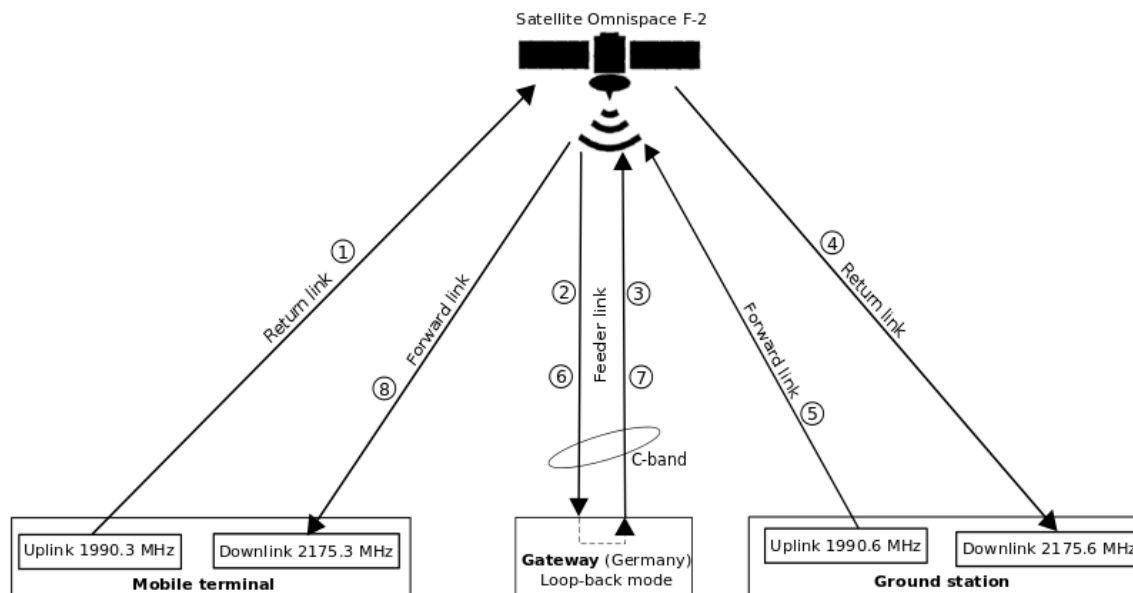
UAV manufacturer and operator (Spain)



- **Objectives**

- Development of the Mobile Satellite Terminal and the Ground Station
- Test and compare the link adaptation algorithms
- Perform channel model measurements
- Test and validate the real-time communications system in terrestrial and aeronautical environments

The elements of the system

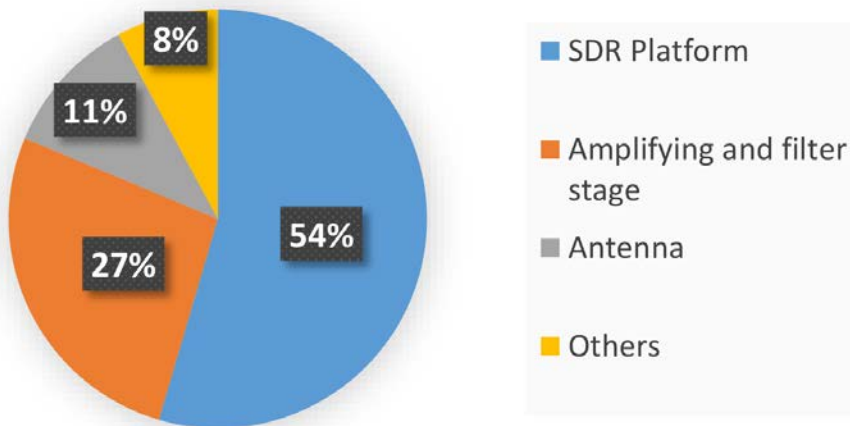


The Mobile Terminal (MT) prototype



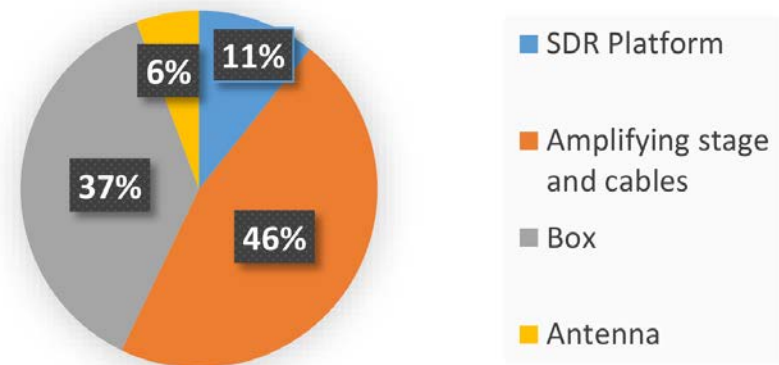
- **Weight:** 3.5 Kg (4.6 Kg including batteries)
- **Dimensions:** 25 x 25 x 10 cm (without the antenna)
- **Data rates:**
 - $\pi/4$ -QPSK bearer: 41,2 –113,6 kbps
 - 16-QAM bearer: 83,6 –211,2 kbps

MT cost breakdown



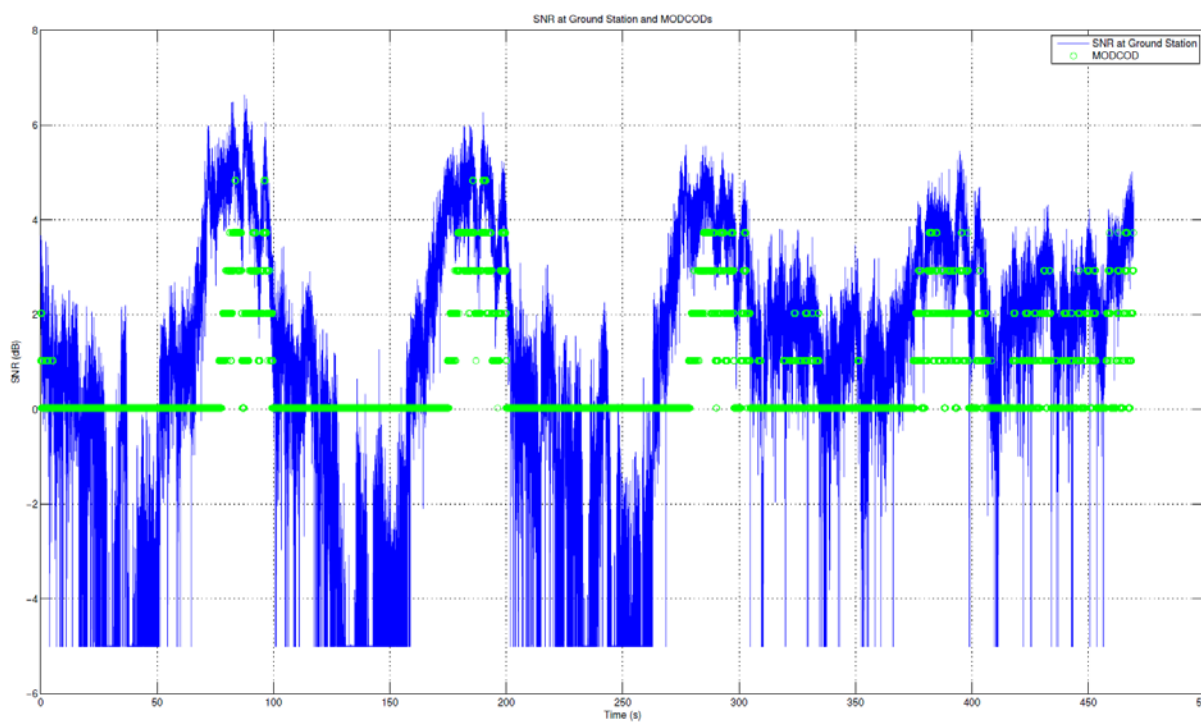
MT weight breakdown

Total = 3,500 g

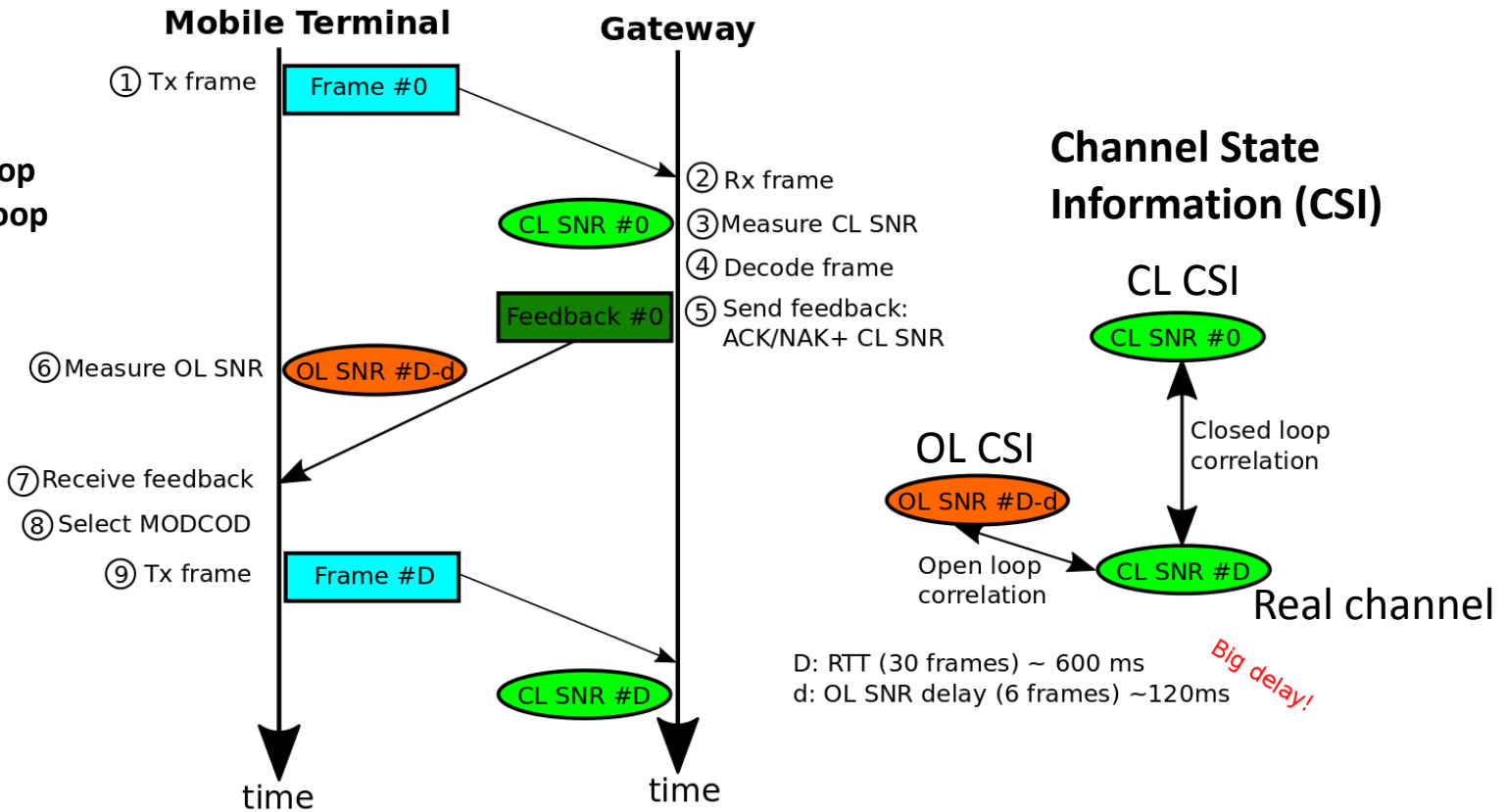


The problem of Link adaptation

- Origin of the variations in the RSSI/SNR
 - Weather conditions
 - Shadowing due to small obstacles
 - Obstruction due to big obstacles (non-Line-of-Sight)
 - Fast fading (multipath)
 - Distance to the satellite (for non-GEO)
 - Antenna gain in the direction of the satellite (changing elevation & azimuth and terminal movement)
 - Beam switch



Link adaptation in the satellite scenario



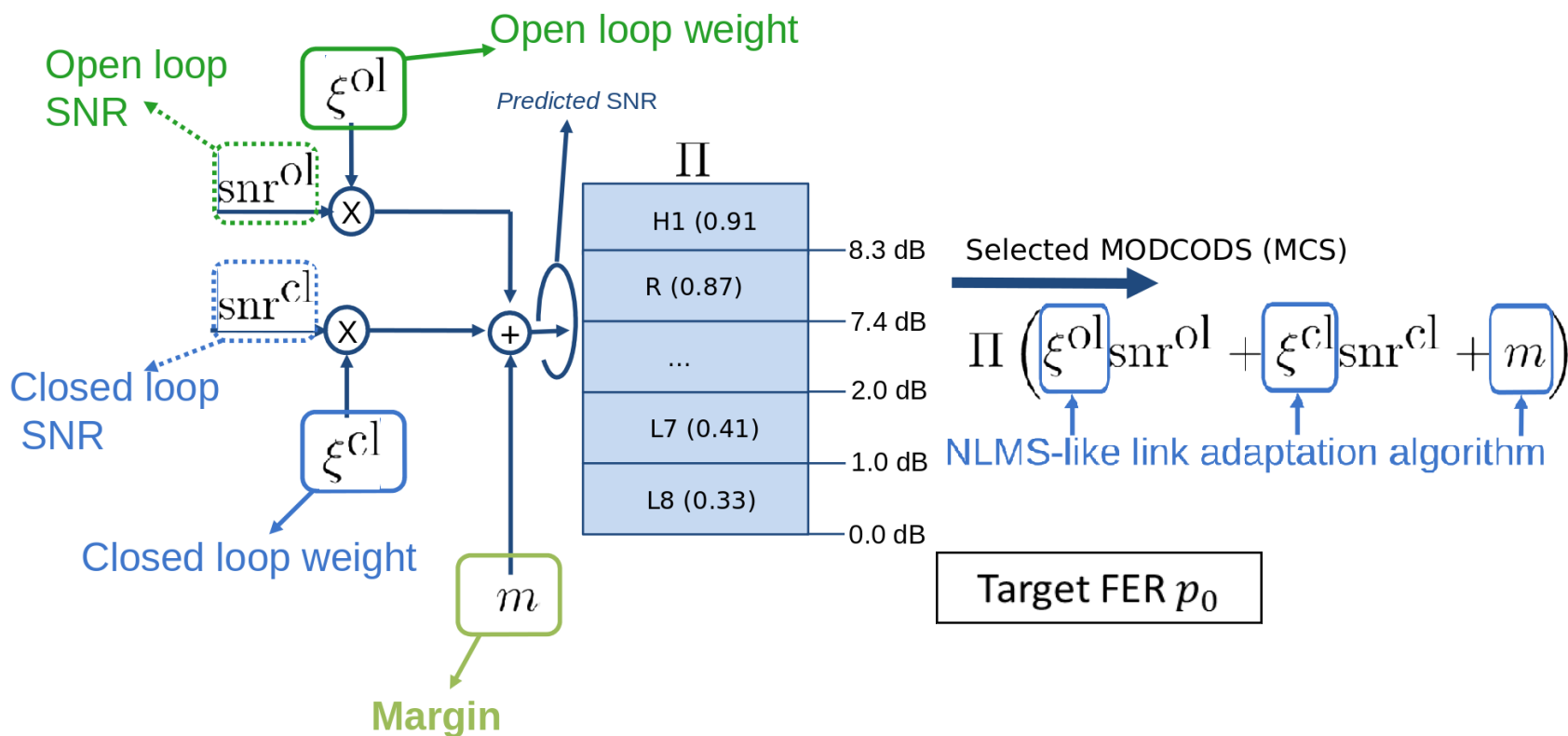
OL = Open loop
CL = Closed loop

Link adaptation in the return link

Our proposal for Link Adaptation in the Return link

ASMS 2014: Balancing closed and open loop CSI in mobile satellite link adaptation

ADAPTIVE MARGIN AND WEIGHTED OPEN AND CLOSED LOOP SNR



ASMS 2016: Field Trials Results

Equations for updating the parameters

- Four similar algorithms were compared:
 - Closed loop
 - Open loop
 - Balanced
 - Balanced convex
- Example of an adaptation rule:

$$\begin{bmatrix} c_{i+1} \\ \boldsymbol{\xi}_{i+1} \end{bmatrix} = \begin{bmatrix} c_i \\ \boldsymbol{\xi}_i \end{bmatrix} - \frac{\mu}{\theta^2 + \|\mathbf{SNR}_{i-d}\|^2} (\epsilon_{i-d} - \tilde{p}_{0,i}) \begin{bmatrix} \theta \\ \mathbf{SNR}_{i-d} \end{bmatrix}$$

$$\boldsymbol{\xi}_i = [\xi^{cl} \ \xi^{ol}]^T$$

$$\mathbf{SNR}_i = [\mathbf{SNR}_i^{cl} \ \mathbf{SNR}_i^{ol}]^T$$

- Practical operation:
 - $\epsilon_i = 0$: **ACK** → Slight \uparrow of Weights and Margin
 - $\epsilon_i = 1$: **NAK** → Strong \downarrow of Weights and Margin

Satellite component

Characteristic	Value
Operator	Omnispace LLC
Satellite	Omnispace F-2 (former ICO F-2)
Orbit	MEO (10,500 km) 45° inclination
Coverage availability	21% (5 hours/day) in 2/3 passes per day
Frequency	S-band @ 2 GHz
Leased bandwidth	200 kHz in each direction
Doppler	± 20 kHz

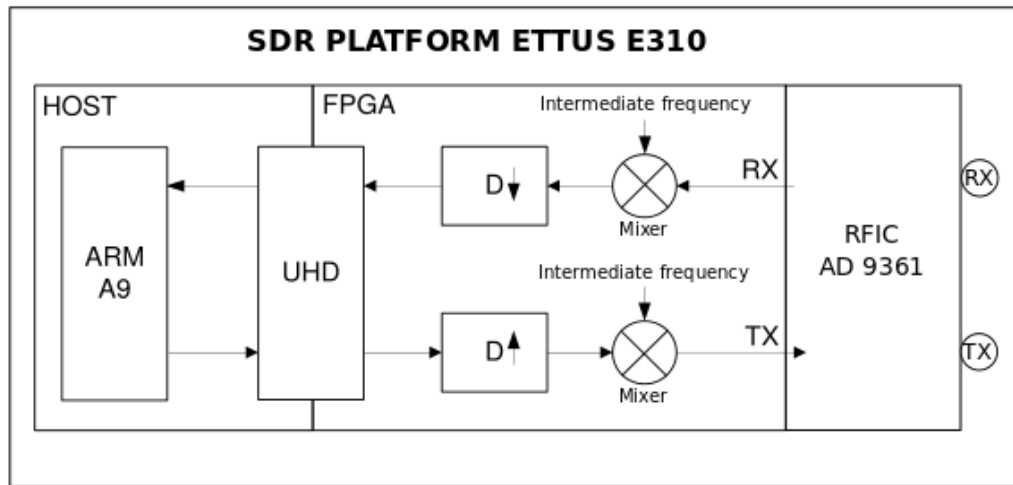
Physical layer

- Standard ETSI TS 102 704, October 2015
 - BGAN (Inmarsat)
- Two shared access bearers were implemented
 - R20T2Q & R20T2X

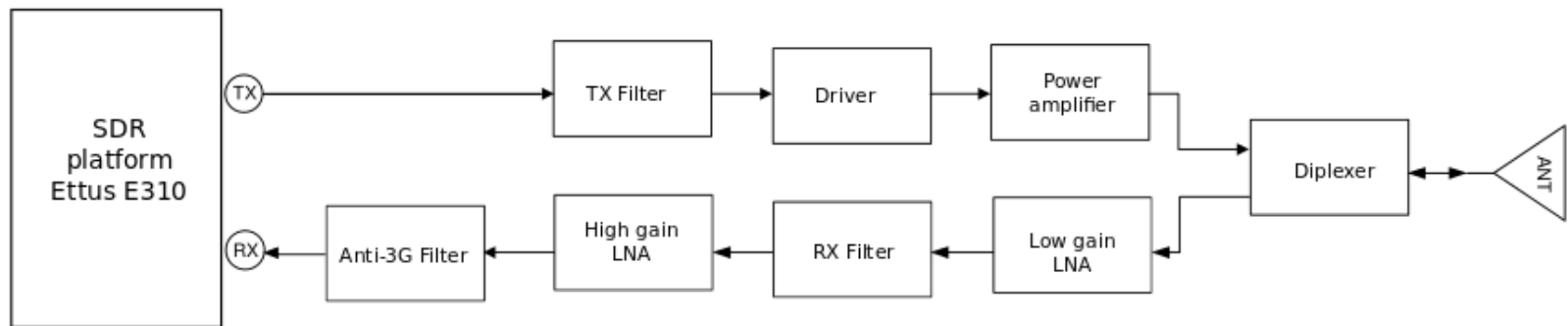
Characteristic	Value
Frame length	20 ms
Modulation	$\pi/4$ -QPSK (Q), 16-QAM (X)
Symbol rate	67,2 ksymb/s
Channel bandwidth	84 kHz
Transmit chain elements	Scrambler, Turbo-coding, Puncturing, Channel Interleaving, Modulation, Matched Filter (RRC)
Turbo-coding	10 code rates: rates from 0.33 to 0.91 (R20T2Q) and from 0.33 to 0.84 (R20T2X)

Hardware

- SDR platform USRP Ettus E310
 - ARM Cortex A9 667 MHz dual core + 7 Series FPGA + AD 9361

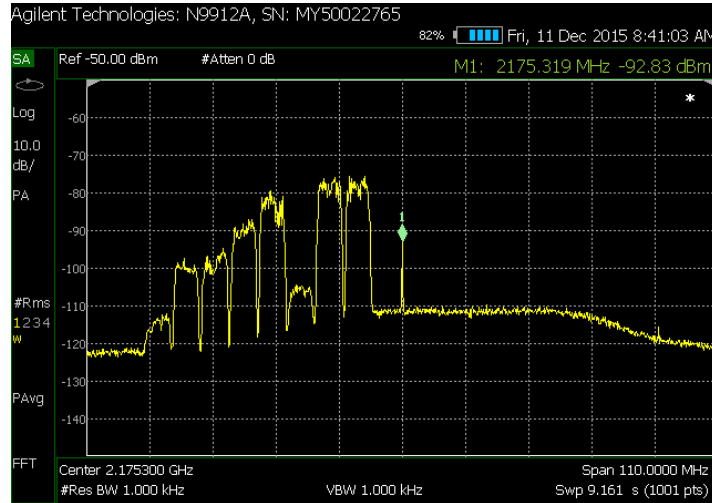


- External analog front-end



Issues during development

3G base stations interferences



Real-time operation

- Optimization of correlations implementation
- Exploit both cores with two threads synchronized with semaphores

High frequency deviation

- Large Doppler (20 kHz) compared with BW (84 kHz)
- **Solution:** Variable bandwidth matched filter

Field trial results together with simulation results

Markers = field trials

Lines = simulations using experimental data

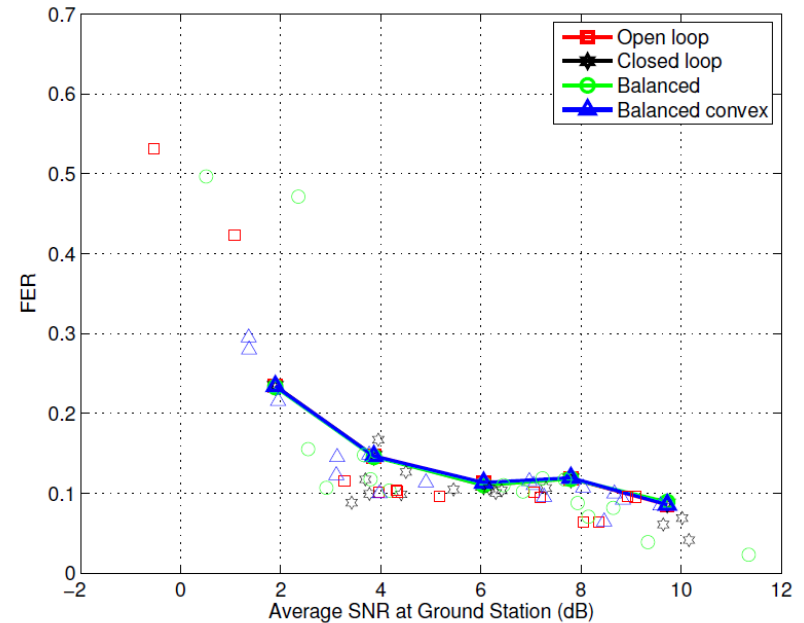
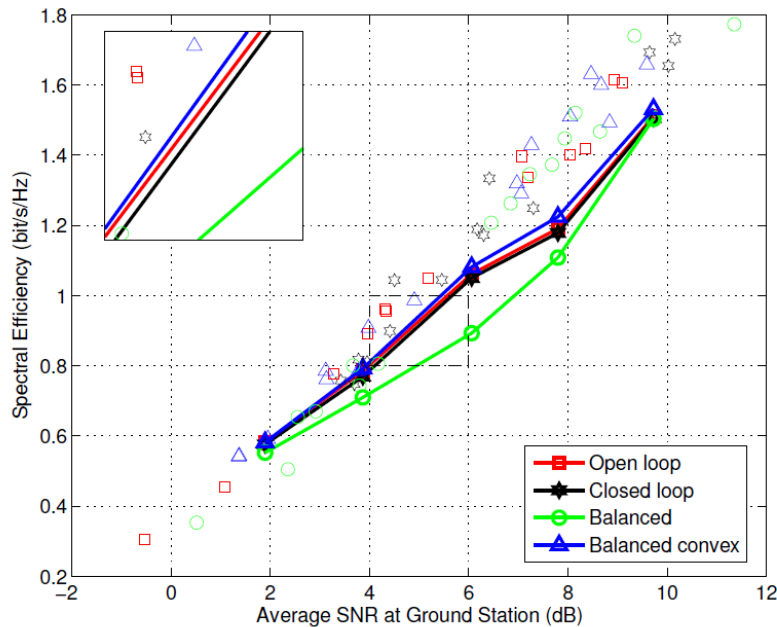
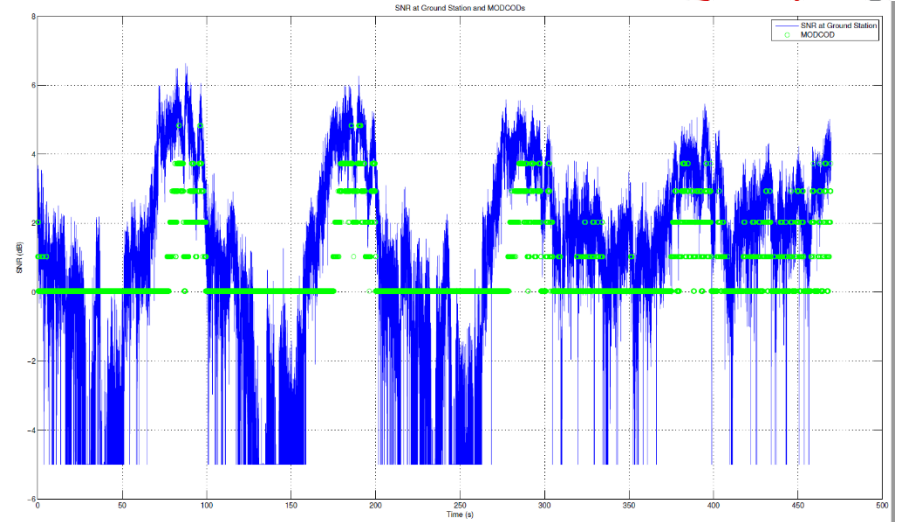


Fig. 7: Mean spectral efficiency (left) and cumulative FER (right) of field trials (independent markers) and simulations (markers connected with lines).

Link adaptation in action

Algorithms can follow the channel variations due to decrement of the antenna gain in the direction of the satellite when the UAV turns

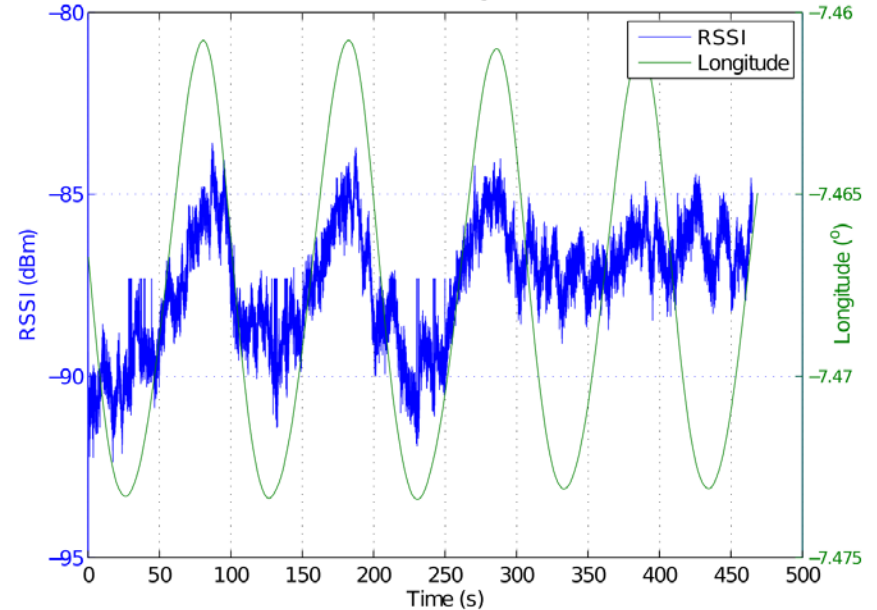
SNR (blue) and MODCODs (green)



UAV trajectory

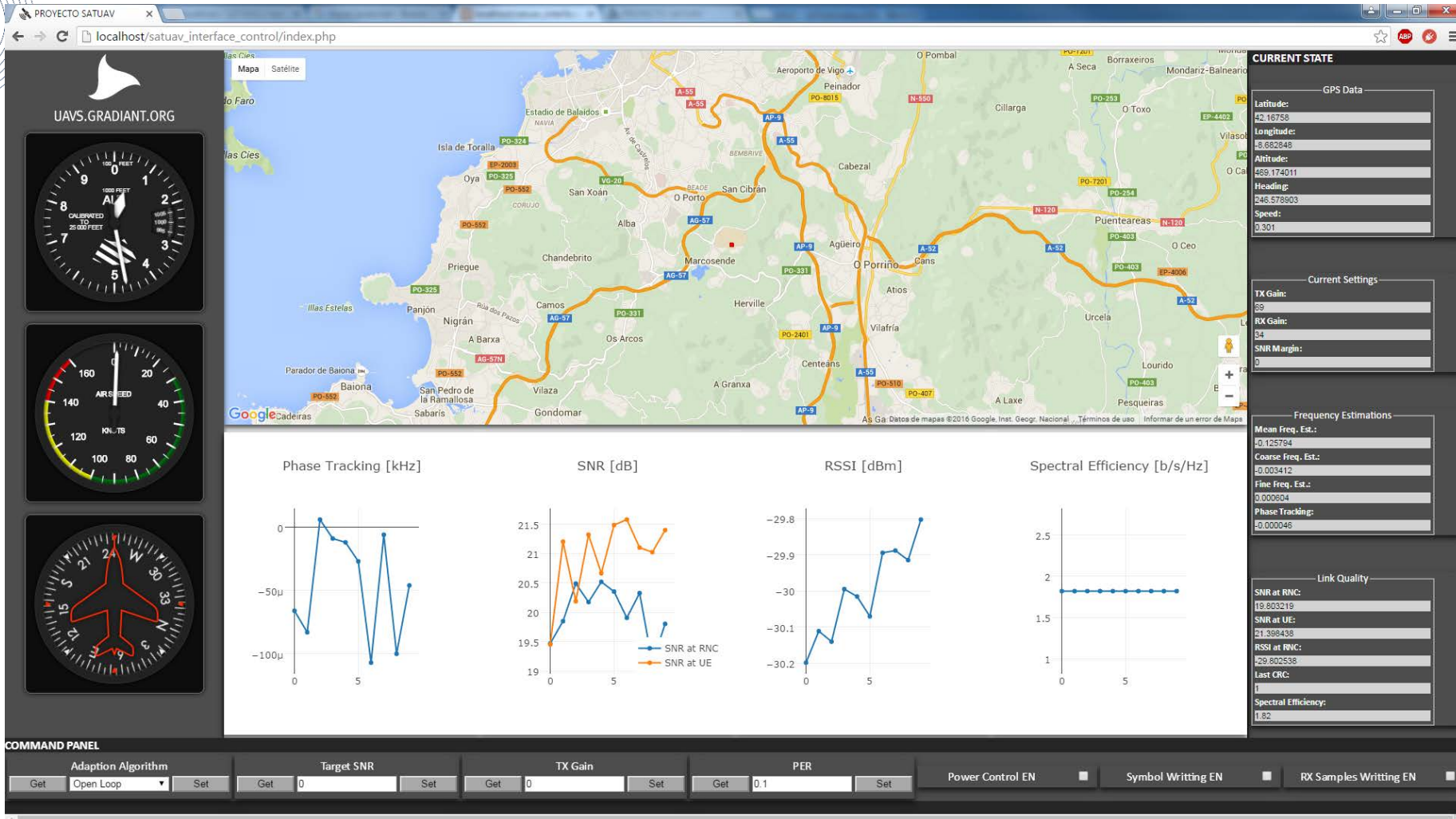


RSSI and longitude



Tracking of the UAV and the SatCom link

- Web application



The screenshot displays the PROYECTO SATUAV web application interface. The main window shows a Google Map of Galicia, Spain, with a red line indicating the UAV's flight path. The interface includes several panels:

- Left Panel:**
 - Logo: UAVS.GRADIANT.ORG
 - Altitude gauge: Shows 0 to 1000 feet.
 - Airspeed gauge: Shows 0 to 160 knots.
 - Compass: Shows heading and cardinal directions.
- Map:** Shows the UAV's path (red line) over a map of Galicia, Spain, with various locations and roads labeled.
- Bottom Left:** Four line graphs showing performance metrics over time (0 to 5 seconds):
 - Phase Tracking [kHz]:** Values fluctuate between approximately -100 and 0.
 - SNR [dB]:** Two lines are shown: SNR at RNC (blue) and SNR at UE (orange). Both fluctuate between 19.5 and 21.5 dB.
 - RSSI [dBm]:** Values fluctuate between -30.2 and -29.8 dBm.
 - Spectral Efficiency [b/s/Hz]:** Values are constant at approximately 1.82.
- Right Panel:**
 - CURRENT STATE:** GPS Data section showing Latitude: 42.16758, Longitude: -8.68248, Altitude: 459.174011, Heading: 248.578903, Speed: 0.501.
 - Current Settings:** TX Gain: 39, RX Gain: 34, SNR Margin: 0.
 - Frequency Estimations:** Mean Freq. Est.: 0.125794, Coarse Freq. Est.: 0.003412, Fine Freq. Est.: 0.000604, Phase Tracking: 0.000046.
 - Link Quality:** SNR at RNC: 19.803219, SNR at UE: 21.398438, RSSI at RNC: 29.802538, Last CRC: 1, Spectral Efficiency: 1.82.
- Bottom Panel:** COMMAND PANEL with controls for:
 - Adaption Algorithm: Open Loop
 - Target SNR: 0
 - TX Gain: 0
 - PER: 0.1
 - Power Control EN:
 - Symbol Writing EN:
 - RX Samples Writing EN:

Conclusions

- The system worked correctly during the final trials
- The open loop SNR seems useful in the link adaptation
- The link adaptation schemes were able to track the fluctuations of the SNR due to the orientation of the UAV
- All algorithms satisfy the objective FER of 10 %
- All algorithms behave similarly in terms of spectral efficiency
- It is very difficult to compare the algorithms under exactly the same conditions
- Later simulations show that balanced convex algorithm outperforms others
- Using SDR technology eases development time

Future work

- Comparison with BGAN algorithms
- Explore new link adaptation algorithms for L-band SatComs which exploit dual polarization
- Deep analysis of all the data collected within the Project
- Continue with the theoretical study of the adaptive algorithms
- Propose link adaptation algorithms for mobile SatCom systems employing DVB-S2X/DVB-RCS2+M in higher frequencies (Ku/Ka band)
- Open a database with the data collected within the SatUAV Project

List of Acronyms

- **ACK.** Acknowledgement
- **ANT.** Antenna
- **BGAN.** Broadband Global Area Network
- **BW.** Bandwidth
- **CL.** Closed loop
- **CSI.** Channel State Information
- **DVB-S2X.** Digital Video Broadcasting - Satellite – Extensions of the Second Generation
- **DVB-RCS2+M.** Digital Video Broadcasting – Return Channel via Satellite with Mobile Extensions
- **ETSI.** European Telecommunications Standards Institute
- **FER.** Frame Error Rate
- **FPGA.** Field-Programmable Gate Array
- **GEO.** Geostationary Earth Orbit
- **LNA.** Low Noise Amplifier
- **MEO.** Medium Earth Orbit
- **MODCOD.** Modulation and Coding Scheme. (Also MCS)
- **NAK.** No-Acknowledgement
- **OL.** Open loop
- **QPSK.** Quadrature phase-shift keying
- **QAM.** Quadrature Amplitude Modulation
- **RFIC.** Radio Frequency Integrated Circuit
- **RPA.** Remotely Piloted Aircraft
- **RRC.** Root Raised Cosine
- **RSSI.** Received Signal Strength Indicator
- **RTT.** Round Trip Delay Time
- **SatCom.** Satellite Communications
- **SDR.** Software Defined Radio
- **SNR.** Signal to Noise Ratio
- **S-UMTS.** Satellite component of UMTS (Universal Mobile Telecommunications System)
- **UAV.** Unmanned Aerial Vehicle
- **UHD.** USRP Hardware Driver
- **USRP.** Universal Software Radio Peripheral
- **VAT.** Value-added tax