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**

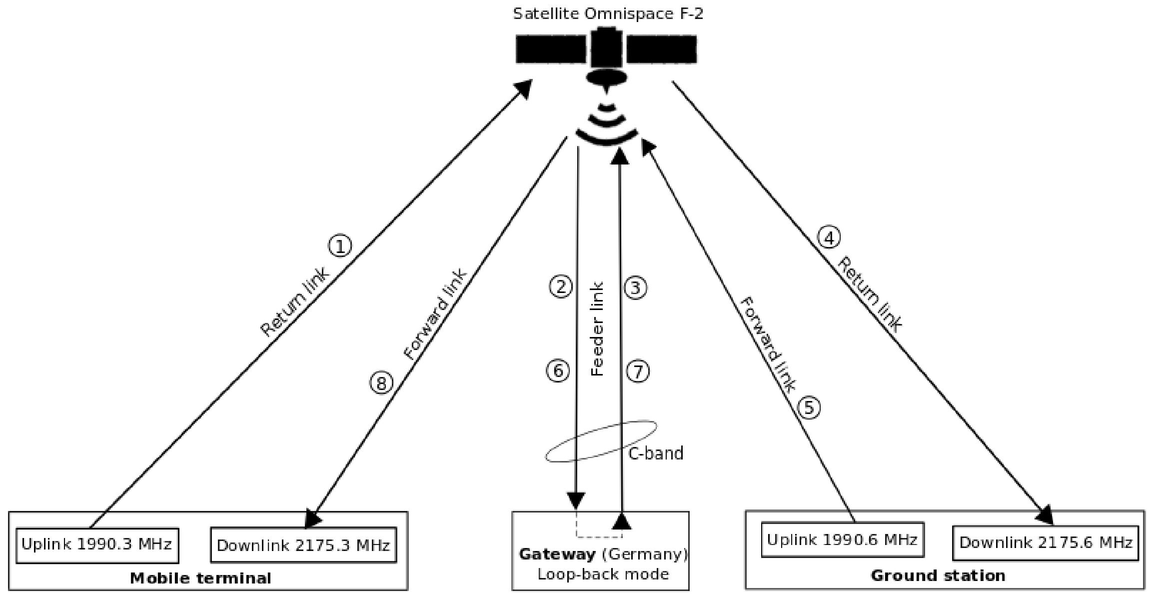
Technological center

Satellite operator (USA)

UAV manufactor and operator (Spain)

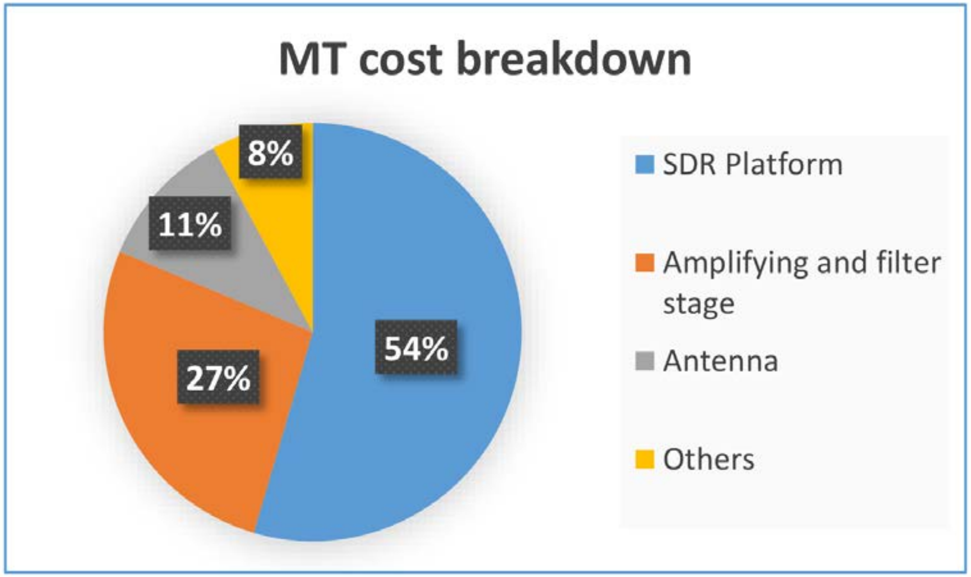
- **Objectives**
  - Development of the Mobile Satellite Terminal and the Ground Station
  - Test and compare the link adaptation algorithms
  - Perform channel model measurements
  - Test and validate the real-time communications system in terrestrial and aeronautical environments

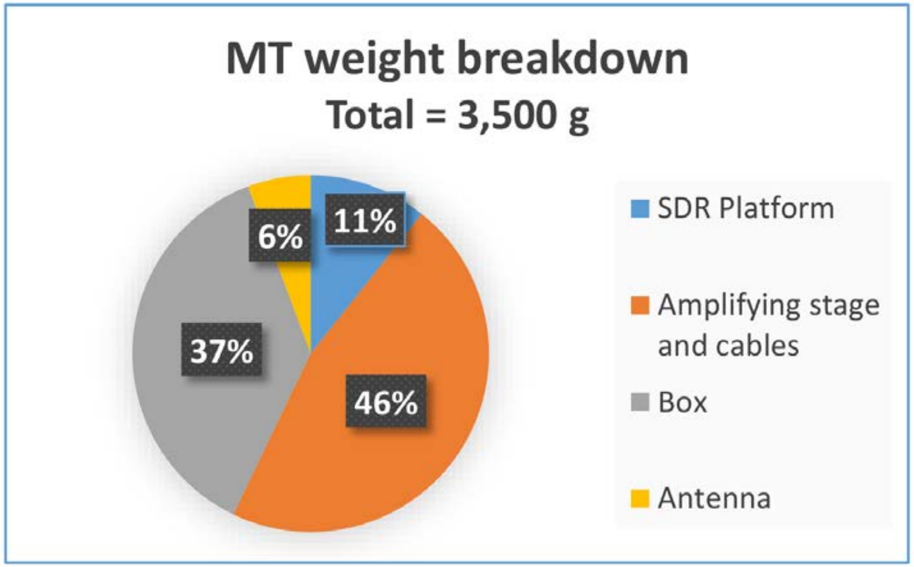
The elements of the system



The Mobile Terminal (MT) prototype

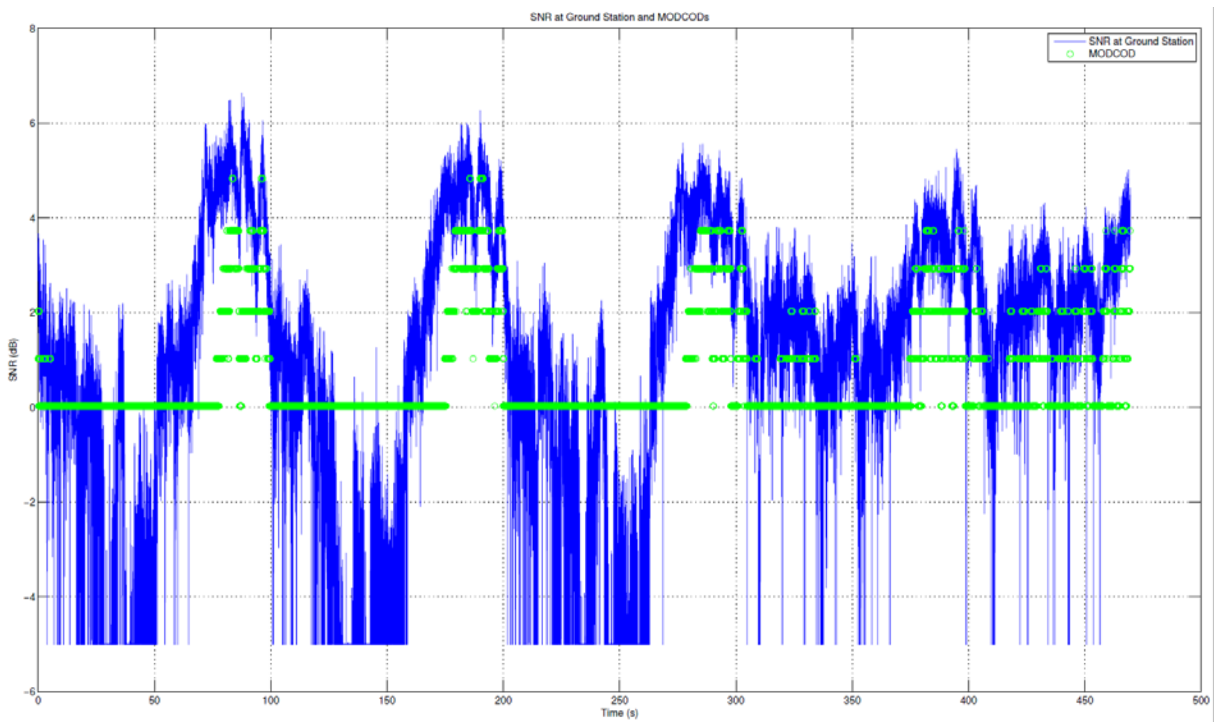
- **Weight:** 3.5 Kg (4.6 Kg including batteries)
- **Dimensions:** 25 x 25 x 10 cm (without the antenna)
- **Data rates:**
  - π/4-QPSK bearer: 41,2 –113,6 kbps
  - 16-QAM bearer: 83,6 –211,2 kbps





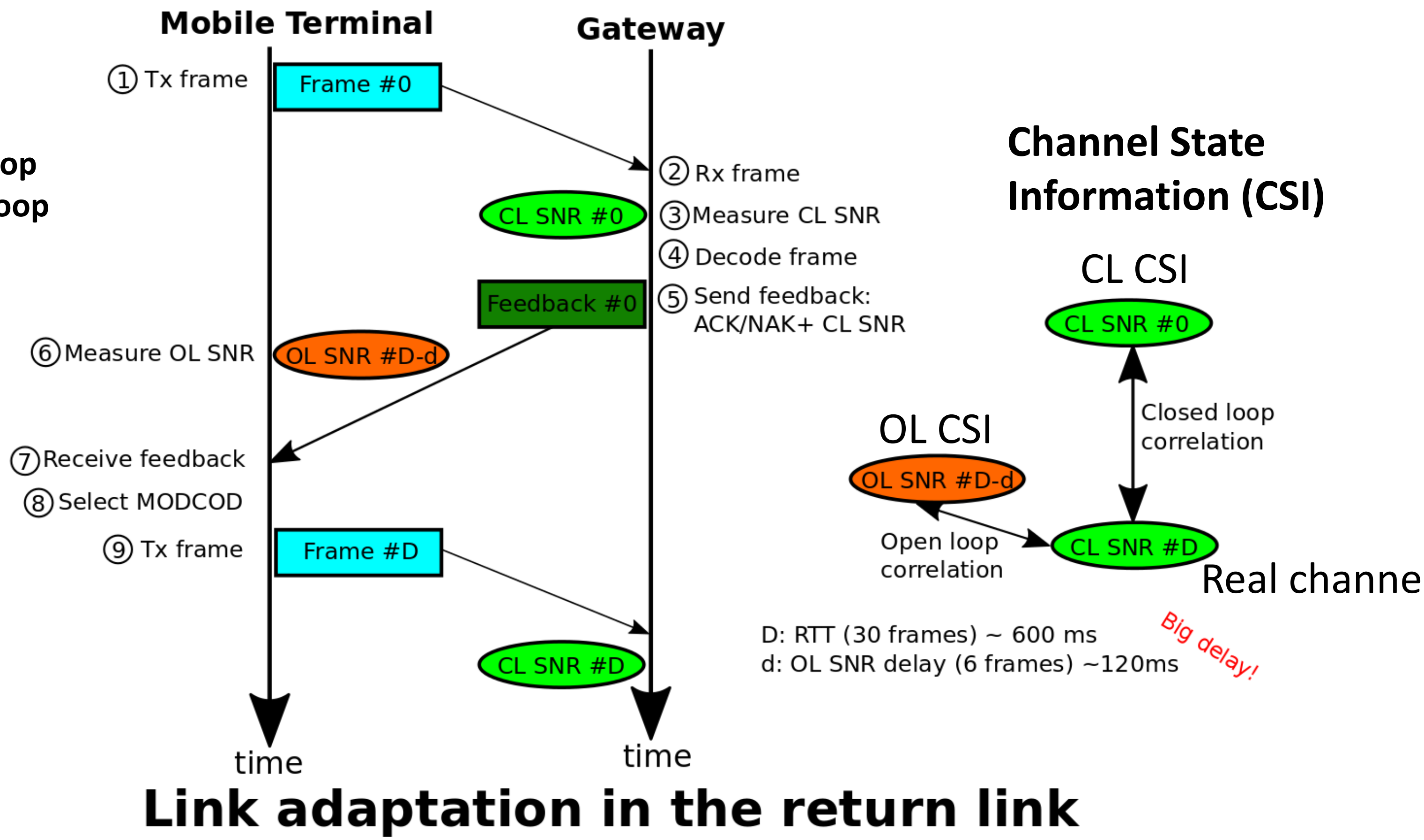
The problem of Link adaptation

- **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

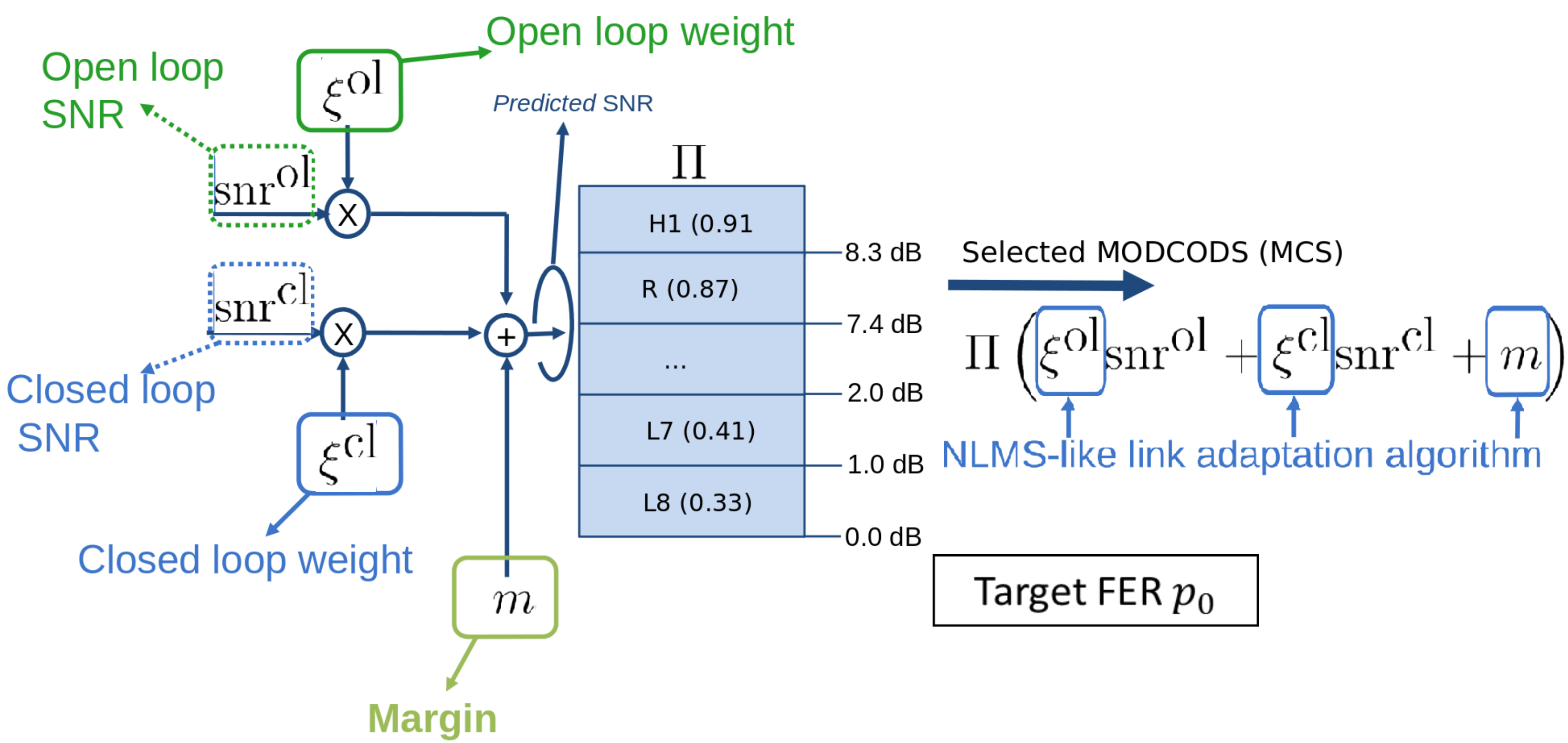
OL = Open loop
CL = Closed loop



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:

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

$$\boldsymbol{\xi}_i = [\xi^{cl} \;\; \xi^{ol}]^T$$
$$\mathbf{SNR}_i = [\mathrm{SNR}_i^{cl} \;\; \mathrm{SNR}_i^{ol}]^T$$

- Practical operation:
  - $\epsilon_i = 0$: **ACK** ⟹ Slight ↑ of Weights and Margin
  - $\epsilon_i = 1$: **NAK** ⟹ Strong ↓of Weights and Margin

Satellite component

Characteristic	Value
Operator	Omnispace LLC
Satellite	Omnispace F-2 (former ICO F-2)
Orbit	MEO (10,500 km) 45º 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

ASMS2016 SPSC2016

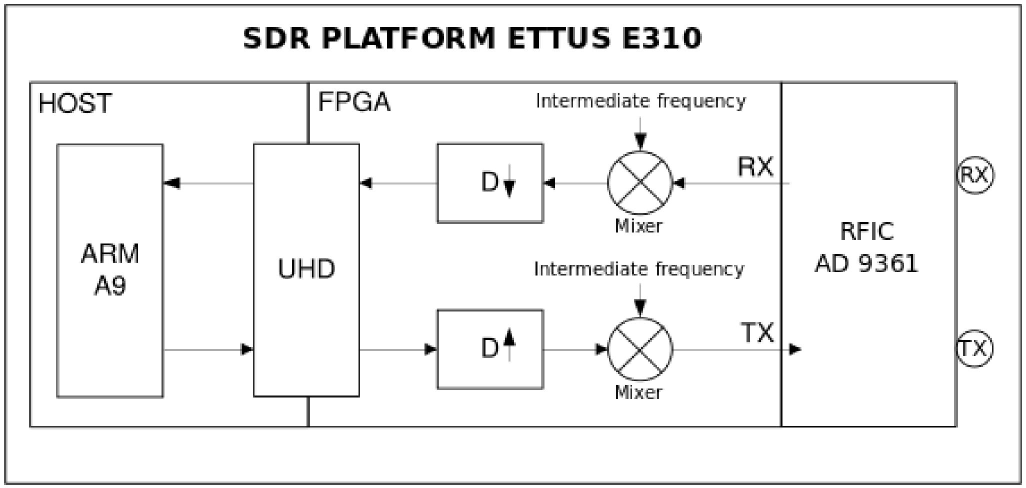
Physical layer

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

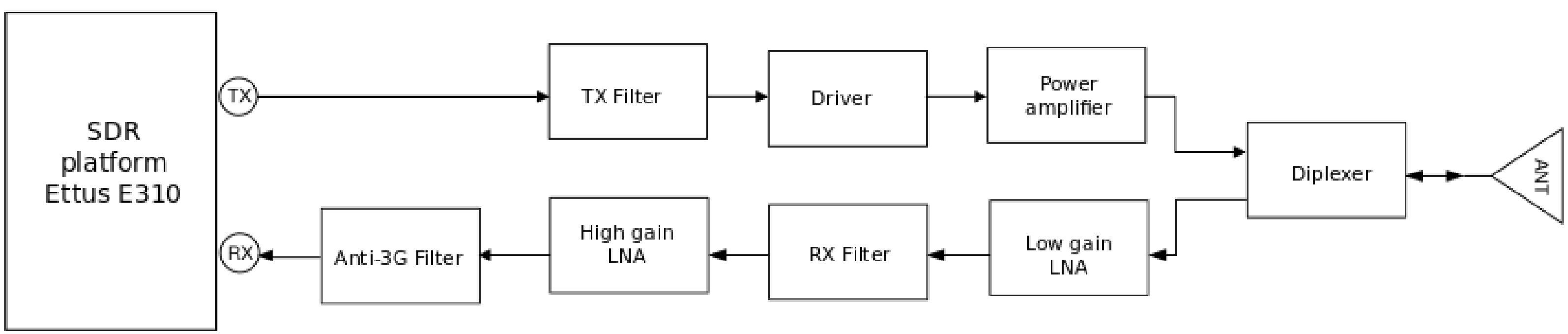
Characteristic	Value
Frame length	20 ms
Modulation	π/4-QPSK (Q), 16-QAM (X)
Symbol rate	67,2 ksymb/s
Channel bandwidth	84 kHz
Transmit chain elements	Scrambler, Turbo-coding, Puncturing, Channel Interleaving, Modulation, Matched Filter (RRC)
Turbo-coding	10 code rates: rates from 0.33 to 0.91 (R20T2Q)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

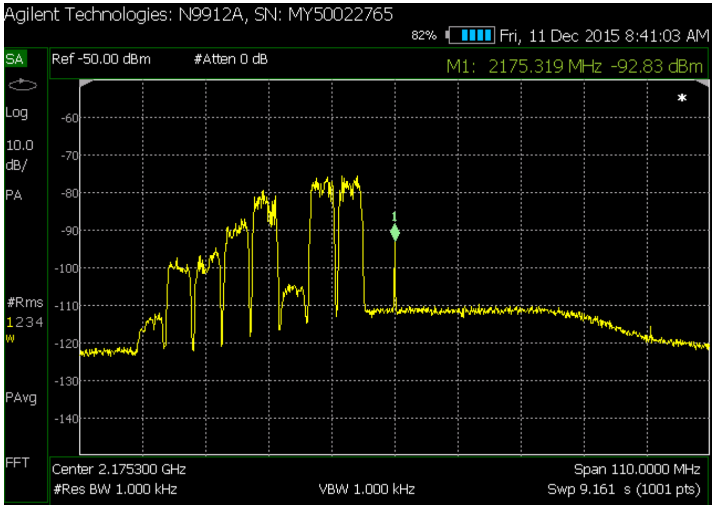


- External analog front-end



Issues during development

3G base stations interferences



High frequency deviation

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

Real-time operation

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

Field trial results together with simulation results

Markers = field trials
Lines = simulations using experimental data

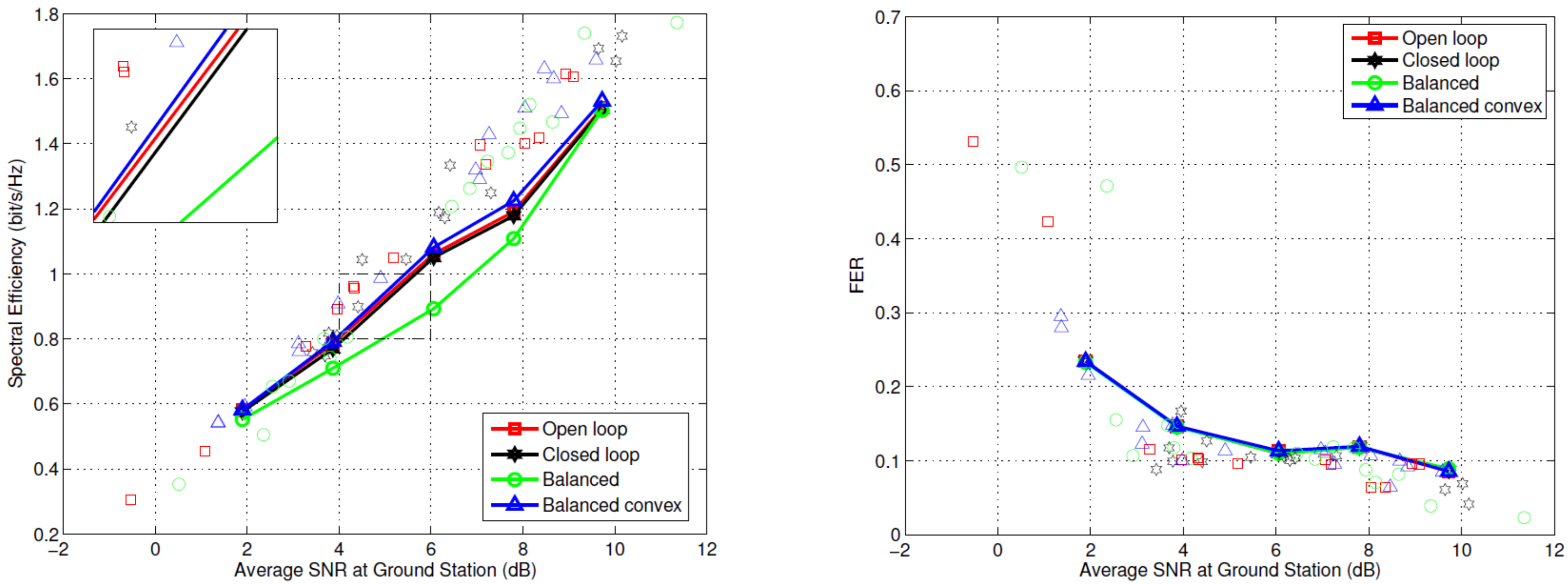
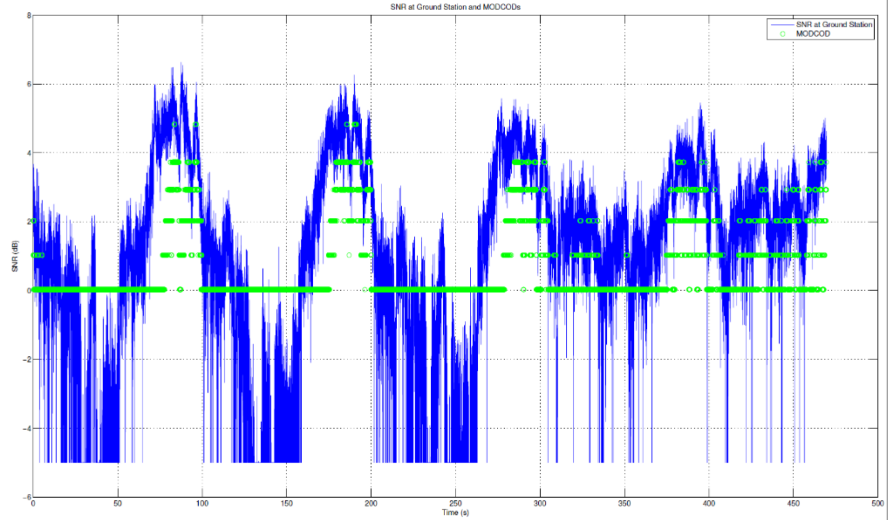


Fig. 7: Mean spectral efficiency (left) and cumulative FER (right) of field trials (independent markers) and simulations (markers connected with lines).

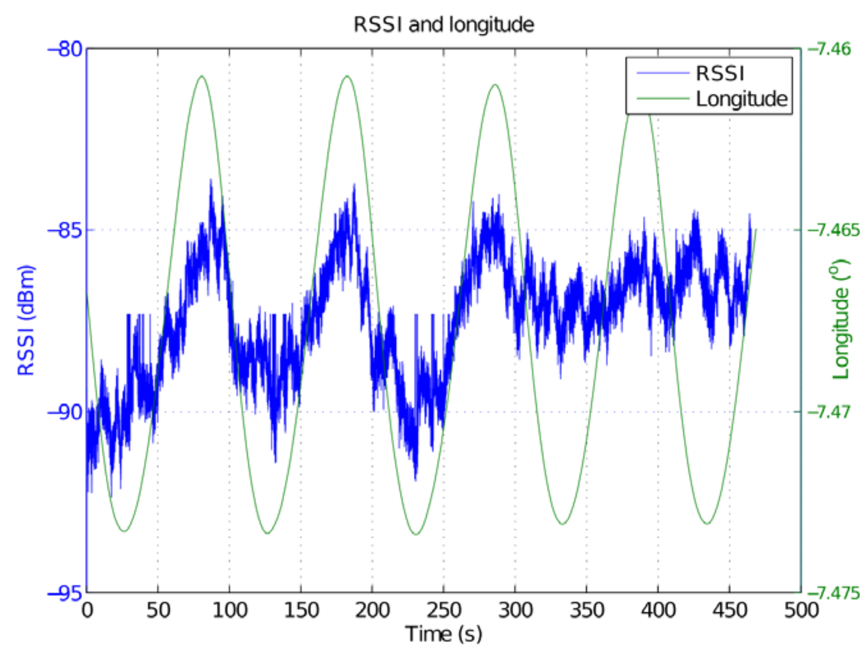
Link adaptation in action

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)

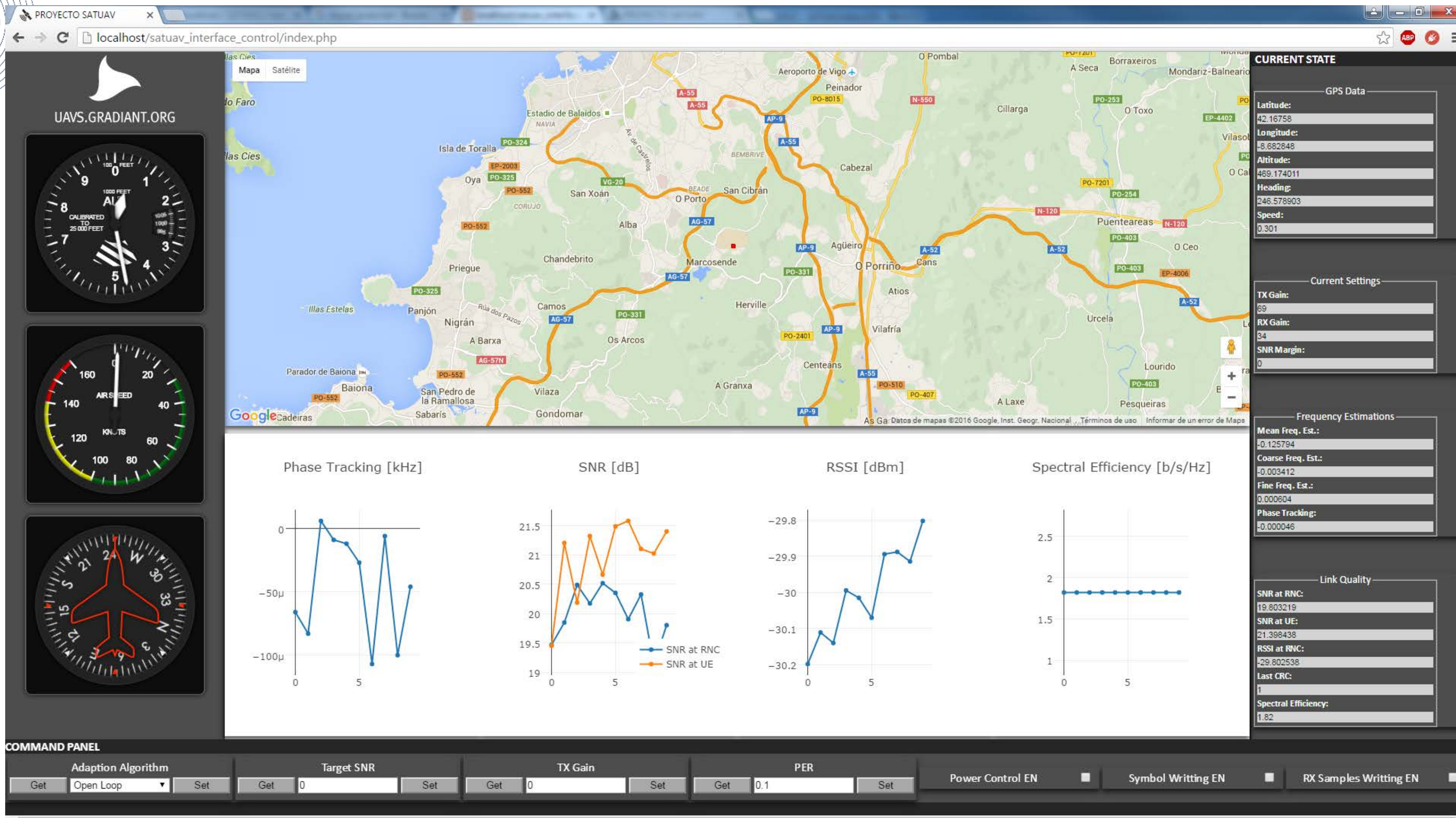


UAV trajectory



Tracking of the UAV and the SatCom link

- Web application



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