Low-RF
Fast Deployable Systems for Emergencies in Difficult Environments
Agenda

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Main conclusions and way forward

Questions & Answers
Project Introduction

Project objective

• Crisis modes are unexpected and can take place anywhere and anytime.

“[…] it is clear that current solutions, especially GNSS-based ones, are not adequate to support the navigation functions required for crisis modes.”

GMV NSL & AAU @ ION GNSS+ 2022

• The objective of this contract is to design and develop a PoC for a Civilian and Assets Recovery System (CARS), conformed by two main elements:
  • Crisis Recovery and Emergency Assistance and Management segment (CREAM). System transmitter.
  • Device for the Recovery and Emergency Assistance and Management segment (DREAM). System receiver.
Agenda

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Project overview

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Task 2
System development
WP 3000

Task 3
Experimentation
WP 4000
WP 5000
Project plan

Project work structure

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Management and coordination

WP 1000
CARS Use Cases, System Requirements and System Specification Definition

WP 3000
CREAM & DREAM Breadboard Development, Integration and Factory Testing

WP 5000
Final Reporting, Acceptance Testing and Exploitation Assessment

WP 2000
CREAM and DREAM Breadboard Detailed Design

WP 4000
CREAM & DREAM PoC Breadboard Validation
Overview of conducted tasks

- Review of existing recovery systems.
- Selection of targeted CARS scenarios.
- Experimentation and validation plan outline.
- CARS system design.
- Hosting platform trade-off study.
- System architecture trade-off structure.
- CARS implementation.
- CARS system assessment.
- Performance study.
- System validation execution.
- Controlled-environment and indicative experimentation.
- Experimentation campaign detailed definition.
- Experimentation campaign execution.
- Controlled-environment and indicative experimentation.
- Experimentation campaign detailed definition.
Agenda

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Accomplished work

State-of-the-art review, scenario selection

System definition, design, development and validation

Real-world experimentation

Main conclusions and way forward

Questions and Answers
Accomplished work

State-of-the-art review, scenario selection (1/4): Crisis recovery systems

<table>
<thead>
<tr>
<th>Crisis recovery systems</th>
<th>Link Topology</th>
<th>Antenna conf.</th>
<th>Operation freq. [MHz]</th>
<th>Link budget figures</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>Tx-Rx Elev. angle</td>
<td>Tx</td>
<td>Rx</td>
<td>Link power [W]</td>
</tr>
<tr>
<td>Walkie-Talkies</td>
<td>O/I</td>
<td>Low</td>
<td>Omni</td>
<td>Omni</td>
<td>27, 49, ~460, ~900</td>
</tr>
<tr>
<td>Amateur Radio</td>
<td>O/O</td>
<td>Variable</td>
<td>Omni</td>
<td>Omni</td>
<td>~140, ~440</td>
</tr>
<tr>
<td>Trunking Radio</td>
<td>O/O</td>
<td>Low</td>
<td>Omni</td>
<td>Omni</td>
<td>~400, ~900</td>
</tr>
<tr>
<td>COWs</td>
<td>O/O</td>
<td>Low</td>
<td>Omni</td>
<td>Omni</td>
<td>Variable</td>
</tr>
<tr>
<td>Satellite Phones</td>
<td>O/O</td>
<td>Variable</td>
<td>Omni</td>
<td>Drt</td>
<td>~1616 - 1626.5</td>
</tr>
<tr>
<td>MANET</td>
<td>O/O</td>
<td>Low</td>
<td>Omni/Drt</td>
<td>Drt</td>
<td>30 - 5000</td>
</tr>
<tr>
<td>BSNET</td>
<td>O/I</td>
<td>Low</td>
<td>Omni</td>
<td>Omni</td>
<td>Variable</td>
</tr>
<tr>
<td>Wireless Mesh</td>
<td>O/I</td>
<td>Low</td>
<td>Omni</td>
<td>Omni</td>
<td>Variable</td>
</tr>
<tr>
<td>Wireless Balloon</td>
<td>O/O/I</td>
<td>High</td>
<td>Omni</td>
<td>Omni</td>
<td>Variable</td>
</tr>
</tbody>
</table>

- There is no universal emergency/crisis recovery system able to operate in all environments.
- Focused on outdoor communications.
- Systems heavily network infrastructure dependant.
Accomplished work

State-of-the-art review, scenario selection (2/4): GNSS systems

<table>
<thead>
<tr>
<th>GNSS</th>
<th>Link Topology</th>
<th>Antenna conf.</th>
<th>Operation freq. [MHz]</th>
<th>Link budget figures</th>
<th>Accuracy [m]</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx-Rx Elev. angle</td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>O</td>
<td>O</td>
<td>High</td>
<td>L1: 1575.42</td>
<td>50 - 240</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L2: 1227.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L5: 1176.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLONASS</td>
<td></td>
<td></td>
<td></td>
<td>L1:1602</td>
<td>20 - 135</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L2: 1246</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L3: 1201</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galileo</td>
<td></td>
<td></td>
<td>High</td>
<td>L1: 1575.42</td>
<td>95 - 160</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E5: 1191.795</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E6: 1278.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BeiDou</td>
<td></td>
<td></td>
<td>High</td>
<td>B1: 1575,42</td>
<td>130 - 185</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B2: 1191,79</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B3: 1 268,52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRNSS</td>
<td></td>
<td></td>
<td>High</td>
<td>L: 1164-1189</td>
<td>40 - 120</td>
<td>10 - 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S: 2483.5-2500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Coverage is global, but subjected to non-cluttered outdoor environments.
- Cluttered environments degrade performance - there is a reliability on terrestrial infrastructure.
Accomplished work

State-of-the-art review, scenario selection (3/4): IPS systems

<table>
<thead>
<tr>
<th>IPS</th>
<th>Link Topology</th>
<th>Antenna conf.</th>
<th>Operation freq.[GHz]</th>
<th>Link budget figures</th>
<th>Accuracy [m]</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx-Rx Elevation angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Link budget figures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accuracy [m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td>Rx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- RF-base indoor localization is accurate only when using UWB technologies.
- There is no universal PNT system that operates in all scenarios.
Accomplished work

State-of-the-art review, scenario selection (4/4): Conclusions

Conclusions

• Next generation CARS should be able to operate in any type of disaster scenarios.
• Other scenarios where GNSS-based navigation/current IPS are not reliable should be also considered.

• Focus is to be put in **challenging scenarios**, with a system able to operate in:
  • **Urban scenarios** such as urban canyons or extremely shadowed/cluttered positions.
  • **Disaster scenarios**, which typically present different propagation profiles.

This aforementioned puts the focus in **indoor** and **deep-indoor** scenarios.
Accomplished work

System definition, design, development and validation (1/5): CREAM & DREAM selection

- Software Defined Radio (SDRs) were chosen for the PoC hardware.
  - It is widely known the broad configuration range and reliability that SDRs provide.

**USRP E312**  
(CREAM, transmitter)

**USRP X310**  
(DREAM, receiver)
Accomplished work

System definition, design, development and validation (2/5): CREAM platform selection

Study was undertaken in order to find out the most suitable CREAM platform, based on the following KPIs:

- Cost
- Weight it can carry
- Size it can accommodate
- Antenna mountings it can offer
- Resilience to environmental conditions
- How rapidly it can be deployed
- Operational time
- Control range
- Dynamics
- Geometry diversity it can provide

Drone stood out as the platform that provides better KPI trade-off.

First ever Low-RF drone test
Accomplished work

System definition, design, development and validation

CREAM payload

(x_d, y_d, z_d)

(x_{s1}, y_{s1}, z_{s1})

(x_{s2}, y_{s2}, z_{s2})

(x_{s3}, y_{s3}, z_{s3})

(x_{s4}, y_{s4}, z_{s4})

L band

UHF, VHF bands

NAV data

GMV offices
Accomplished work

System definition, design, development and validation (3/5): CREAM – DREAM RF link
Accomplished work

System definition, design, development and validation (4/5): Signal propagation

Initially and taking ESA’s input, three frequencies were selected for testing:

- 113 MHz (VHF)
- 225 MHz (VHF)
- 400 MHz (UHF)
- 500 MHz (UHF)

All the selected are allocated frequencies, UK Spectrum Regulator (OFCOM) was contacted in order to obtain test frequencies. OFCOM granted the following:

- 113 MHz
- 133 MHz
- 144 MHz
- 272.25 MHz
- 325 MHz
- 350.5 MHz
- 401.5 MHz
- 500 MHz

RETEVIS RT20 Dual-band 144 MHz / 430 MHz
RETEVIS RT1/3 UHF 400 MHz – 520 MHz
Accomplished work

System definition, design, development and validation (5/5): Frequency selection

- Distance: 8 m.
- Both CREAM and DREAM are located in the same corridor, facing each other in a straight line.
- Corridor setting is likely to cause impaired signal due to reflections.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Range</th>
<th>Frequency / MHz</th>
<th>Bandwidth / MHz</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>113</td>
<td>10</td>
<td>OK</td>
<td>100% worked</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>133</td>
<td>10</td>
<td>OK</td>
<td>100% worked</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>144</td>
<td>10</td>
<td>Fair</td>
<td>50% worked</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>222.25</td>
<td>10</td>
<td>N/A</td>
<td>Data not collected</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>325</td>
<td>10</td>
<td>N/A</td>
<td>Data not collected</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>350.5</td>
<td>10</td>
<td>N/A</td>
<td>Data not collected</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Data not collected</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>401.5</td>
<td>10</td>
<td>N/A</td>
<td>Data not collected</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Did not work</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>401.5</td>
<td>10</td>
<td>OK</td>
<td>Worked &gt; 90% success rate</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Did not work</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>500</td>
<td>10</td>
<td>OK</td>
<td>100% worked</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Barely worked with &lt; 10% success rate</td>
<td></td>
</tr>
</tbody>
</table>

Results summary
Accomplished work

System definition, design, development and validation (5/5): Frequency selection

Results summary

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Run#</th>
<th>Frequency [MHz]</th>
<th>Bandwidth [MHz]</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHORT antenna (Antenna 1)</td>
<td>1</td>
<td>11.3</td>
<td>10</td>
<td>Fair</td>
<td>Worked with &lt; 33 % success rate</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>13.3</td>
<td>10</td>
<td>Ok</td>
<td>100 % worked</td>
</tr>
<tr>
<td>LONG antenna (Antenna 2)</td>
<td>3</td>
<td>40.15</td>
<td>10</td>
<td>Ok</td>
<td>Worked with &gt; 80 % success rate</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>401.5</td>
<td>1</td>
<td>Not ok</td>
<td>Worked with &lt; 20 % success rate</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>400</td>
<td>10</td>
<td>Ok</td>
<td>Worked 100 %</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>500</td>
<td>10 (60m)</td>
<td>Ok</td>
<td>Worked 100 %</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1</td>
<td>Not ok</td>
<td></td>
<td>Work with &lt; 50 % success rate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>CREAM – DREAM distance</th>
<th>Surroundings</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMV NSL Nottingham</td>
<td>40 m</td>
<td>CREAM and DREAM are located in line of sight, with no obstacles.</td>
<td>-</td>
</tr>
<tr>
<td>GMV NSL Nottingham</td>
<td>60 m</td>
<td>CREAM and DREAM are located in line of sight, with no obstacles.</td>
<td>-</td>
</tr>
</tbody>
</table>
Accomplished work

System definition, design, development and validation

CREAM platform
CREAM
DREAM
Accomplished work

Real-world experimentation (1/8): Experimentation scenario overview
Accomplished work

Real-world experimentation (2/8): Calibration

Traditional building

Thermo-efficient building
Accomplished work

Real-world experimentation (2/8): Calibration

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Effective penetration loss (traditional building)</th>
</tr>
</thead>
<tbody>
<tr>
<td>133 MHz</td>
<td>10.4</td>
</tr>
<tr>
<td>401.5 MHz</td>
<td>16.0</td>
</tr>
<tr>
<td>500 MHz</td>
<td>8.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Effective penetration loss (thermal-efficient building)</th>
</tr>
</thead>
<tbody>
<tr>
<td>133 MHz</td>
<td>15.2 dB</td>
</tr>
<tr>
<td>500 MHz</td>
<td>25.2 dB</td>
</tr>
</tbody>
</table>
Accomplished work

Experimentation results (3/8): System performance validation
Accomplished work

Real-world experimentation (3/8): System performance validation
Accomplished work

Real-world experimentation (3/8): System performance validation
Accomplished work

Real-world experimentation (4/8): System performance validation results (traditional)

Outdoor scenario

- $f = 133$ MHz, $d_C = 540$ m
- $f = 133$ MHz, $d_C = 2$ km
- $f = 401.5$ MHz, $d_C = 540$ m
- $f = 401.5$ MHz, $d_C = 2$ km
- $f = 500$ MHz, $d_C = 540$ m
- $f = 500$ MHz, $d_C = 2$ km

Indoor scenario

- $f = 133$ MHz, $d_C = 540$ m
- $f = 133$ MHz, $d_C = 2$ km
- $f = 401.5$ MHz, $d_C = 540$ m
- $f = 401.5$ MHz, $d_C = 2$ km
- $f = 500$ MHz, $d_C = 540$ m
- $f = 500$ MHz, $d_C = 2$ km

$h_C$: CREAM Height
$d_C$: CREAM Distance
Accomplished work

Real-world experimentation (4/8): System performance validation results (traditional)

Outdoor scenario

Indoor scenario
Accomplished work

Real-world experimentation (5/8): System performance validation results (thermo-eff)

Outdoor scenario

Indoor scenario
Accomplished work

Real-world experimentation (5/8): System performance validation results (thermo-eff)

Outdoor scenario

Indoor scenario

$h_h$: CREAM Height
$d_d$: CREAM Distance
Accomplished work

Real-world experimentation (6/8): LEO pass emulation
Accomplished work

Real-world experimentation (6/8): LEO pass emulation

- Projection of a LEO pass at 500 km into a 40 m height was carried out by extrapolating a LEO orbit into 40 m height and map associated positions.

Elevation range evaluated corresponds to $[10^\circ, 170^\circ]$
Accomplished work

Real-world experimentation (7/8): LEO pass emulation results

Traditional building

Thermo-efficient building
Accomplished work

Real-world experimentation (7/8): LEO pass emulation results

Traditional building

Thermo-efficient building
Accomplished work

Experimentation results (8/8): extrapolation to LEO orbit
Agenda

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Main conclusions and way forward

Questions and Answers
Main conclusions and way forward

Contract conclusions

• This project shows the **successful first-stage development of a flexible and fast-deployable CARS based on SDR systems.**

• The first stage of the development **demonstrates 133 MHz, 401.5 MHz and 500 MHz provide promising results** in terms of signal propagation and navigation capabilities.
  - **The PoC is based on a single Tx-Rx system** with Spread-Spectrum signals.

• **Experimentation in relevant environments has been carried out** to validate the developed proof-of-concept system.

• Experimentation resembling **LEO satellites geometry** have been carried out in order to verify the validity of the system for the LEO-PNT case.
Main conclusions and way forward

What’s next?

- Extend analysis to other frequencies (S band, C band, higher UHF band)
- Platform design optimization
- Broaden test scenarios and buildings (including different Tx. platforms)
- Analyse other waveforms and signal designs
Thank you

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