ENHANCED AIR-GROUND COMMUNICATIONS IN FAST MOVING, MULTI-PATH ENVIRONMENTS

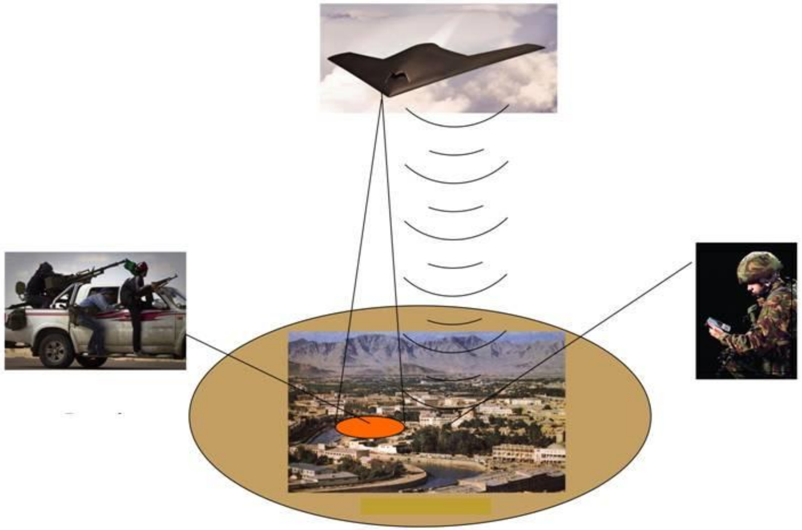
Samuel Guillouard (TeamCast)
Olivier Rousset (TeamCast)
Kevin Mille (Thales Communications & Security)

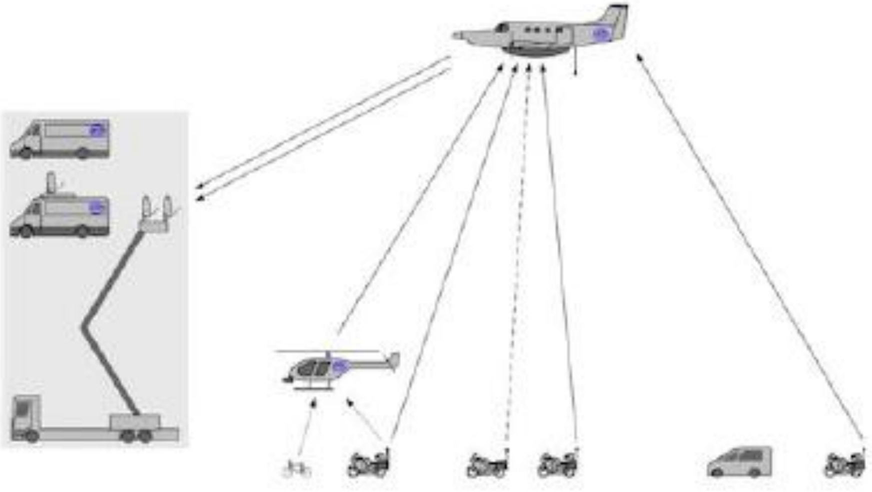
Introduction

- Contribution to address
  - air-ground and air-air transmissions,
  - operating in harsh environments, i.e. with high delay spread and high Doppler drift/spread
- Target applications
- Proposed solution
- Hardware implementation
- Performance measurements
- Conclusion / future works

Applications: military & civilian

- Military applications
  - Air-ground transmission
  - Close Air Support
  - Receiver in Urban area
- Civilian applications
  - Aircraft flight test
  - Electronic News gathering





Applications: main requirements

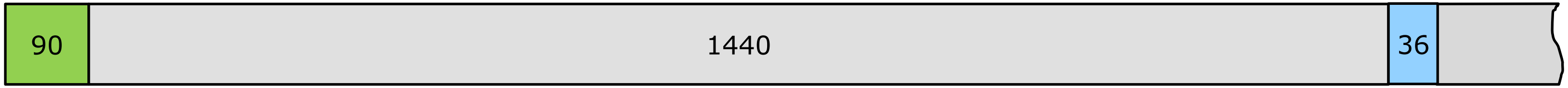
Criterion	Target performance
Propagation channel	LOS or NLOS
Range	up to a few tens of kilometers
Data rate	a few Mbit/s
Carrier frequency	Civil : 2 to 6 GHz Military : C & Ku Band
Maximum speed	Up to 300 m/s
Antennas	Omni-directionnal
Maximum delay spread of channel	5 µs
Target frame error rate (FER)	$< 10^{-2}$ (1%)

Proposed solution: key parameters

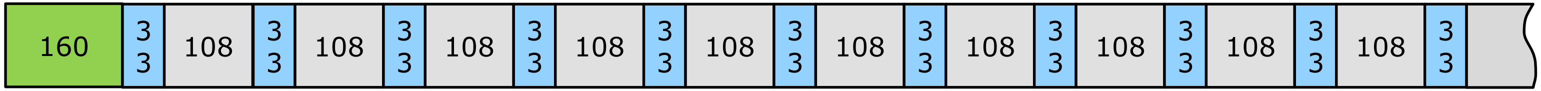
- Use of single carrier technology, for low PAPR and high Doppler drift/spread reasons
- Re-use of DVB-S2 FEC scheme, close to Shannon limit
- Definition of a new Physical Layer (PL) frame
  - High pilot rate to cope with high Doppler drift/spread
  - Long pilot sequences for propagation channel estimation
  - Dedicated PL header supporting frequency offset
  - Spectral efficiency reduction by 30% vs legacy DVB-S2 frames
  - Limited set of configurations
    - 3 symbol rates : 2, 4 and 8 Mbaud
    - 5 modes : QPSK 1/2, 2/3, 4/5 – 8PSK 2/3, 5/6

Proposed solution: frame structure

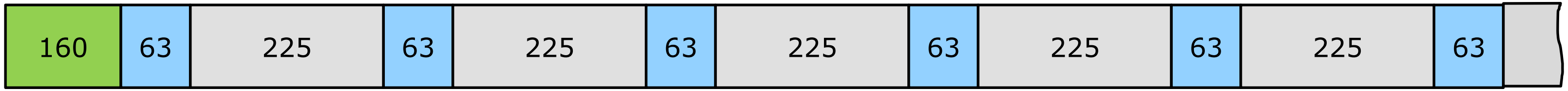
- DVB-S2 PL frame (with pilot)



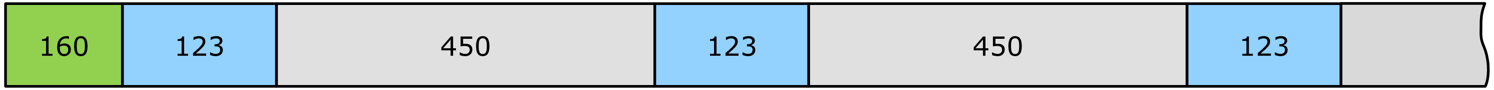
- ECHO PL frame (2 MBds – QPSK)

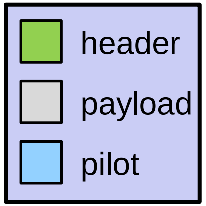


- ECHO PL frame (4 MBds – QPSK)



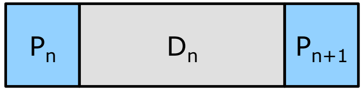
- ECHO PL frame (8 MBds – QPSK)





Proposed solution: BDFE introduction

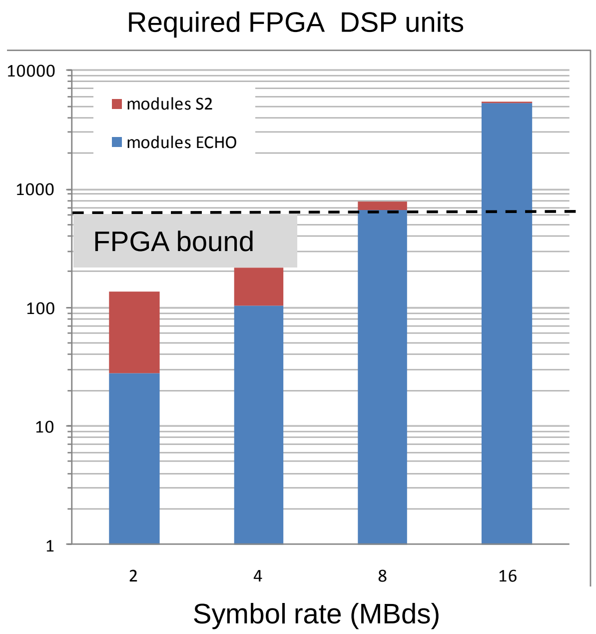
- Block Decision Feedback Equalizer :
  - Process a « Pilot-Payload-Pilot » block



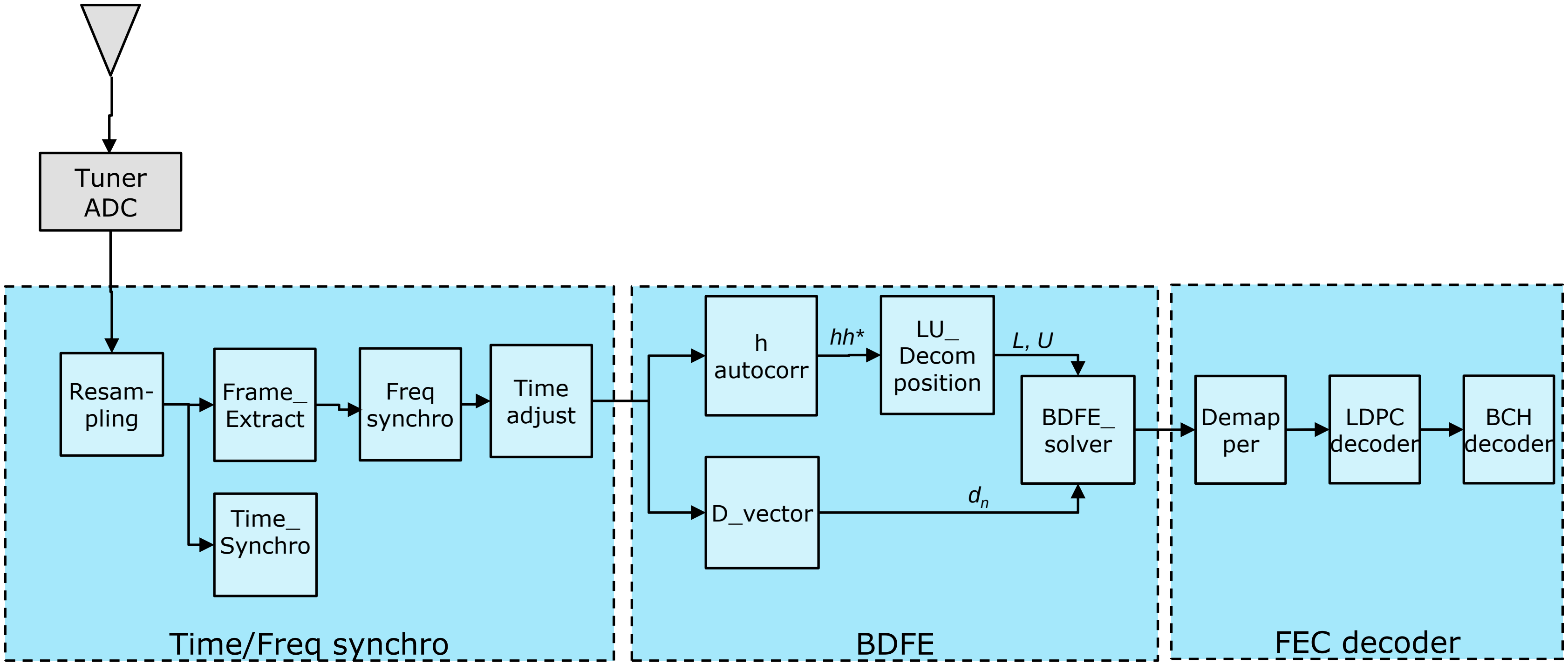
    - Get ***h*** estimation from pilots P_n and P_{n+1}
    - Perform phase correction on the « Pilot-Payload-Pilot » interval
    - Compute $\boldsymbol{R_h}$ to feed the ***[H]*** matrix
  - Solve the equation $\boldsymbol{[H]\cdot b=d}$
    - ***b*** denotes the vector of transmited symbols D_n
    - ***d*** denotes the vector of received symbols, filtered by ***h****
    - By performing a LU decomposition : $\boldsymbol{[H]=L\cdot U}$ where L and U are lower and Upper triangular matrix respectively
    - And successively solving
      - $\boldsymbol{L\cdot y=d}$
      - $\boldsymbol{U\cdot b=y}$

Proposed solution: BDFE features

- The BDFE provides true Minimal Square Error over the complete block of data, i.e. it outperforms other DFE performances
- The drawback is a complexity increase (cubic increase) when improving the length of the data blocks
  - Most of ressources usage dedicated to the LU decomposition
  - Major constraint in pilot and data length values

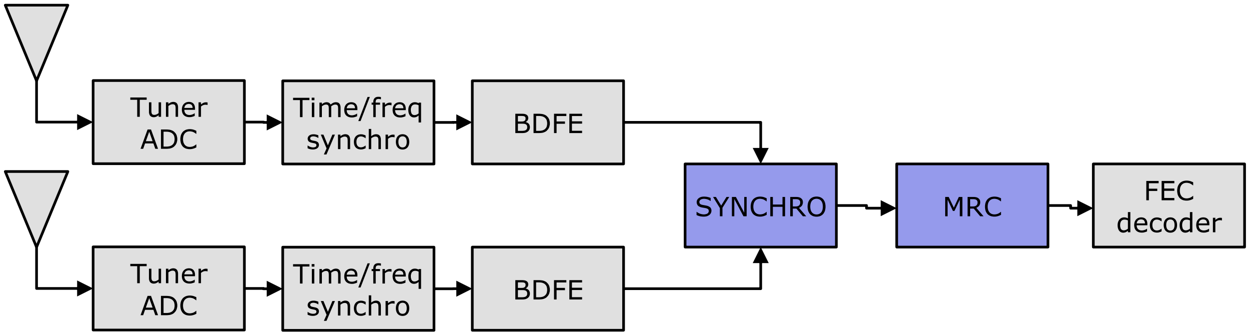


Proposed solution: receiver architecture



Proposed solution: with spatial diversity

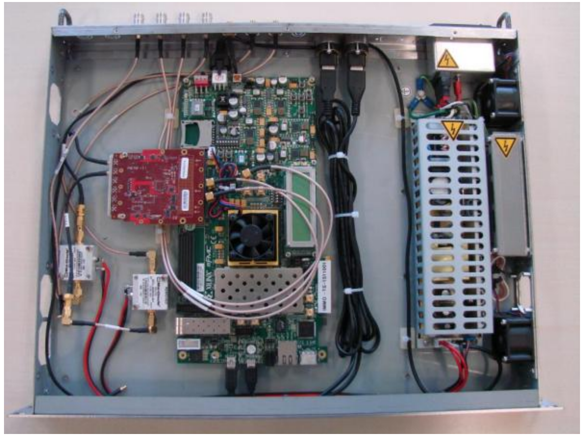
- Add a second Antenna and a second Rx path
- 2 independant BDFEs are operating in parallel
- The 2 equalized Rx paths are synchronized and combined, according to the MRC (Maximum Ratio Combining) algorithm



- Reaches the maximum achievable diversity gain
- Do not require synchronized Rx paths (in phase/frequency)
- Still works with a single Rx path

Proposed solution: hardware implementation

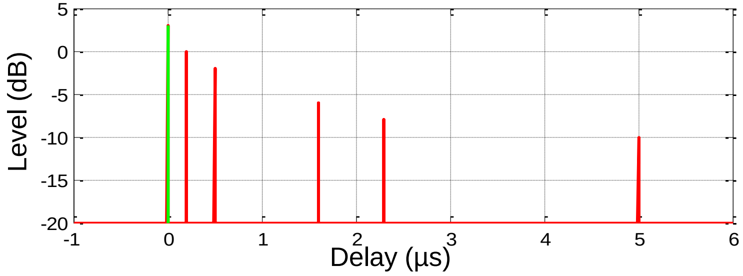
- ECHO project : Single Rx path version
  - Dual FPGA implementation :
    - Demod part : FPGA Xilinx Virtex 6 LX195
    - FEC part : FPGA Xilinx Virtex 5 LX110
- MAXSIMO project : Dual Rx paths
  - Single FPGA implementation
    - Demod + FEC in a single Xilinx Virtex 7 VX485
  - Dual LNAs / ADC



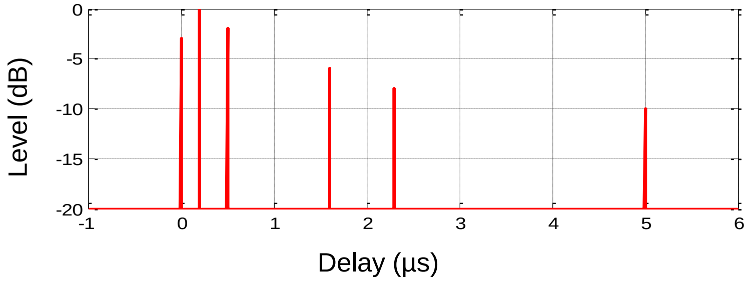
MAXSIMO Receiver (with diversity)

Channel models

- Air-Ground models
  - AS-LOS-URB
    - Air-ground configuration, Urban environment with guaranteed Line of Sight
    - 6 paths with delays up to 5 µs

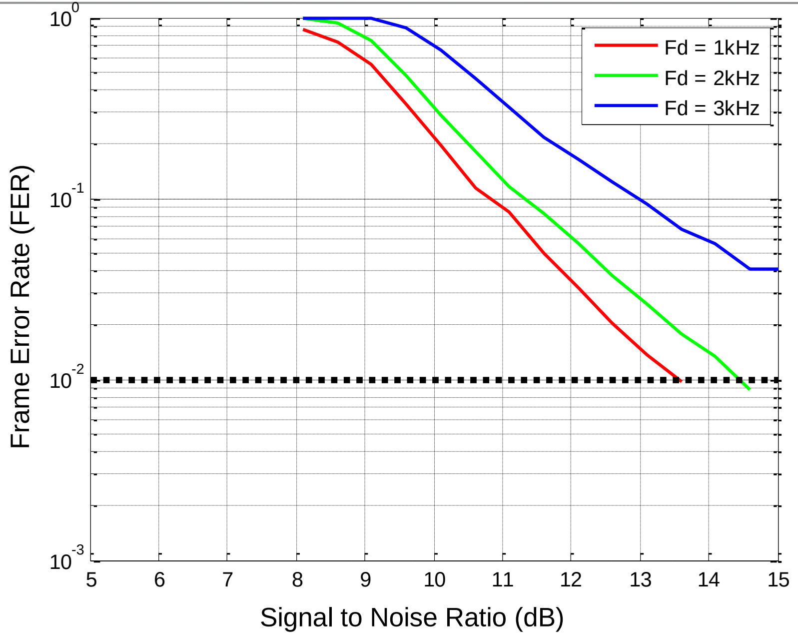


  - AS-NLOS-URB
    - Air-ground configuration, Urban environment without Line of Sight
    - 6 paths with delays up to 5 µs
    - Close to TU-6 terrestrial urban channel model



Performances results without diversity

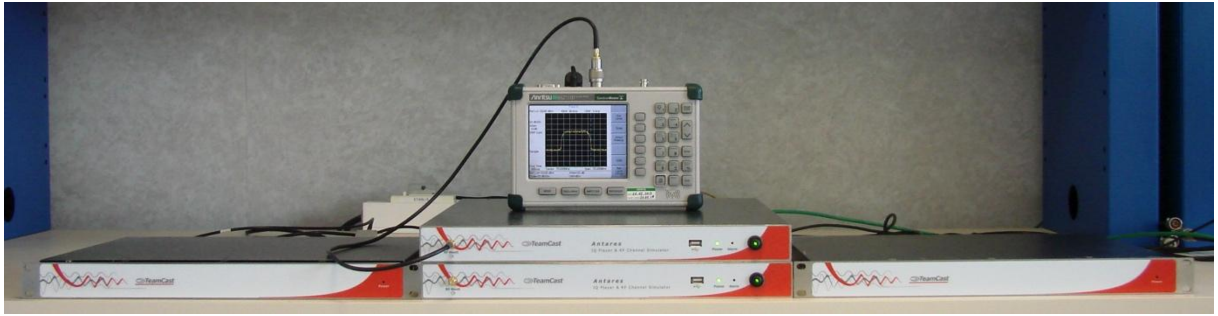
- AS-LOS-URB
  - 6 paths within 5 µs
  - 1 direct path
- Obtained results for QPSK 2/3
  - AWGN :
    - C/N= 5.3 dB @ FER 1%
  - AS-LOS-URB channel
    - 13.5 dB @ Fd=1 kHz
    - 14.5 dB @ Fd=2 kHz
    - 19 dB @ Fd=3 kHz
  - AS-NLOS-URB channel
    - 16.6 dB @ Fd=1 kHz
    - KO for Fd>=2 kHz

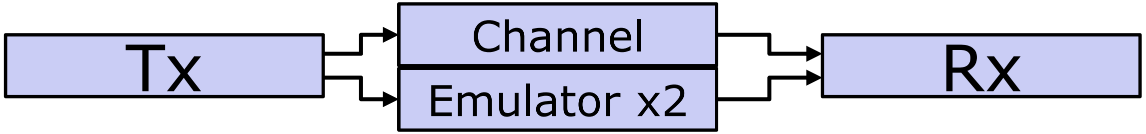


QPSK 2/3 – 8 MBaud performances
AS-LOS-URB model

Performances results with spatial diversity

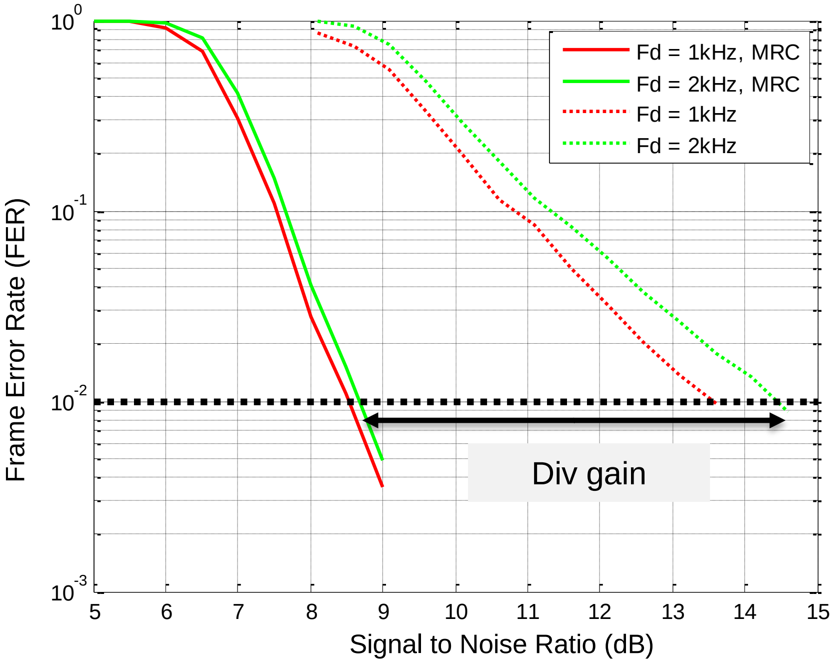
- In lab validation with two channel emulators
  - The channel emulators are fully decorrelated
  - Corresponds to a channel model without correlation between the Rx paths
  - => Results gives the maximum achievable diversity gain





Performances results with spatial diversity

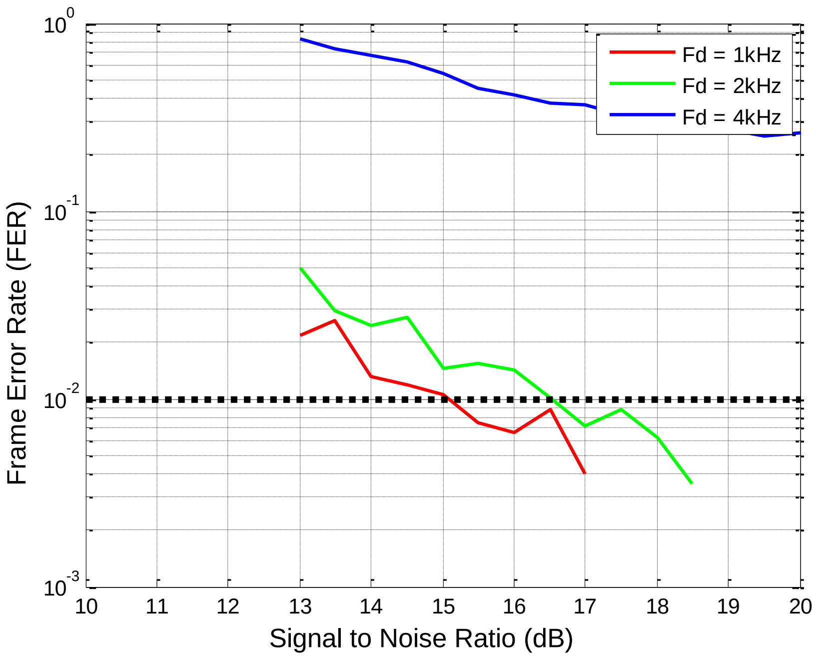
- AS-LOS-URB
  - 6 paths within 5 µs
  - 1 direct path
- Obtained results
  - Gain from 1 to 10 dB depending on the mode
  - Example QPSK 2/3-8 MBaud: 6 dB of diversity gain for a FER of 1%, $F_{Doppler}$ 2 kHz



QPSK 2/3 – 8 MBaud performances
AS-LOS-URB model

Performances results with spatial diversity

- AS-NLOS-URB
  - 6 paths within 5 µs
  - No direct path
- Obtained results
  - Gain from 0 to 7 dB on robust modes (i.e. QPSK)
  - Some modes become operational with spatial diversity
    - 8 MBaud – QPSK 4/5 for SNR > 15 dB
    - 8 MBaud – 8PSK 2/3 for SNR >19 dB



QPSK 4/5 – 8 MBaud performances
AS-NLOS-URB channel model

Performances synthesis

- In lab performances measurements and simulation results are in line
- ECHO technology is exploitable in urban environment for air-ground transmissions
- No line of sight configuration reduces the number of possible modes (8PSK for instance)
- But spatial diversity – with full decorrelation- can compensate this limitation
- For urban channel model, spatial diversity brings
  - A gain of 1 to 10 dB
  - A bandwidth gain of about 30% by enabling 8PSK modes previously not operational

Conclusion

- Development of a new single carrier modulation scheme
  - Cope with high Doppler frequency (up to 4 kHz) and high delay spread (5 µs), thanks to a dense pilot structure
- Hardware proven
  - BDFE implementation up to 8 MBaud
  - Performances in line with simulation
- Extension to spatial diversity
  - Dual independant BDFE with MRC combination scheme
  - Diversity gain, up to 10 dB, measured in lab condition
- Future works
  - Evaluate Rx correlation on the measured diversity gain
  - Refine the channel models
  - Evaluate alternative equalizer scheme to enable higher symbol rates

Thanks for your attention!

TeamCast
Alain UNTERSEE
Alain.untersee@teamcast.com
Tel: +33 (0) 2 23 25 26 80
Fax: +33 (0) 2 23 25 26 85

Thales Communications @ Security
Kevin MILLE
Kevin.mille@fr.thalesgroup.com
Tel: +33 (0) 1 46 13 22 24
Fax: +33 (0) 1 46 13 25 55

