Microflown AVISA

3D Acoustic Situational Awareness

Mobile Sound Ranging Array

Bristol, UK, Future Indirect Fires Conference, 28 th February 2017
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Unclassified

Contents

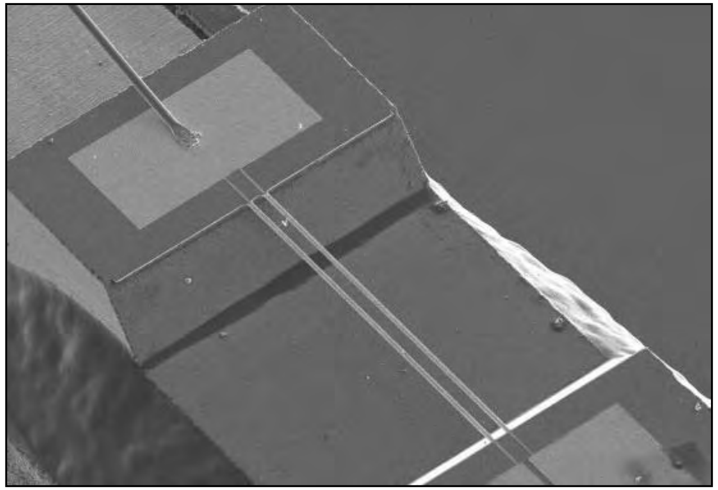
- Acoustic vector sensors allowing low SWaP mobile sensor nodes
- Synergies with radars
- Recent (2016) test results from several artillery ranges
- Incremental value of bringing sensor node forward
- Integration in Battlefield Management Systems
- Drone based sensor nodes
- Ongoing developments
- Need for further testing opportunities

Value proposition

Microflown AVISA provides complete 3 D acoustic situational awareness:

- detecting, classifying, localizing (and where applicable) tracking all sorts of audible threats:
  - Small Arms Fire (SAF)
  - **Rockets/ Artillery and Mortars (RAM)**
  - Helicopters, drones, heavy ground vehicles and (non cooperative) vessels
- from all kinds of platforms:
  - **Unattended Ground Sensors**
  - **Ground Vehicles**
  - **Unmanned Aerial Vehicles**
  - Buoys
  - Helicopters
  - Soldiers

Game changer: acoustic particle velocity



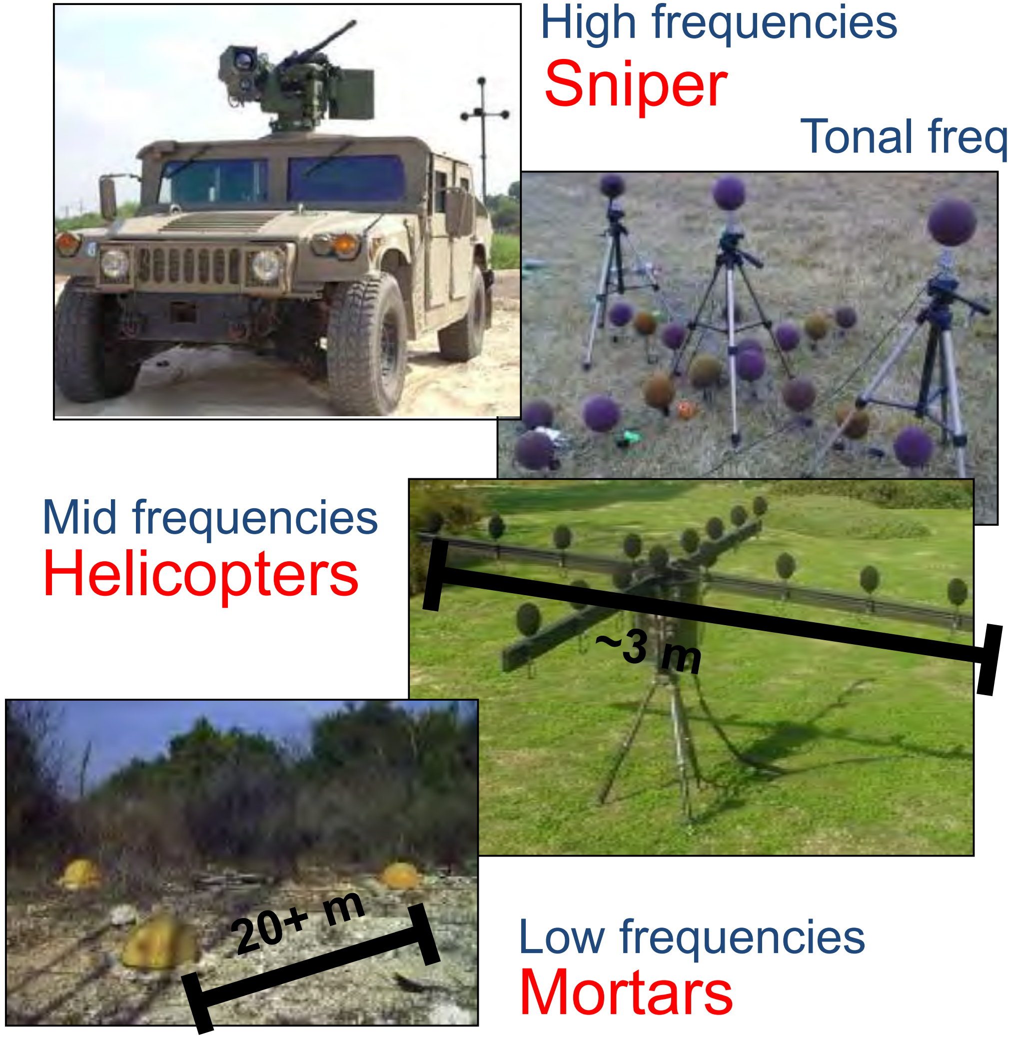
Microphone measures sound pressure (result)

Microflown measures Particle Velocity (cause)

Acoustical	<->	electrical	<->	energy
Sound pressure	<->	voltage	<->	potential
Particle velocity	<->	amperes	<->	kinetic

Directionality obtained from acoustic arrays

- The spacing in between the microphones determines upfront the frequency with optimal signal to noise (narrow banded), thus dedicated to a certain sort of audible threat)
    - small spaced microphone arrays are dedicated for high frequencies only
    - large spaced microphone arrays are dedicated for low frequencies
- Microflown sensors do not have this issue. They are broad banded and allow simultaneously a multi-threat localisation capability based on its broad-banded nature



AMMS multi-threat localization

High Frequencies
Sniper, Small Arms

Various Frequencies
Tonal Sound Sources

Low Frequencies
Mortars, Artillery

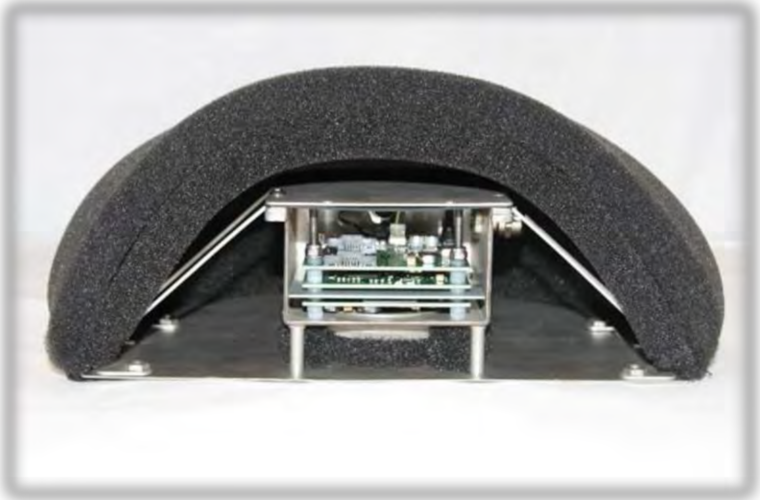
Broad-banded
AMMS

60cm

Acoustic Multi-Mission Sensor

An Acoustic Multi Mission Sensor consists of:

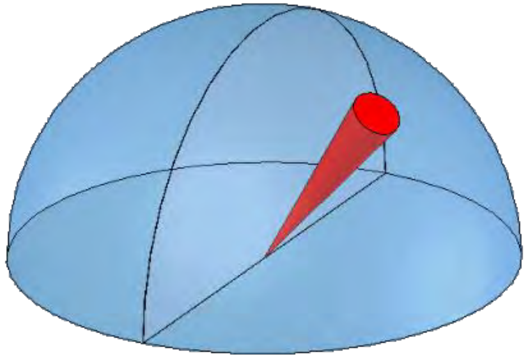
- a sensor node (2 Microflowns + 1 microphone)
- PCB stack for powering, signal conditioning and communication
- DSP
- sheet metal frame
- windcap



AMMS features

An AMMS itself:

- covers a broad frequency range
- hears all around in a full hemisphere
- is passive, cannot be detected/jammed
- requires no “line of sight”
- points in the direction of a sound source
- is low SWaP (26,5 cm diameter, 15 cm height, 1,75 kg, <2W)
- also works under adverse weatherconditions (in the night, with fog or rain)



Geo-boom

Specifications:

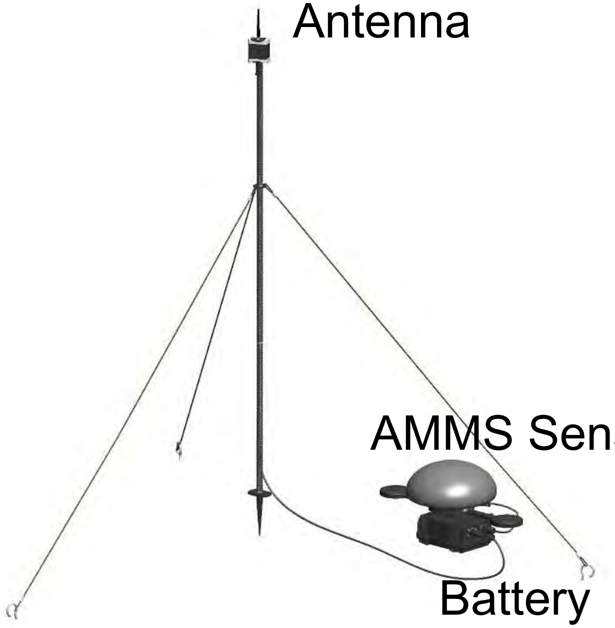
- allows self orientation of the AMMS <1 degree*
- provides accurate position down to 1 meter*
- sends position and orientation automatically to the Command Post
- updates continuously the position
- sizes 60x15x4cm, weighs 1kg, consumes 2.5W
- has levelling tool on the boom

*in ideal situation, with full GNSS (GPS, Glonass,BeiDou) coverage

Mobile Sound Ranging Array – Typical Hardware

- 1 MSRA C2 Command Post & 7 - 10 MSRA Sensor Posts (Wireless)

MSRA Command Post



MSRA Sensor Post

MSRA Sensor Post

A MSRA Sensor Post consists of:

- 1 x AMMS + Geo-boom
- 1 x antenna and carbon antenna mast
- 1 x communication unit:
  - Wireless 868/900MHz
  - Optional hard-wired solution
- 1 x ruggedized Multi-Battery Case:
  - 2557 battery - 2 days operational time; or
  - 2590 battery - 5 days operational time

  - Total Sensor Post weight 5kg (excl. battery)

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Mobile Sound Ranging Array Command Post

The MSRA Command Post consists of:

- 1 x ruggedized laptop/ tablet with Windows and AMMS C2 software
- 1 x USB powered router
- 1 x antenna and carbon antenna mast
- 1 x bus cable (up to 25 meters) between the communications unit

and USB powered router

- 1 x communication unit:
  - Wireless 868/900MHz
  - Optional hard-wired solution

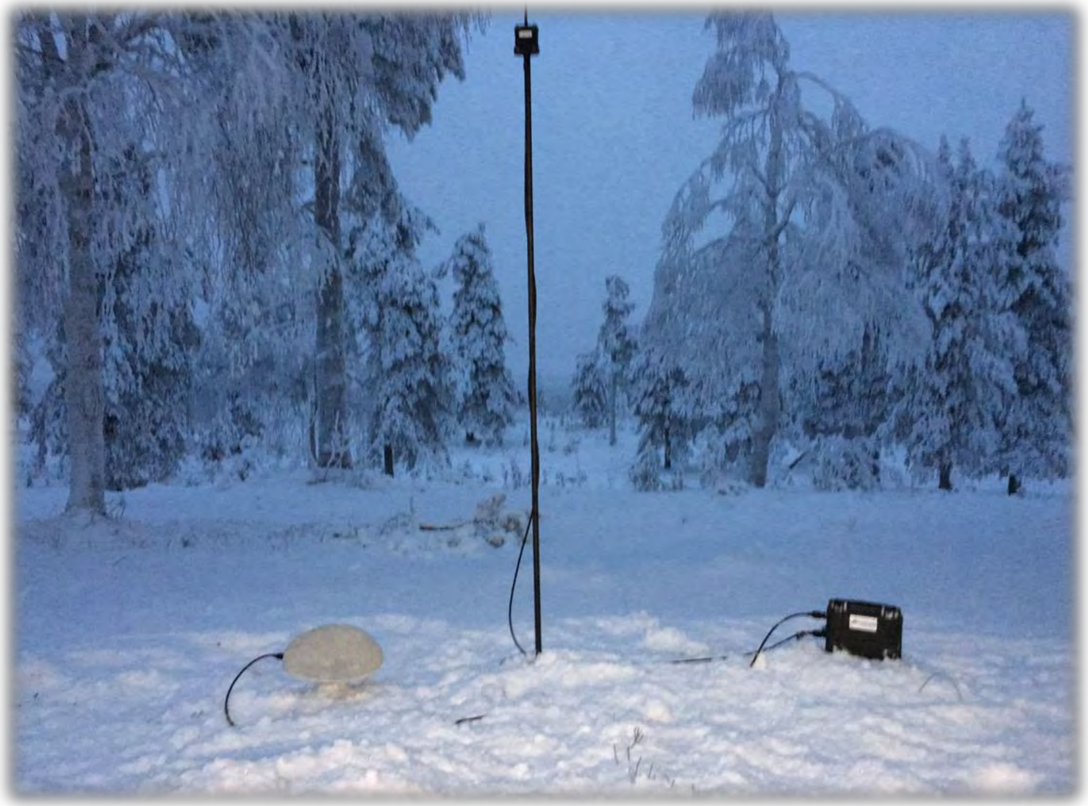
Power consumption

An MSRA Sensor Post with Geo-boom consumes 4,5 W.

Various battery options are available:

	Standard battery	2590 Battery
Operational time	2 days	5 days
Battery type	Sealed Lead Acid / AGM	Lithium-ion
Voltage	12 V	14.4 V
Capacity	7.2 Ah	14.4 Ah
Weight	3.43 kg	2.49 kg
Ruggedized box dimension	21.6 x 18.0 x 10.2 cm	

Camouflage coloured windcaps (optional)



Rapid deployable weather station

A rapid deployable real-time weather station module is available to connect to the AVISA bus network.

This module will improve the accuracy of localization made by the Mobile Sound Ranging Array system.

The weather station provides necessary input to the AMMS C2 software:

- wind speed and direction (based on its orientation)
- ultrasonic wind readings up to 70 knots
- air temperature
- barometric pressure & humidity

System Status Overview

AMMS information:

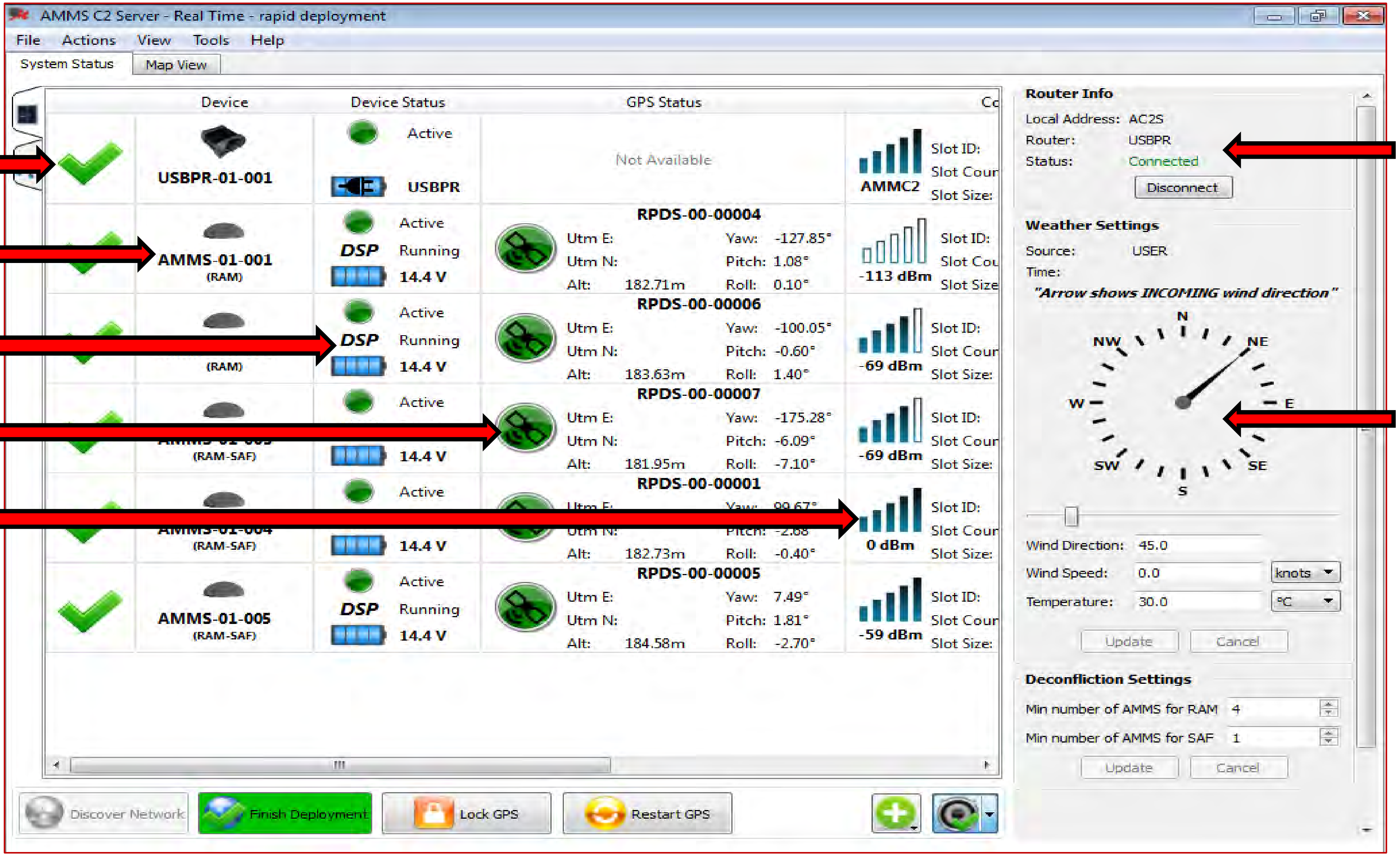
All settings correct

Sensor ID number and role presented

DSP and battery status

UTM GPS and positioning information

Comms signal strength and settings displayed

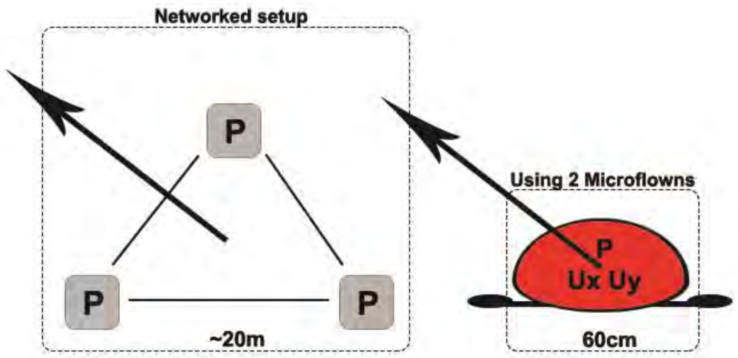


AMMS C2 USB router information

User can add meteo data (windspeed, direction and temperature)

AMMS has an extremely small footprint

Required footprint for Direction of Arrival



	Traditional	AMMS
Signal processing	Broad banded audio	Local
Frequency sensitivity	Narrow banded	Broad banded

P = sound pressure (traditional microphone)

P Ux Uy = sound pressure and 2-axis flown sensors (traditional microphone and two microflowns)

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Small footprint allows mobility

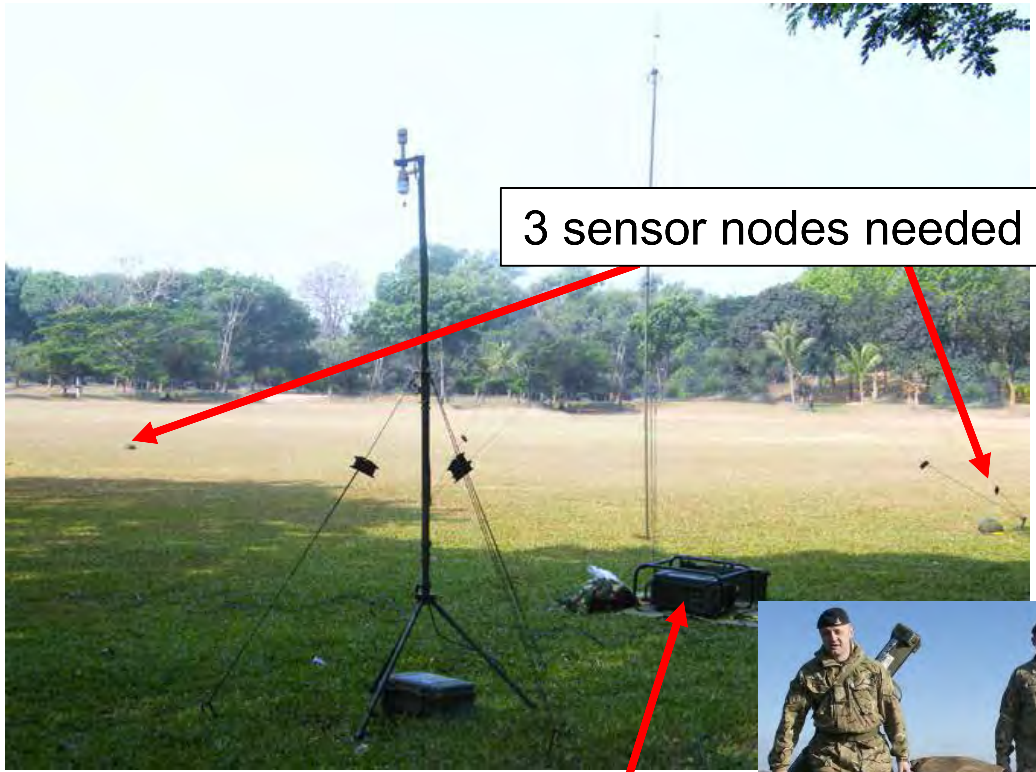
A sensor node can be used on various platforms:

- unattended ground sensor
- reconnaissance vehicle
- Perch & Listen Multicopter



MSRA and HALO comparison

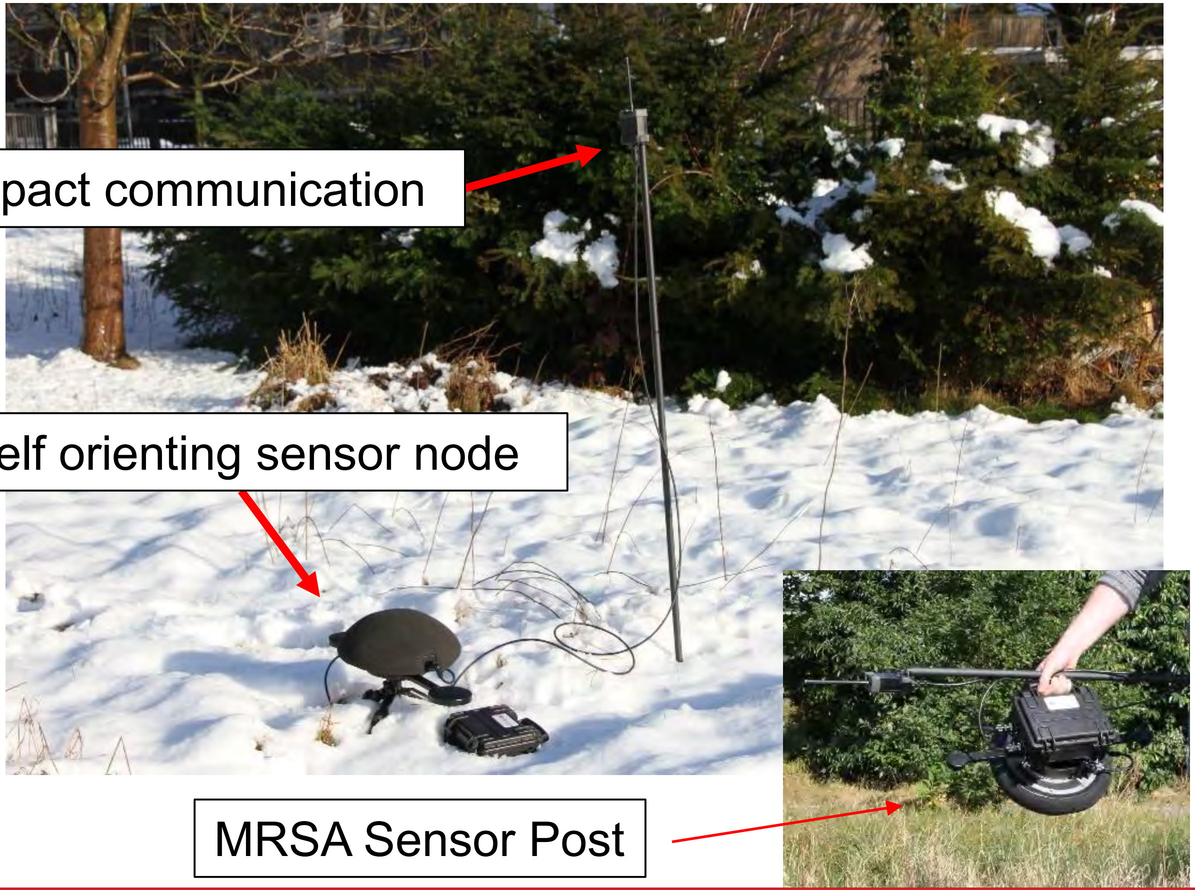
HALO SENSOR POST



3 sensor nodes needed

heavy communication

MSRA SENSOR POST



compact communication

1 self orienting sensor node

MRSA Sensor Post

HALO vs. MSRA SWaP features

Description	HALO		MSRA	
	Unit	Total	Unit	Total
Command Post weight (* 1)	232 KG	232 KG	5 KG	5KG
Sensor Post weight (*8)	41 KG	328 KG	5 KG	40 KG
Manpower (*8)	20 minutes with 2 soldiers	160 minutes with 2 soldiers	5 minutes by one soldier	40 minutes by one soldier
Footprint Sensor Post	Equilateral triangle of 20m in flat area		Less than 1 square meter	

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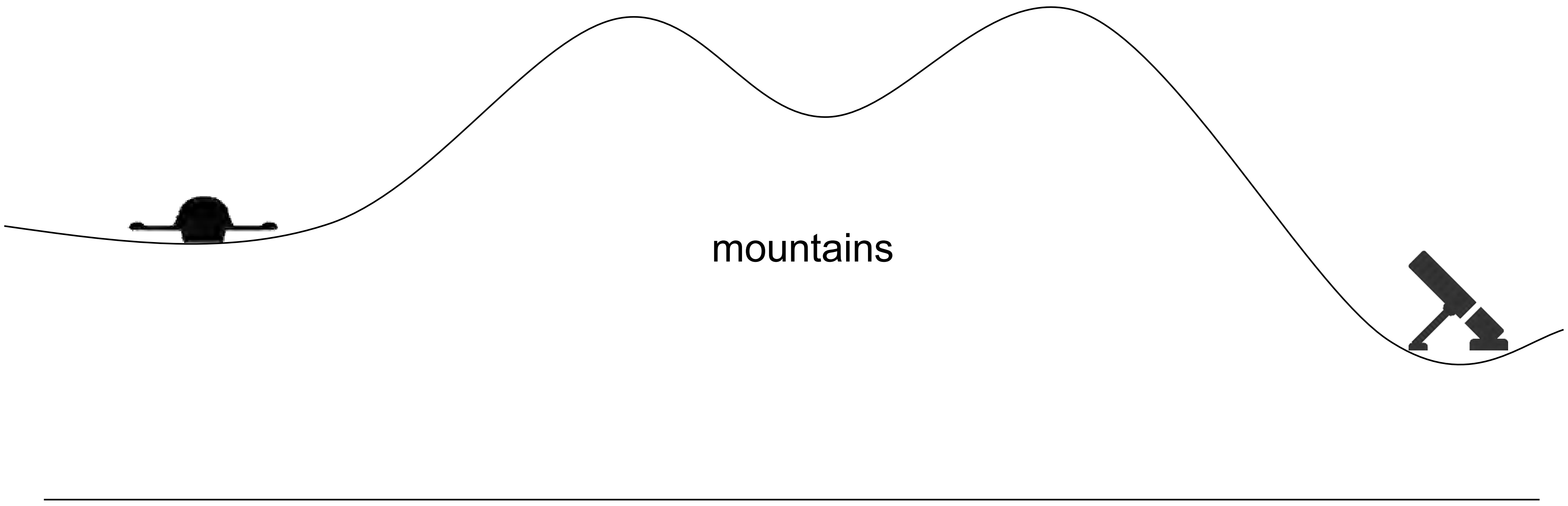
Conventional weapon location radar

- is active, hence:
  - sticking out as a high value primary target
  - consuming power that is scarce in a fluid battlefield
- is costly
  - capital costs (notably three systems are required to have one in operation)
  - labor costs
  - energy costs
- is hierarchical (top down distribution of information)
- requires a line of sight
- has a dead volume around it

No line of sight

Unlike radars and cameras, acoustics do not require a line of sight.



East Ukraine – Electronic Warfare

"Our soldiers are doing the training with the Ukrainians and we've learned a lot from the Ukrainians," said Lt. Gen. Ben Hodges. "A third of the [Ukrainian] soldiers have served in the ... combat zone, and no Americans have been under Russian artillery or rocket fire, or significant Russian electronic warfare, jamming or collecting — and these Ukrainians have. It's interesting to hear what they have learned."

"Our biggest problem is we have not fought in a comms-degraded environment for decades, so we don't know how to do it," Buckhout said. "We lack not only tactics, techniques and procedures but the training to fight in a comms-degraded environment."

Russia maintains an ability to destroy command-and-control networks by jamming radio communications, radars and GPS signals, according to Laurie Buckhout, former chief of the US Army's electronic warfare division, now CEO of the Corvus Group. In contrast with the US, Russia has large units dedicated to electronic warfare, known as EW, which it dedicates to ground electronic attack, jamming communications, radar and command-and-control nets.

http://www.defensenews.com/story/defense/policy-budget/warfare/2015/08/02/us-army-ukraine-russia-electronic-warfare/30913397/

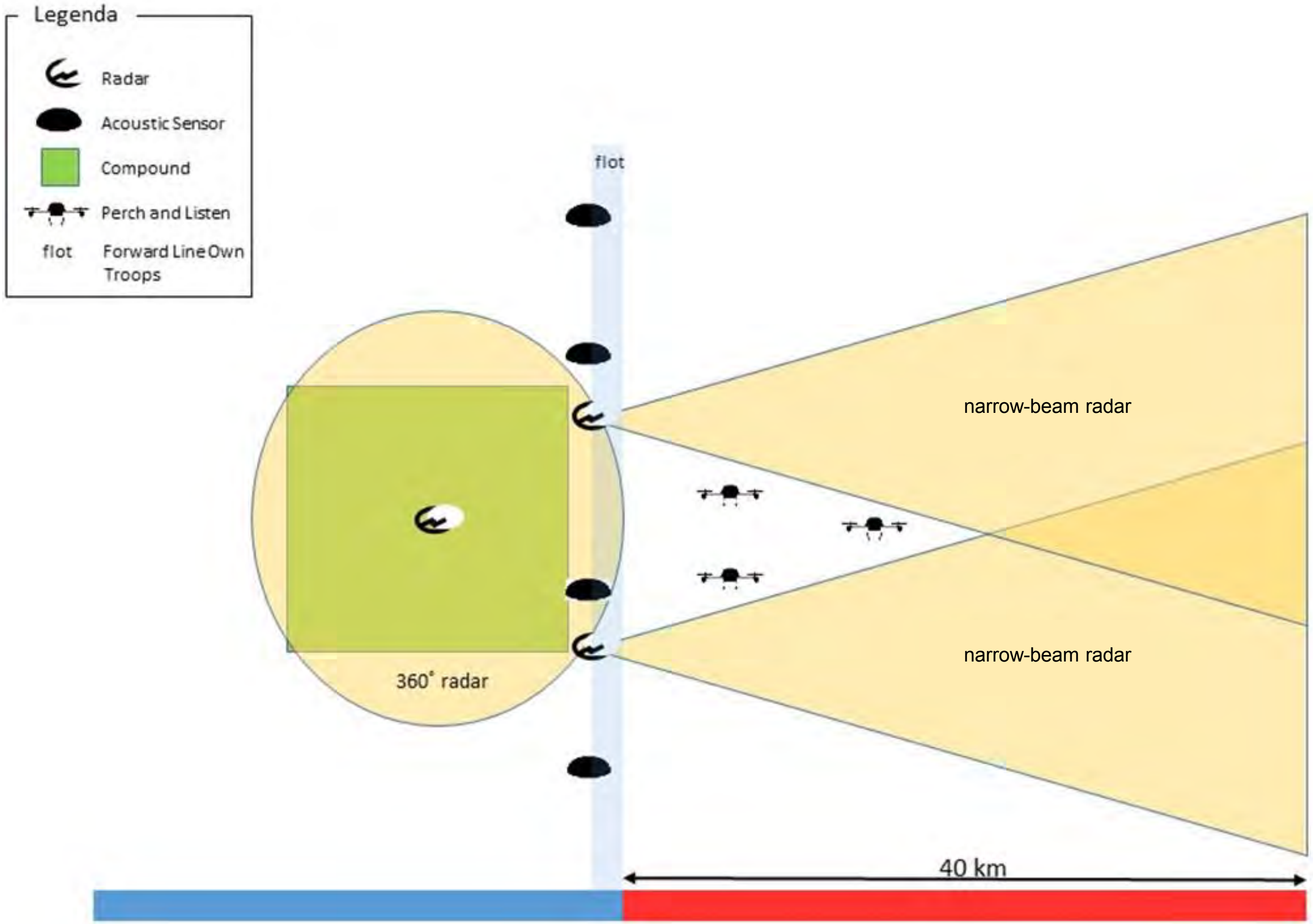
East Ukraine > other observations

Apart from Electronic Warfare, there are at least two other observations:

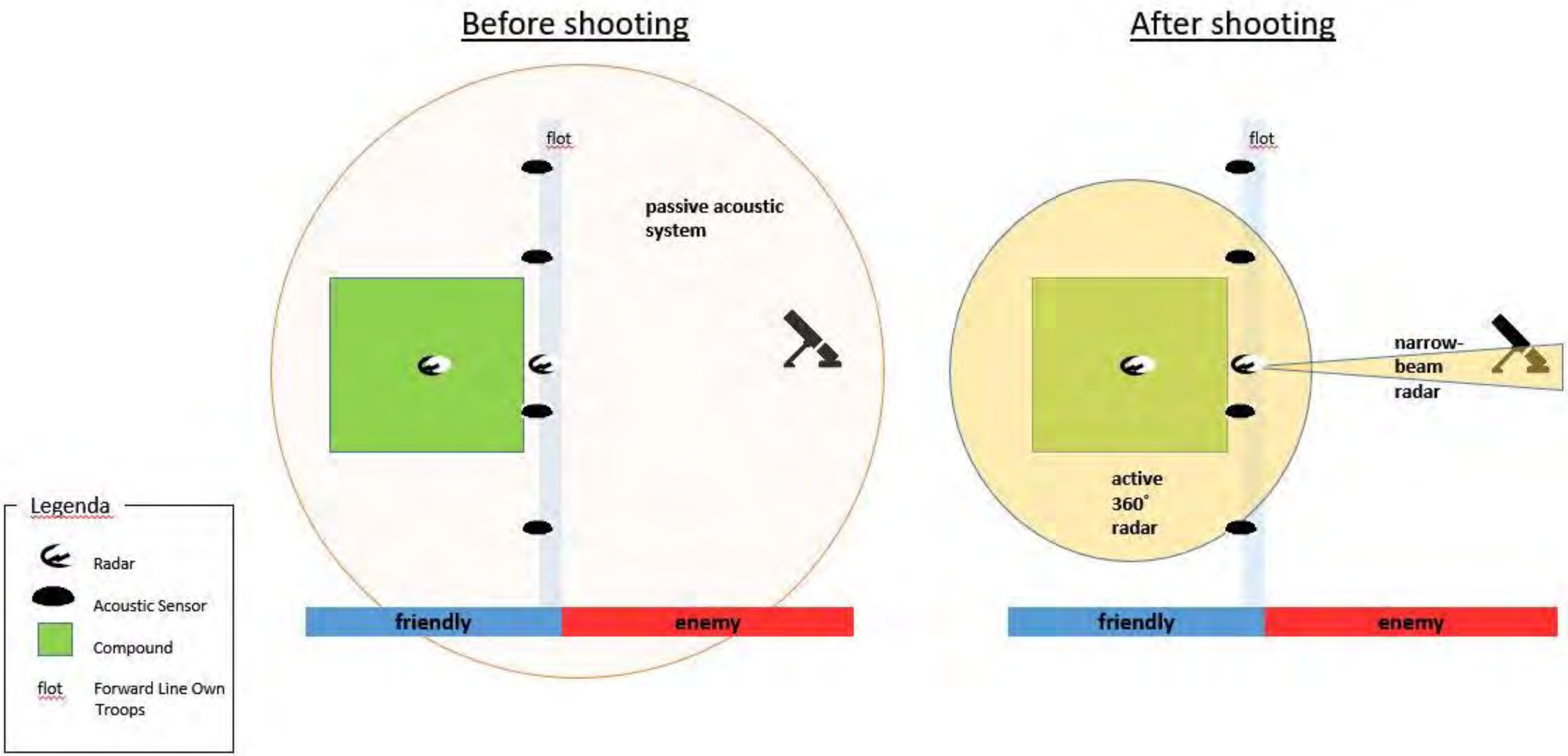
- Spetsnaz snipers take out with a single shot high primary target radar posts
  > as the radar is top down hierarchical, the enemy is blind

- artillery rounds come from larger distances and relocate faster than ever
  > time span from sensing, shooting and reaching the enemy becomes critical
  (especially for slow propagating acoustics)
  > readjusting radars for larger distances creates larger white spots around the radar
  post itself

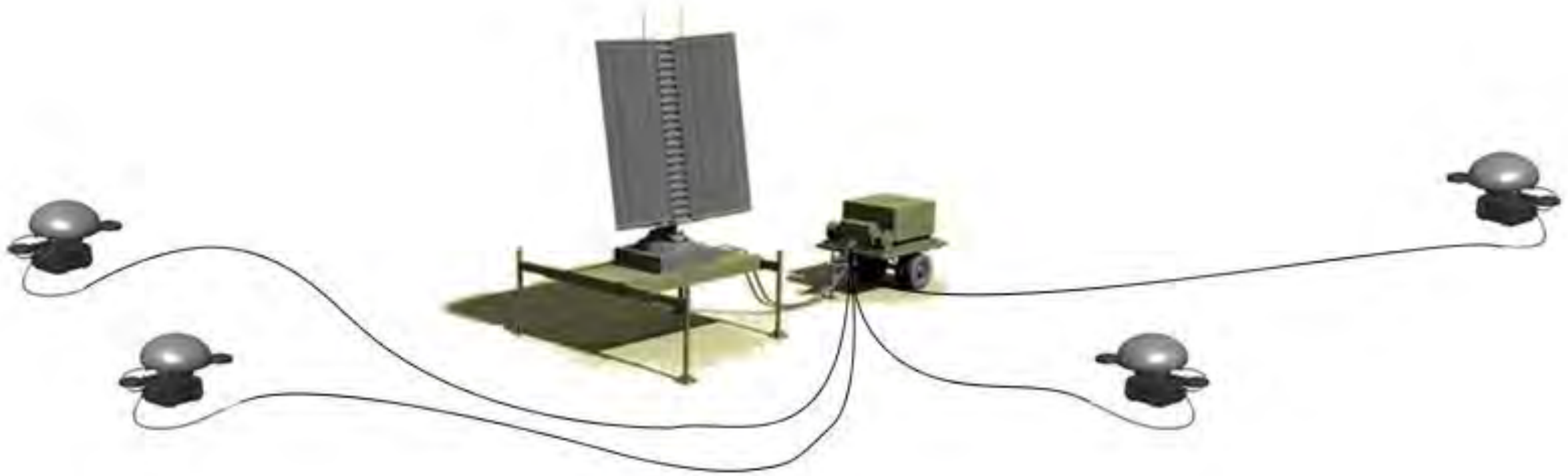
AMMs as gapfillers for narrow-beam radars



Use passive Mobile Sound Ranging Array as long as possible



Active radar unit with passive mobile sound ranging array



Hard wired communication

The Mobile Sound Ranging Array can be made completely passive by using a two-wire cable instead of wireless communication.

The wire between stations can be up to 1 kilometer.

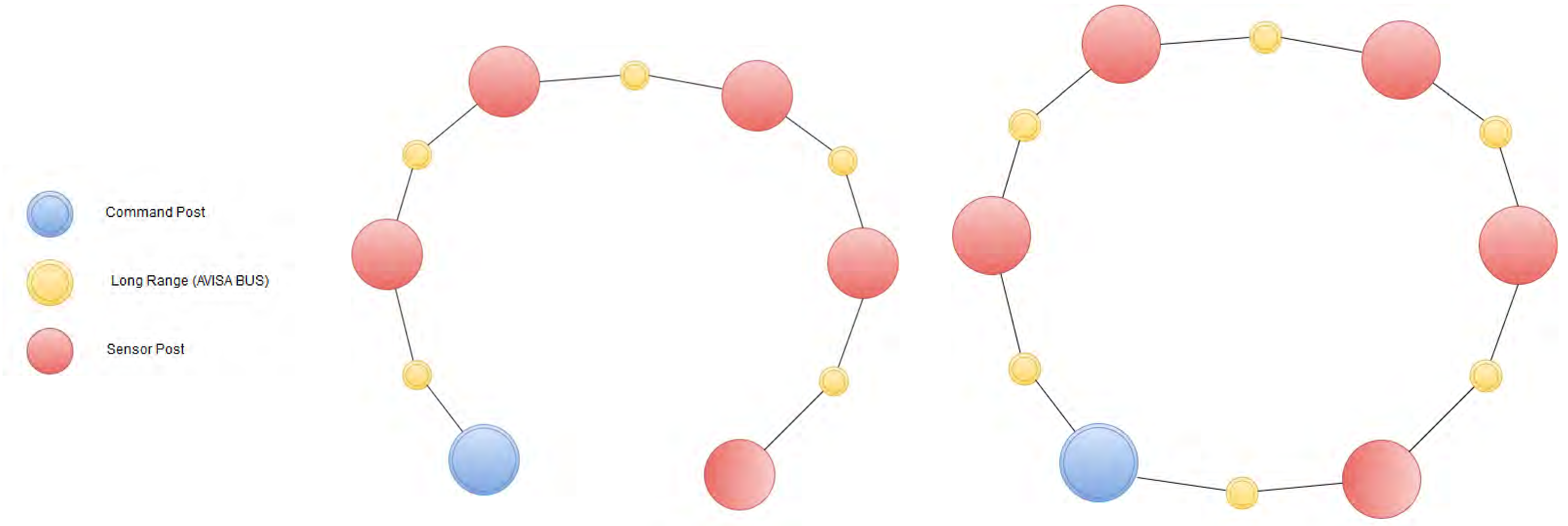
A ring topology can be used.

Thus the MSRA becomes completely passive.

Hence, the enemy cannot:

- detect the system
- use Electronic Warfare measures against the system

Hard wired, unjammable, fully passive system



Nowadays doctrine

Technology allows the use of narrow-beam radars

Use passive MSRA as long as possible

Use radar only when a sector alert has been triggered by MSRA

Narrow beam radar can never be detected by triangulation

The goal is to increase survivability, reliablity and robustness

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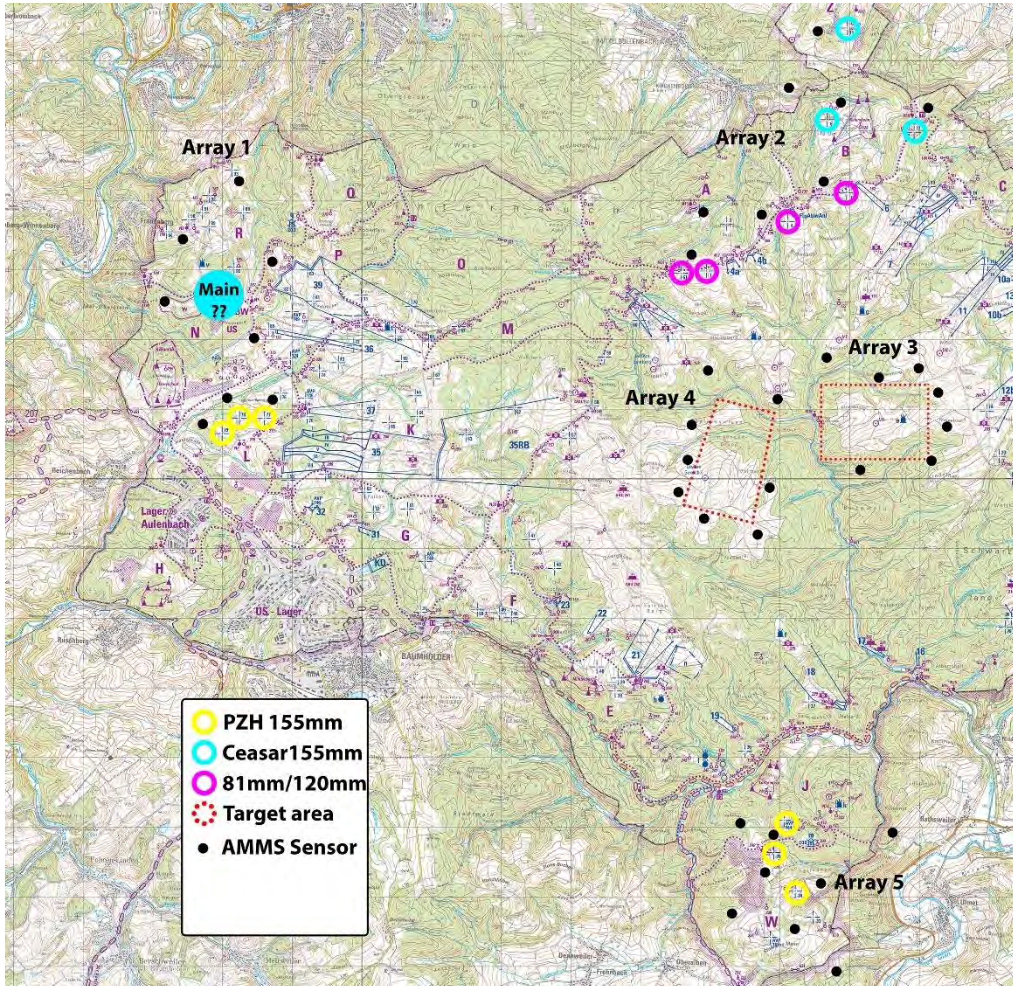
Exemplary test results 2016

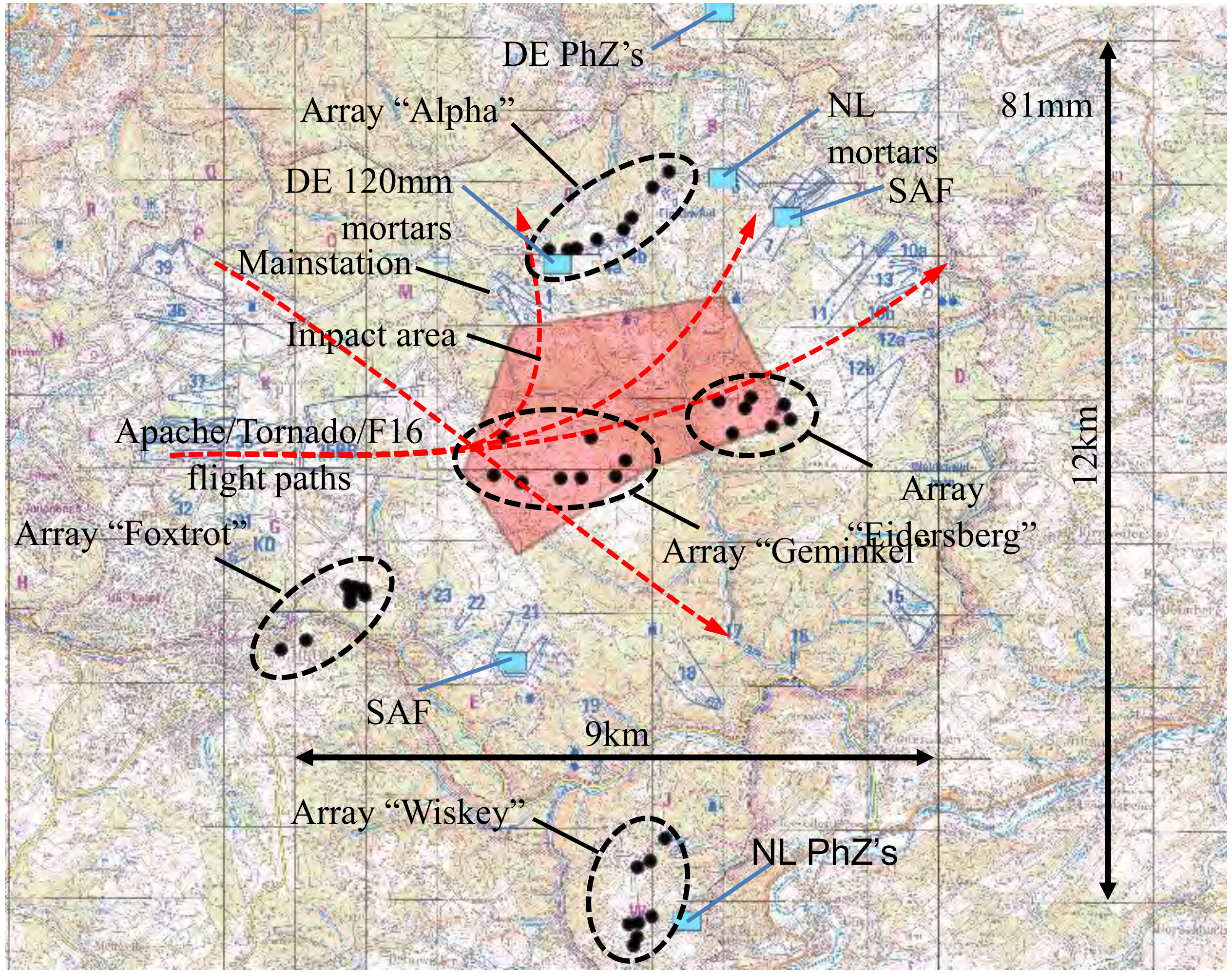
- Germany, Baumholder, NATO Griffin Strike, Sept 2016
- Canada, Petawawa, October 2016
- Finland, Lapland, November 2016

Germany, Baumholder, Sept 2016

During the NATO Griffin Strike exercise, various sorts of mortars (81 and 120 mm Hellfire missiles) and 155 mm PZH howitzers fired in an open but hilly environment.

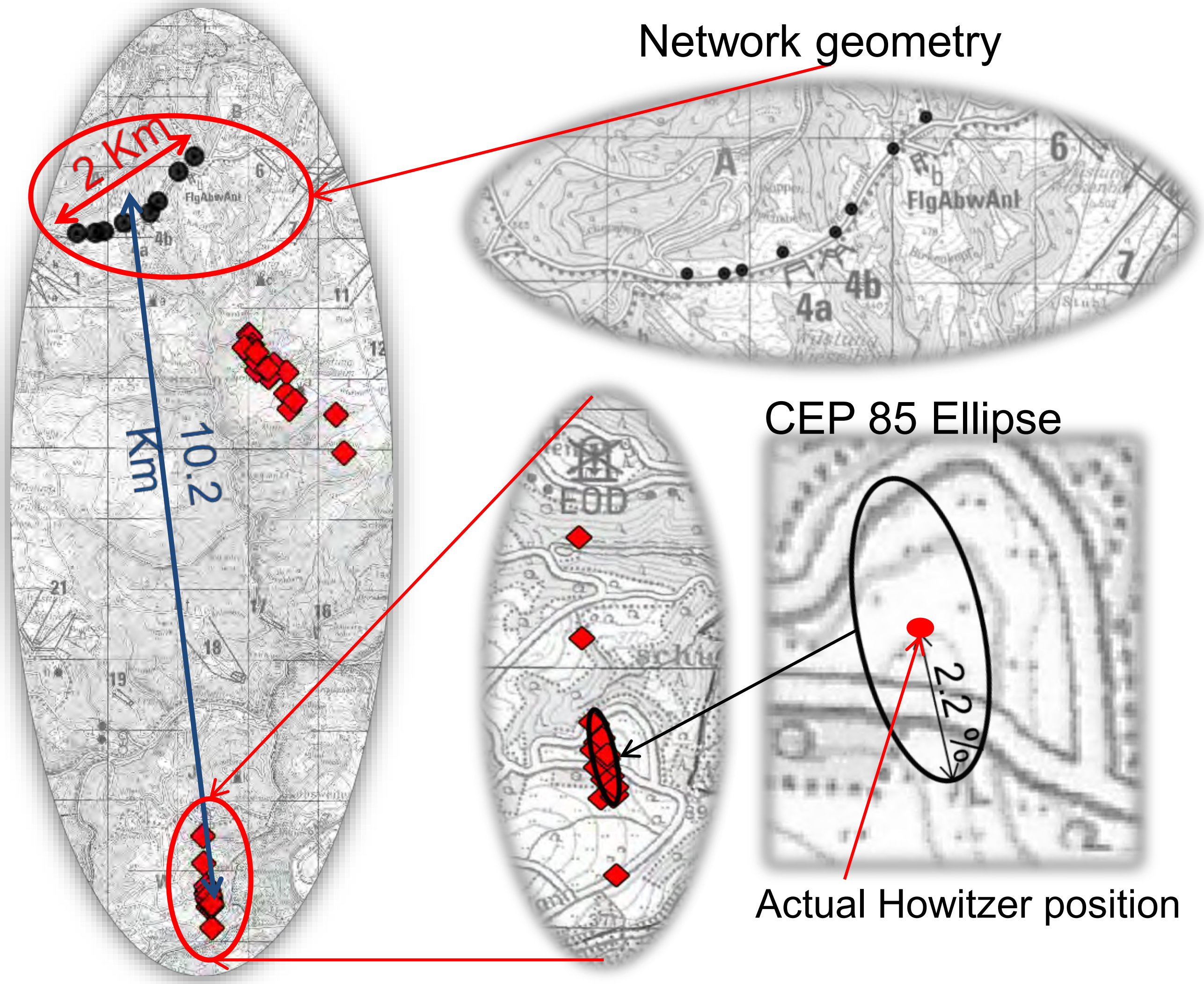
Five MSRA's were deployed for audio recording





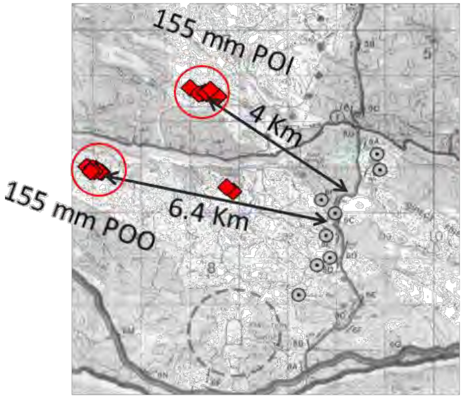
Germany – Baumholder NATO exercise Griffin Strike

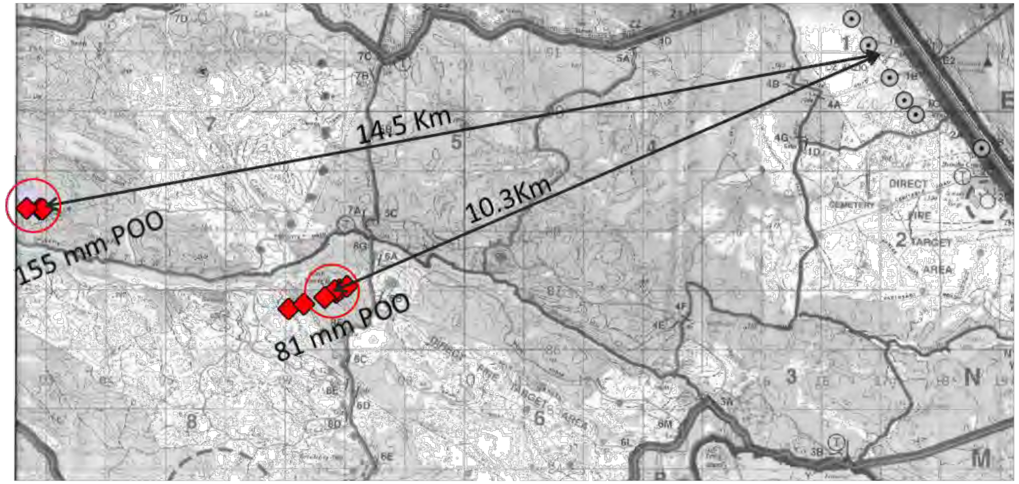
- A network of AMMSs deployed along the road
- 8-AMMS network that spans 2 Km approx.
- 155 mm Howitzers 10.2 Km away to the South
- Impact area 2.5-4 Km away to the South-East
- 100 rounds were processed:
  - ✓ All launches and impacts were detected
  - ✓ Range error:
  - ✓ CEP85 for launches = 2.2 % of range (210 m)
  - ✓ DOA error:
  - ✓ CEP85 = 0.15 % of range < 0.2 degrees

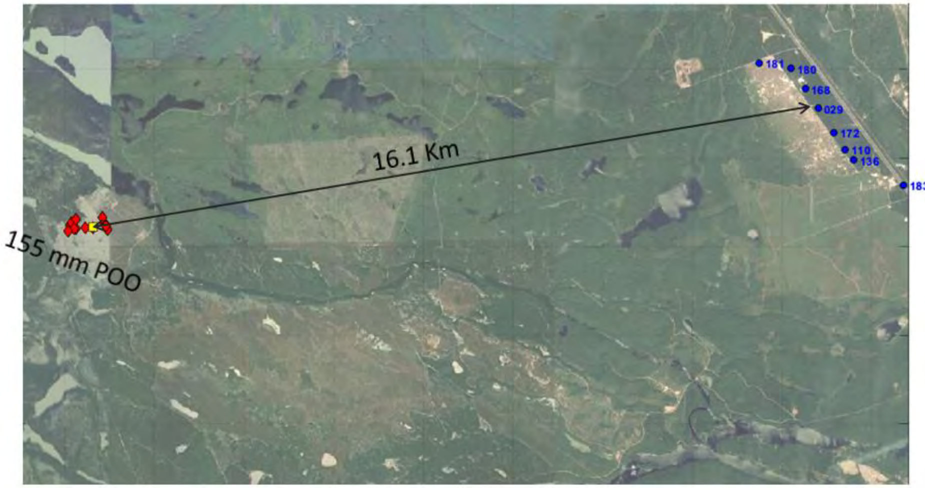


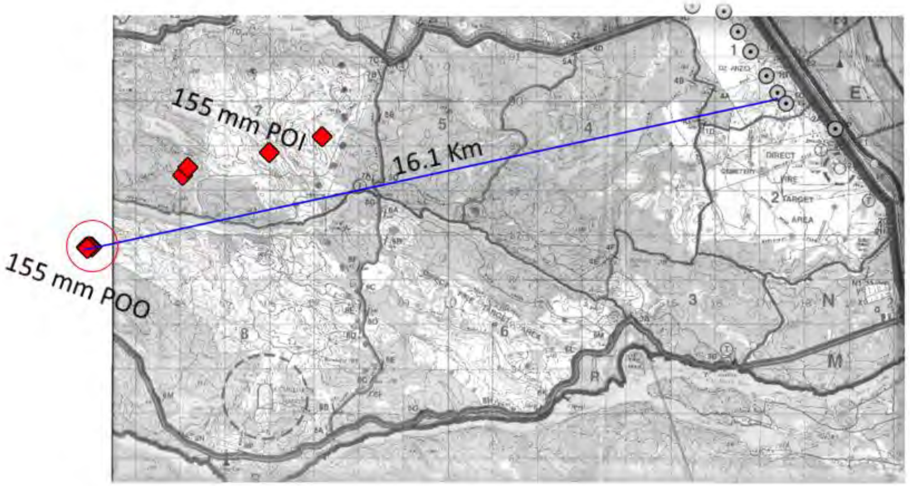
Canada – Petawawa October 2016

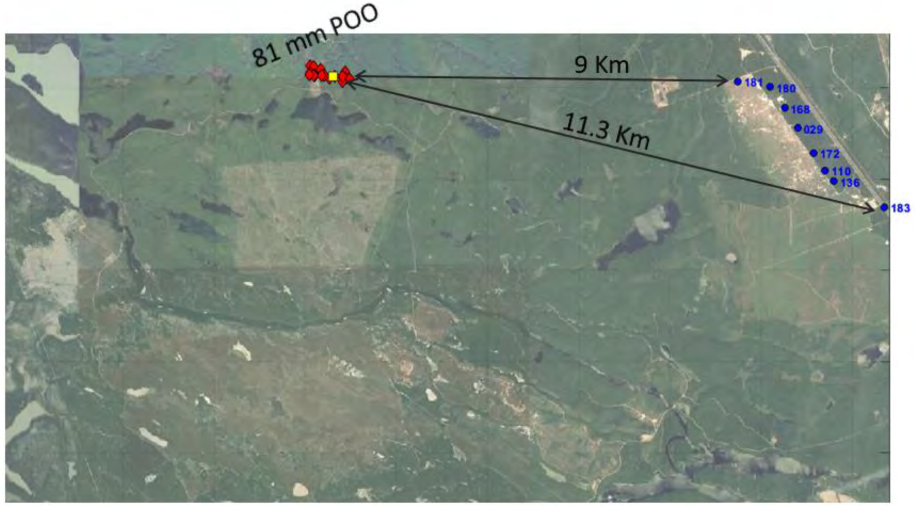

Canada – Petawawa October 2016











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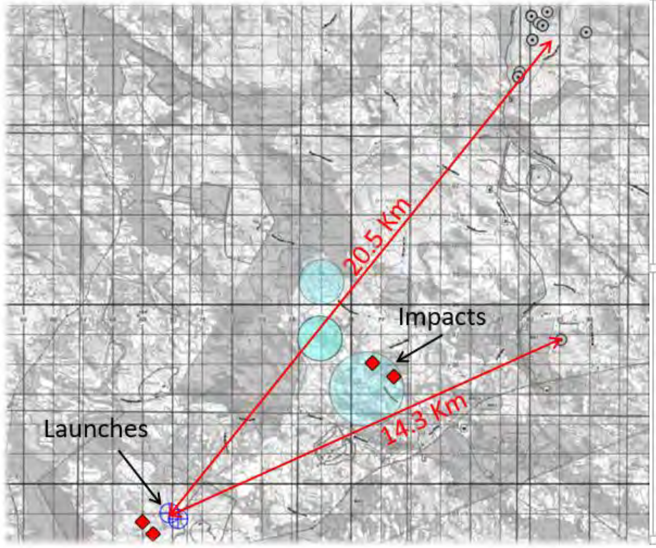
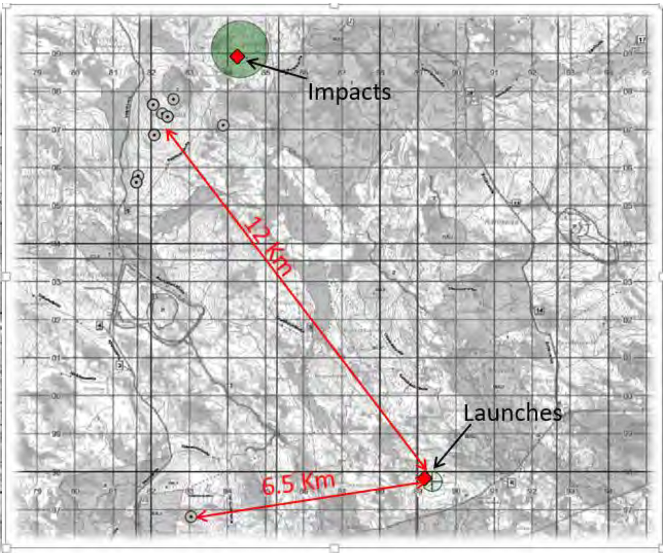
In Finland, MSRA was tested in a dense forest

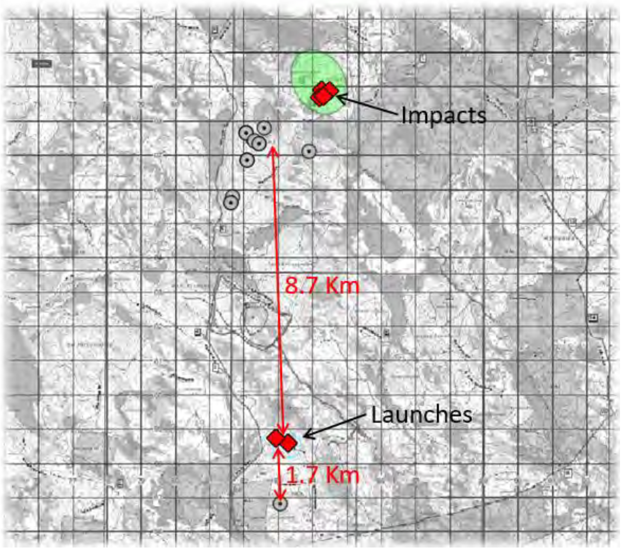
Firing units and results Finland 2016



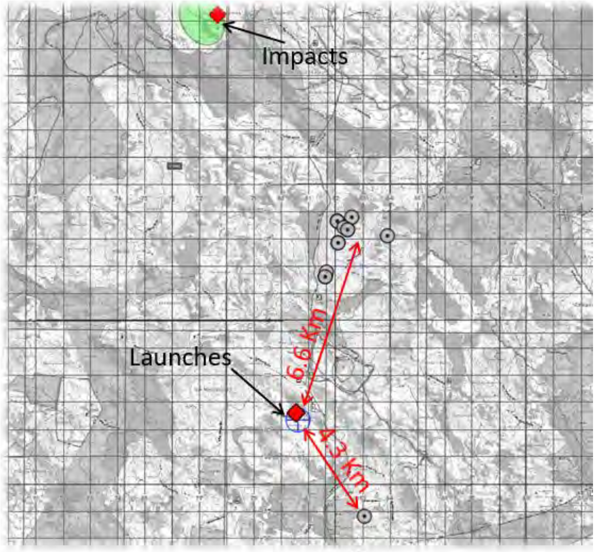
- ❑ **B1 122 mm PSH 74 (Self propelled howitzer)**
  - Launches detected at 21 Km
  - Localization error < 5% of range
  - Direction of arrival error < 0.1 deg



- ❑ **K1 155mm K9 Thunder (Self-propelled howitzer)**
  - Launches detected at 12.5 Km
  - Localization error < 2% of range
  - Direction of arrival error < 0.1 deg



- ❑ **122 mm howitzer (D-30) H63**
  - Launches detected at 8.7 Km
  - Localization error < 2% of range
  - Direction of arrival error < 0.1 deg

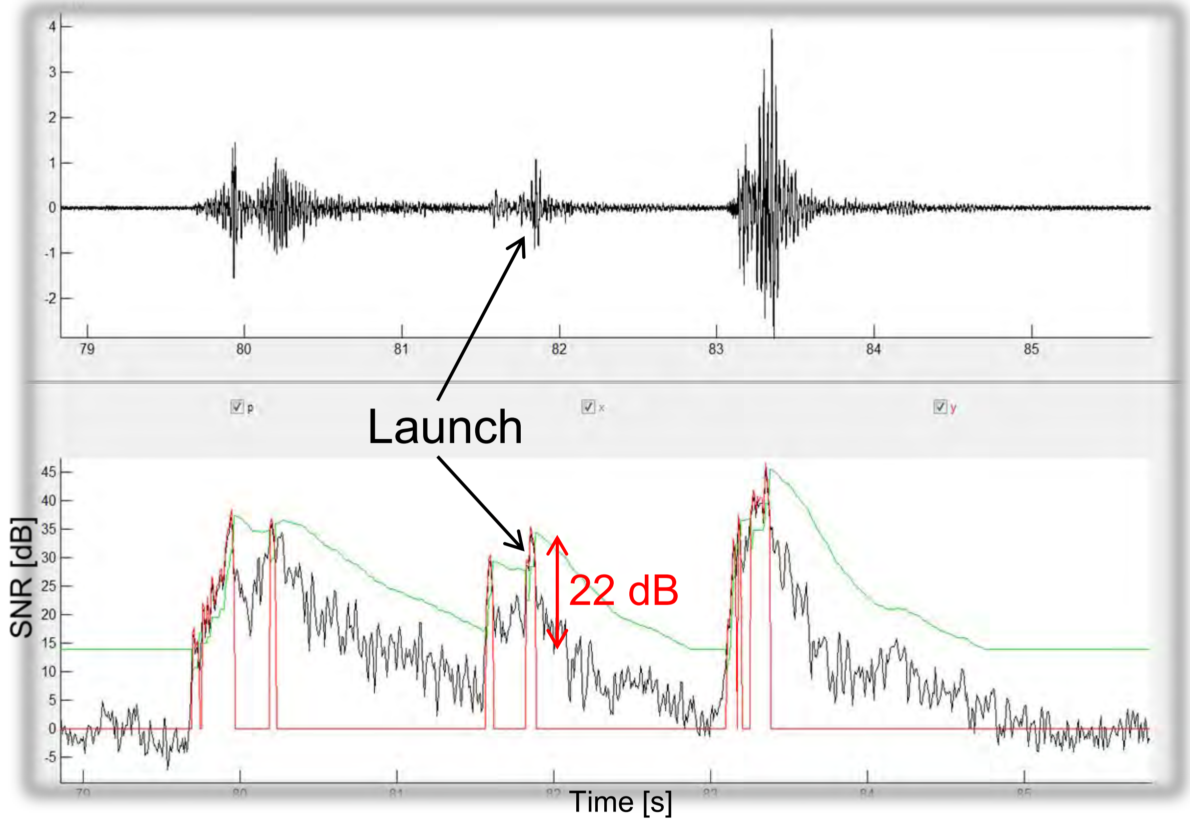


- ❑ **Multi Launch Rocket System (MLRS)**
  - ✓ 5 shots and 3 impacts were detected
  - ✓ Localization error < 250 meters
  - ✓ Direction of arrival error < 0.1 deg

Outlook on maximum detection ranges

Based upon signal to noise ratios on the AMMS, Microflown AVISA believes it may detect at 40 km, under favorable weather conditions though.

But it needs to be tested.



Launch: 2S1/ 122PSH74

(122 mm howitzer) at 21.3 Km (POO)

Contents

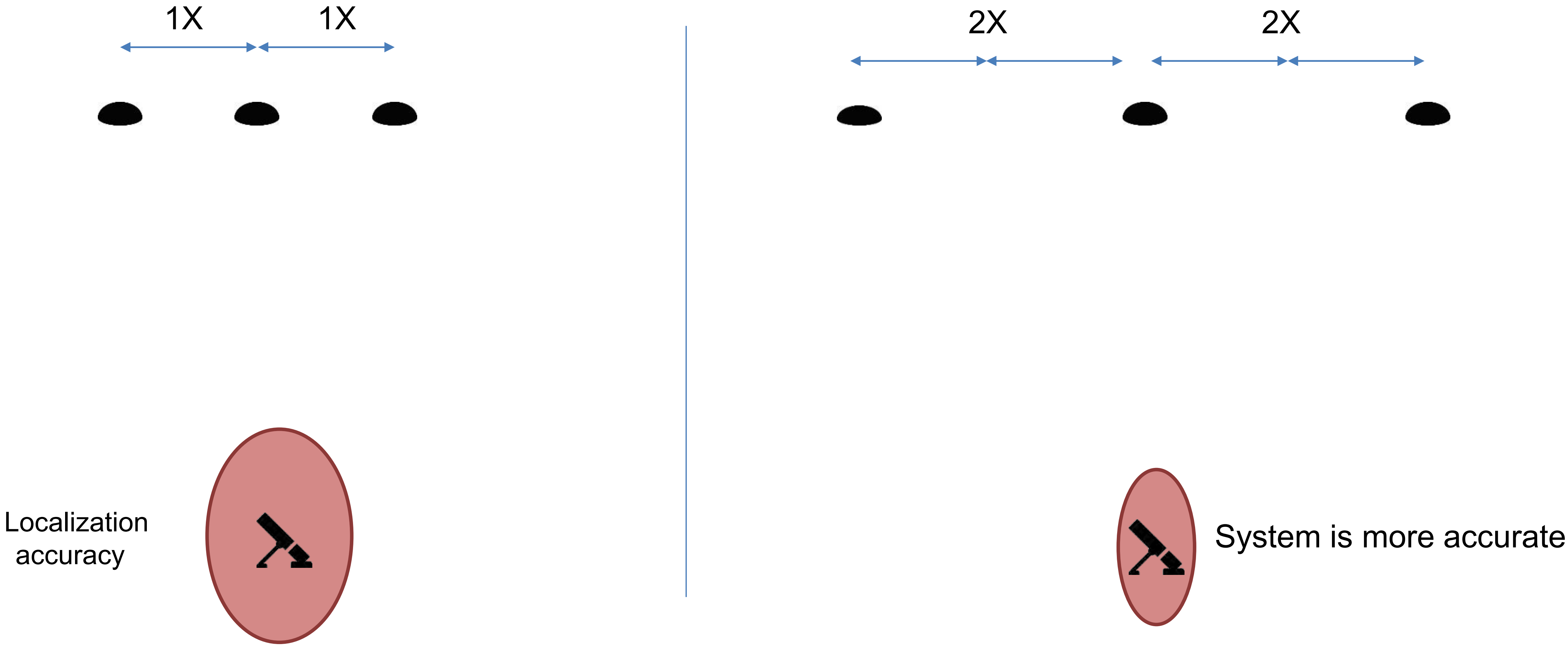
- Acoustic particle velocity as the enabler
- The Mobile Sound Ranging Array (hardware and software)
- Synergies with radar
- Test results 2016
- Incremental value of bringing sensor node forward
- Integration in Battlefield Management System

Incremental value of sensor nodes

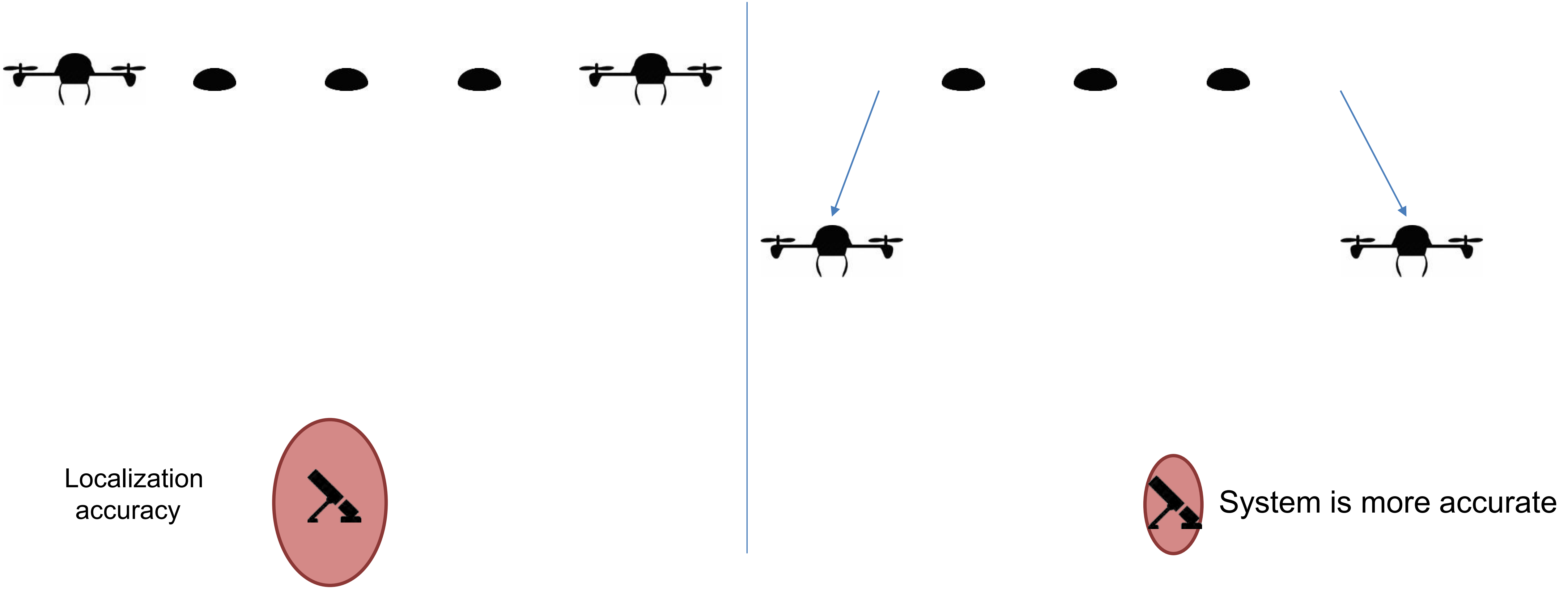
To increase localization accuracy several options are possible:

- extend baseline
- increase amount of sensor nodes
- close in on enemy, bringing a sensor node forward
    - use of Perch and Listen sensor; or
    - forward listener

Extending baseline



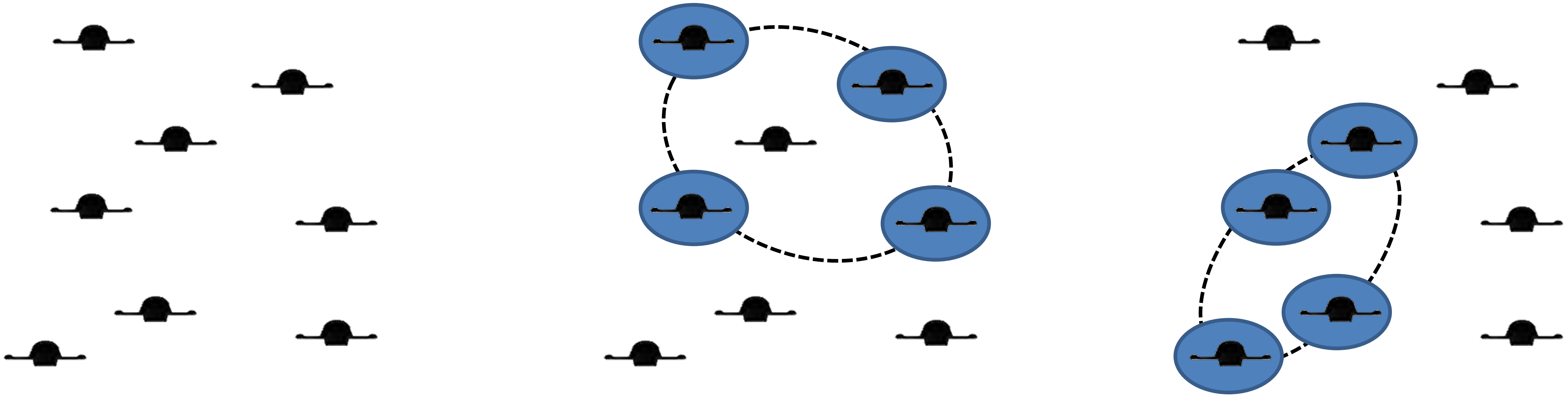
Closing In



Simulating various array configurations

By combining various time stamped audio recordings, in postprocessing an assessment can be made of the performance of a certain array configuration

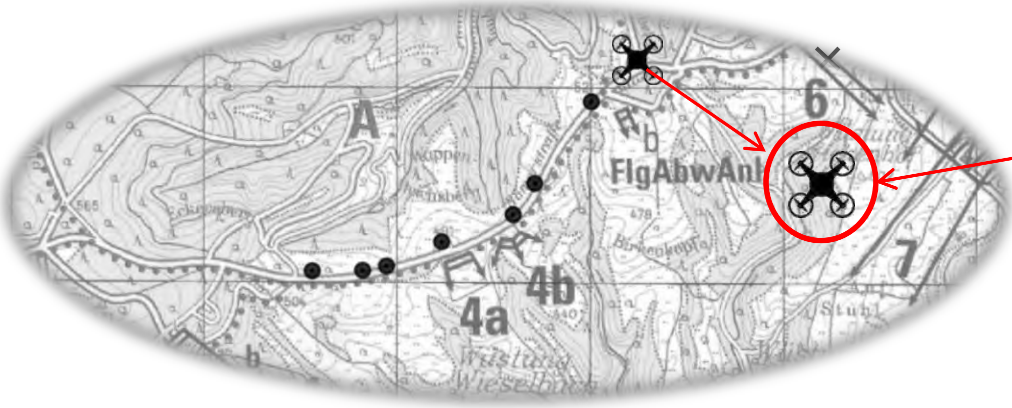
Actual Recordings | Array Configuration 1 | Array Configuration 2



Use of Perch & Listen multicopter

Microflown AVISA offers an Unmanned Forward Listener called Pearch & Listen (P&L), that:

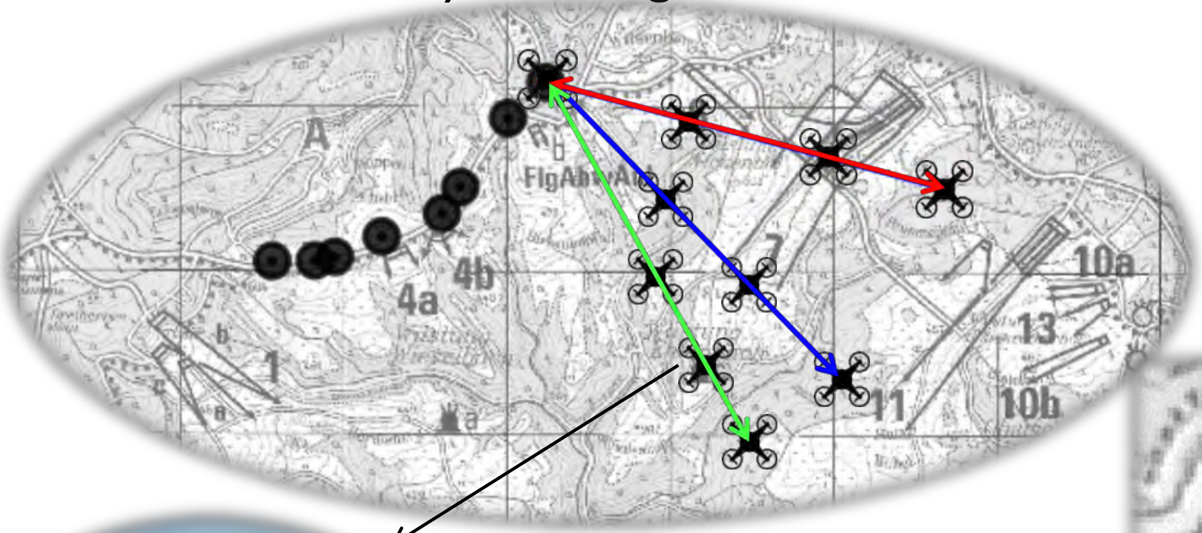
- is a stable quadcopter based platform
- deploys an AMMS deep into the hostile territory or difficult-to-access areas
- allows for a wider array span to improve the accuracy
- provides GEO reference information in real time (position and orientation)



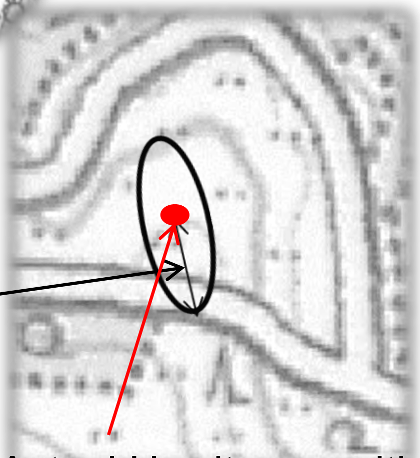
P&L: Forward Listener

Accuracy improvement vs Forward Listener range

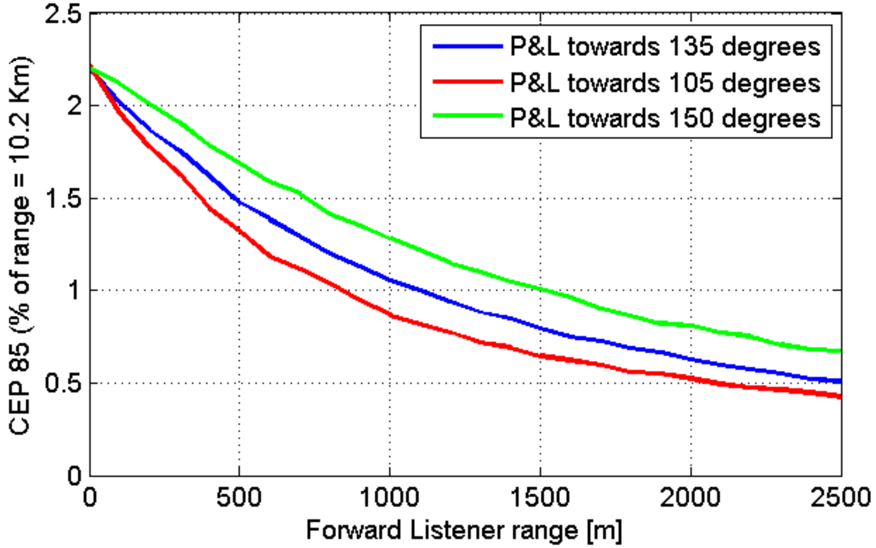
- Real measurements have been used to assess the incremental value of the **P&L**:
  - ✓ **The furthest sensor (to the weapon) can be used as forward observer (when flown forward) resulting in a noticeable accuracy improvement**



The accuracy noticeably improves if the P&L range increases (Forward Listener)

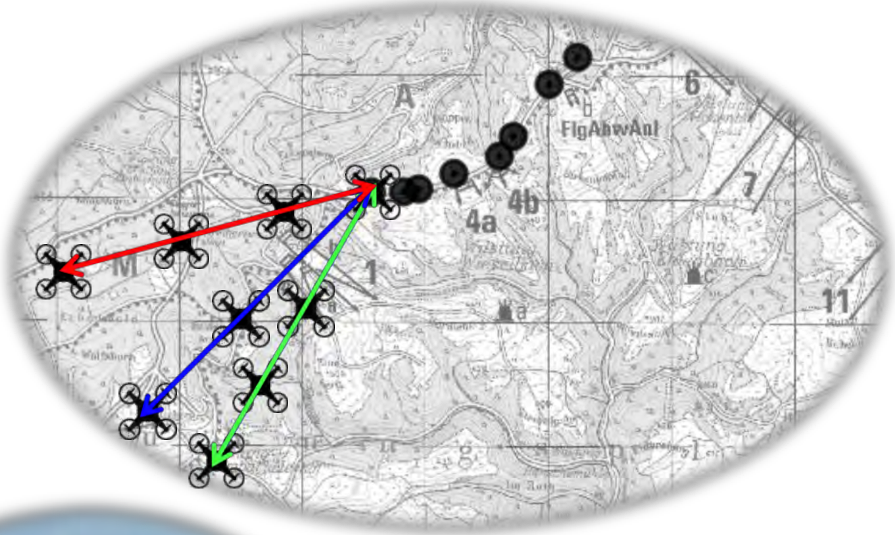


Actual Howitzer position



Accuracy improvement vs Forward Listener range

- Real measurements have been used to assess the incremental value of the **P&L**:
  - ✓ **The sensor more towards the West is a forward observer – Better accuracy improvement**



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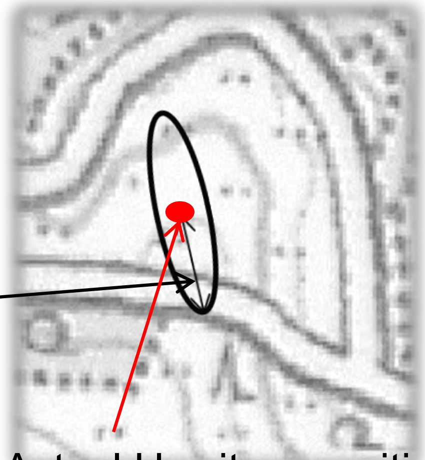
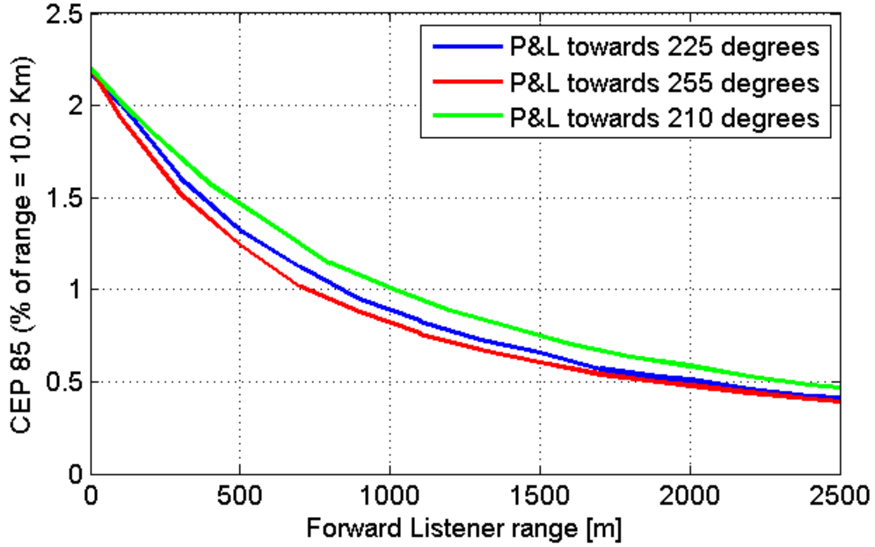


Actual Howitzer position



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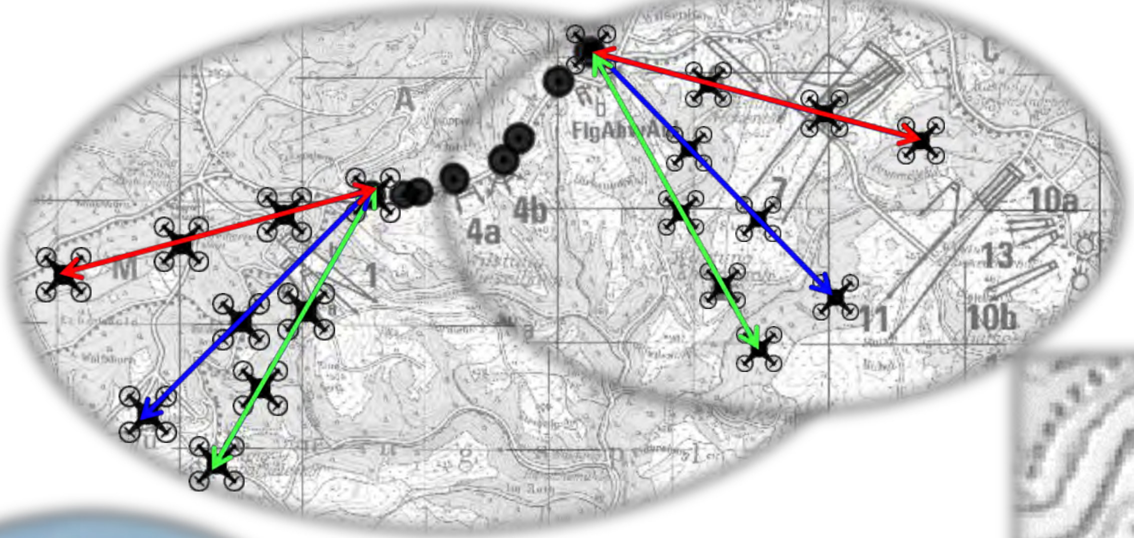
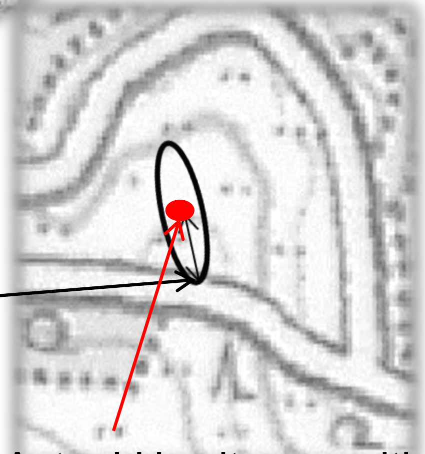
Accuracy improvement vs Forward Listener range

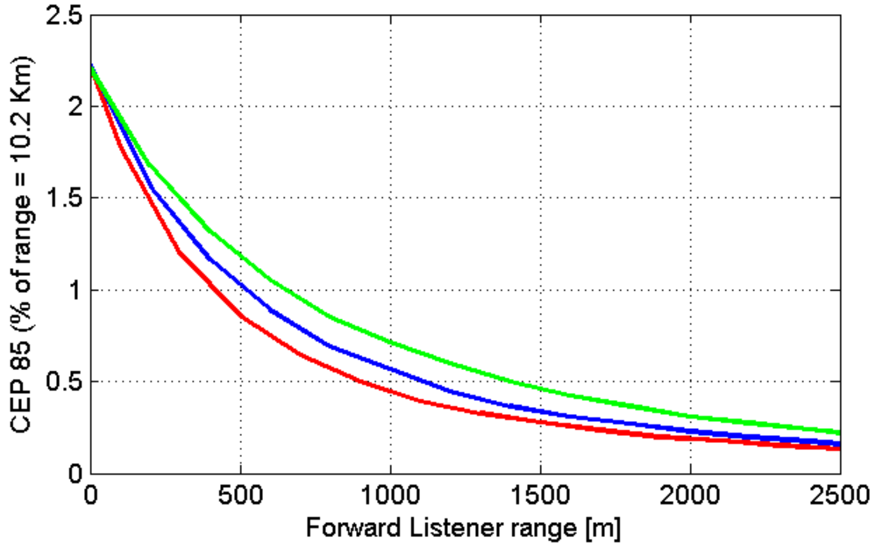
- Real measurements have been used to assess the incremental value of the **P&L**:
  - ✓ **Both sensors are forward observers – Best accuracy improvement**



The accuracy noticeably improves if the P&L range increases (Forward Listeners)



Actual Howitzer position



Influence factors localization ranges

The localization ranges will depend upon a variety of influence factors:

- audible event itself:
  - sort of weapon system
  - cargo charge
- weather:
  - wind
  - humidity
- topography:
  - trees
  - snow
  - landscape

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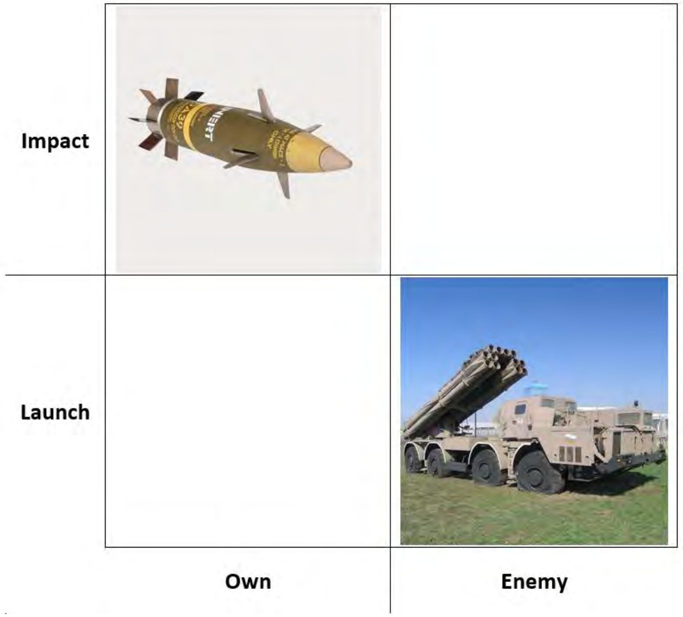
AVISA’s Battlefield Management System

In essence, AVISA’s BMS is about the acoustical separation of:

- own impacts
- enemy’s launches

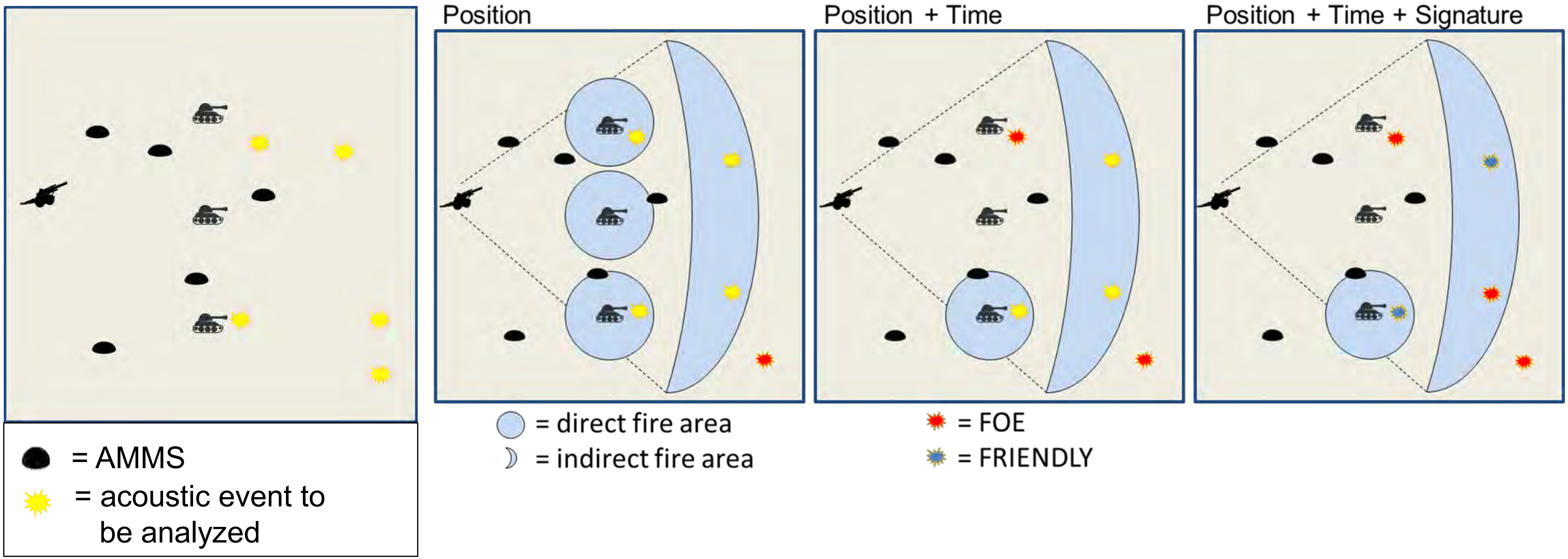
To distinguish hostile firing positions from own impacts coordinates, a (layered) approach can be followed, using:

- position information (defining “circle of noise”)
- time information (defining “time window of noise”)
- acoustic signatures (analyzing the remainder of events)



Analyzing acoustic events by applying filters

Initial battlefield situation

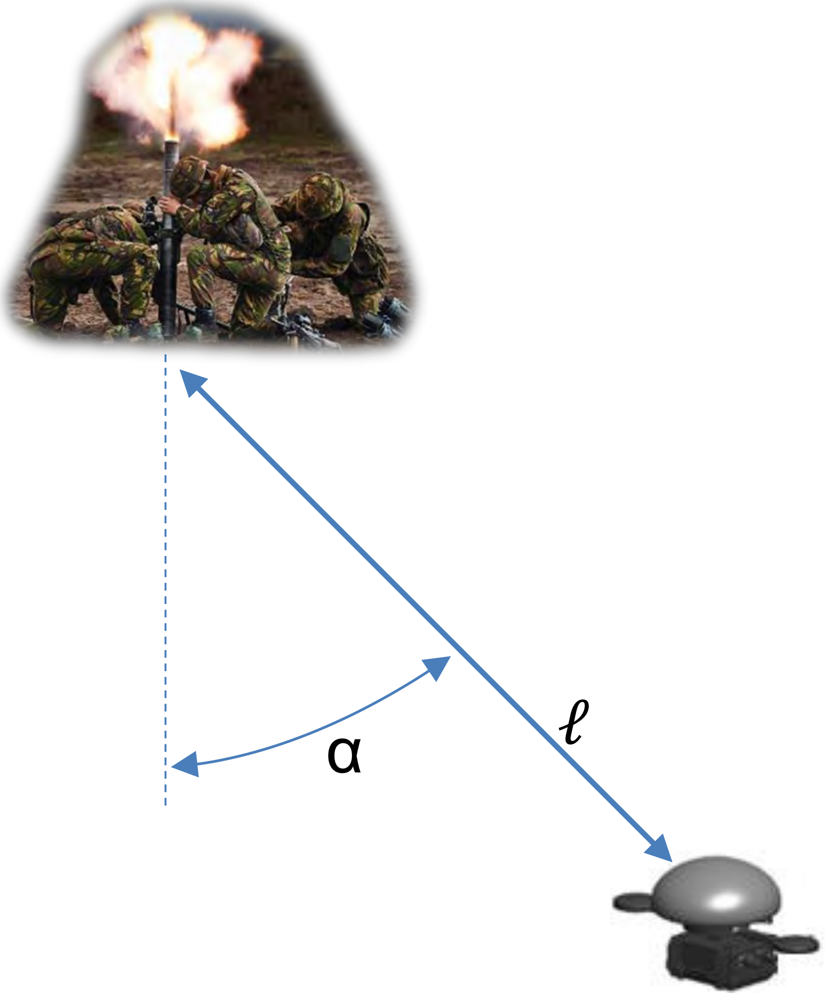


One of two way communication with BMS

	AFSIS	AVISA	
Current	HYPERION	Secure Gateway AVISA LOCALIZATIONS	Sensitivity settings
Future	Sensitivity Settings Predictable events ("own fire")		

A priori knowledge of own events

The MSRA benefits from a priori knowledge on own events as they can be used to reduce the number of events during hostilities to be analyzed significantly



Full integration with BMS

Two way communication with digitized platforms provides info on timestamp, target and estimated time of flight.

This can trigger the AMMSs near the estimated impact area to listen more carefully at the end of the time of flight

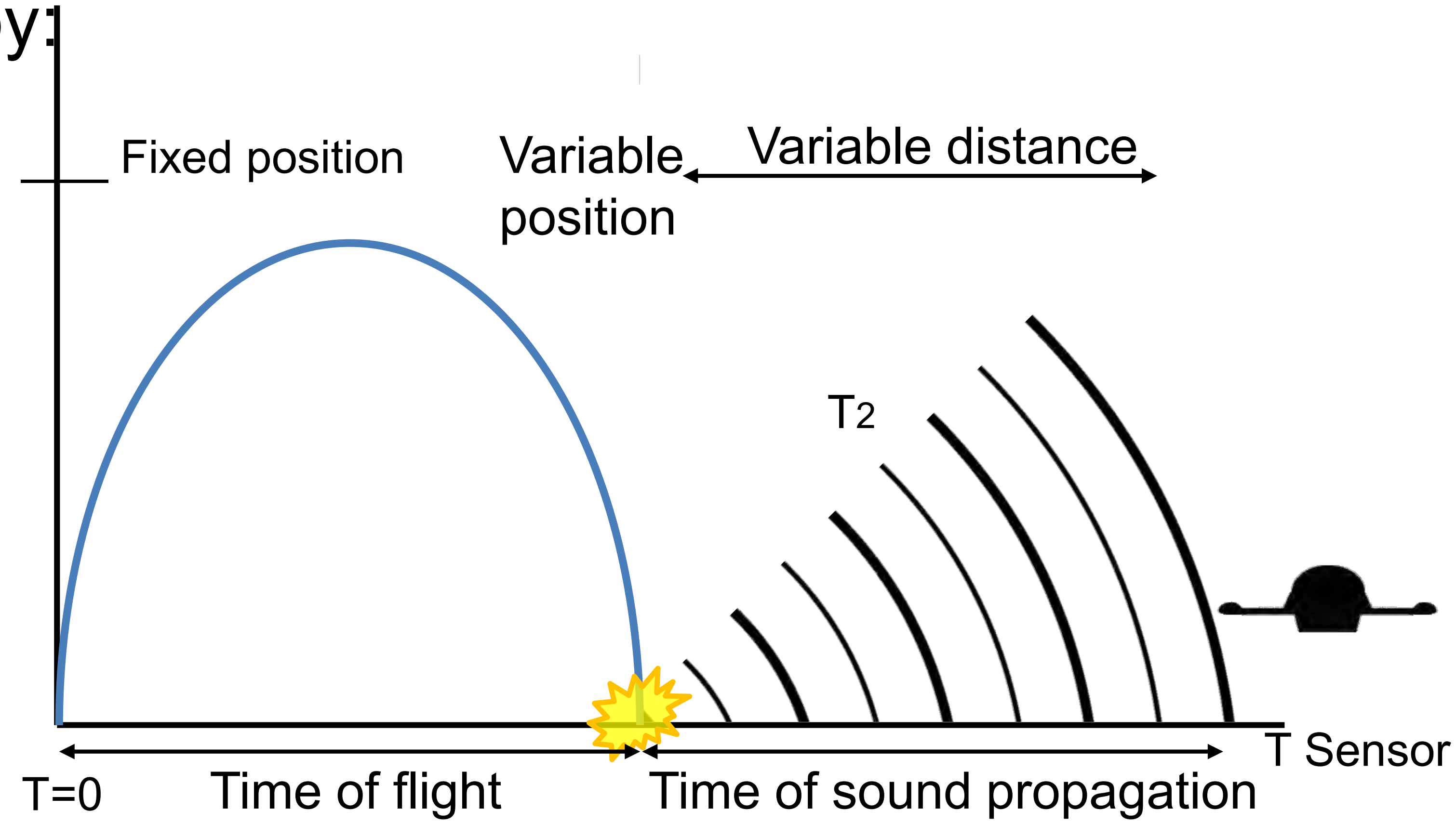
Deploy additional AMMS

Alternatively an external acoustic trigger can be used, deploying an AMMS near the gun or even on the weapon platform itself.

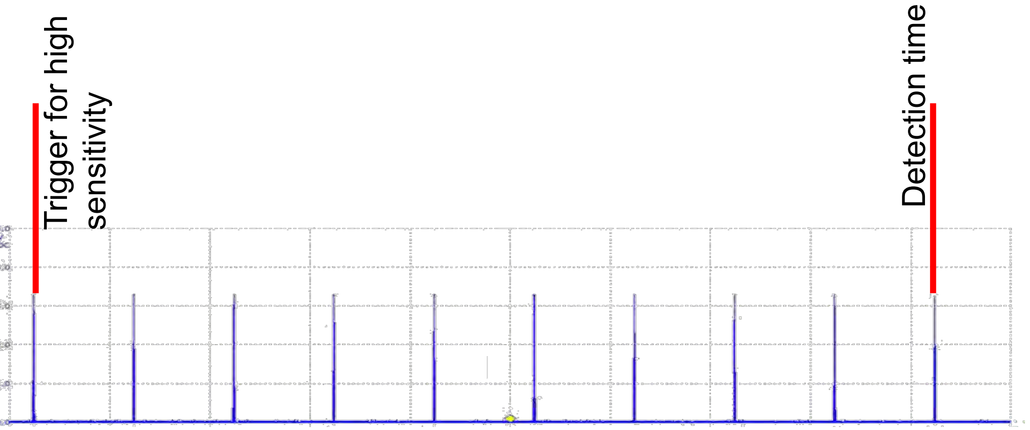
AVISA's Battlefield Management System

The time window is defined by:

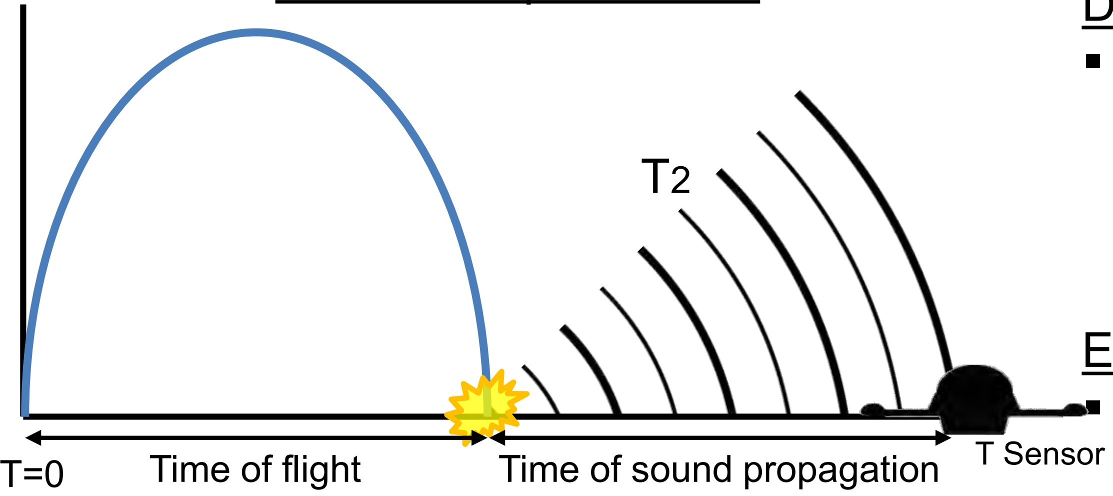
- timestamp of round fired
- the expected time of flight before exploding
- the time delay for the explosion noise to reach the sensor node



Using of PPS for multi-purposes



GPS Pulse per second



Firing table timing

The Pulse-Per-Second (PPS) can be extracted from the GPS on each AMMS sensor. Making it possible to use it for different purposes.

System Time synchronization

- The PPS can be used for an exact timestamp to synchronize the total AMMS system.

Dynamic sensitivity trigger

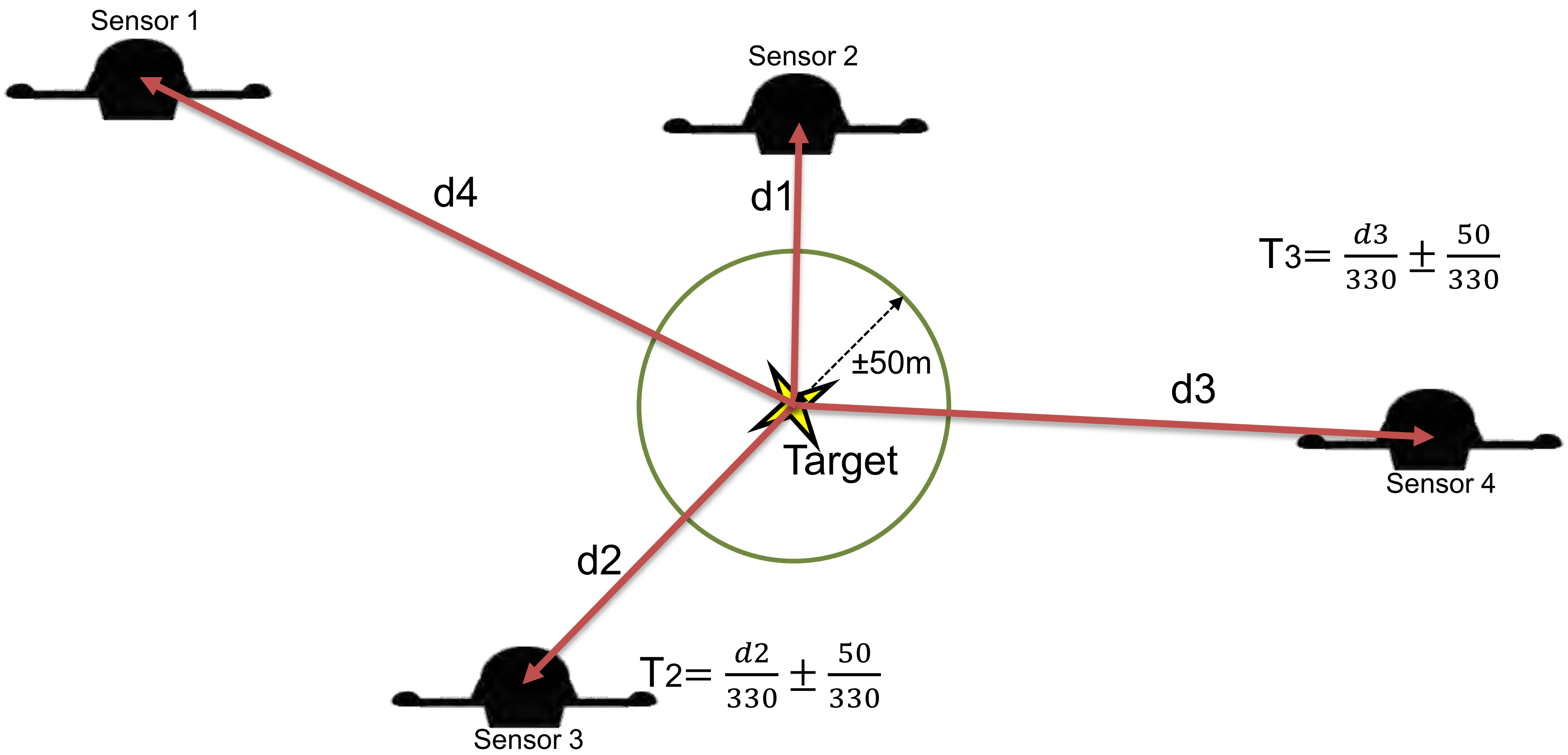
- For training purpose, one sensor can be placed close to the point of origin (POO) where the time of sound propagation is the shortest. This will trigger the whole AMMS in high sensitivity mode.

Exact time locations on fired shots

- If there is any interest in the exact timestamp of the fired shot, this can be exactly retrieved easily and direct from the AMMS C2 interface

Time delays

With target known the time delay to each AMMS sensor is known

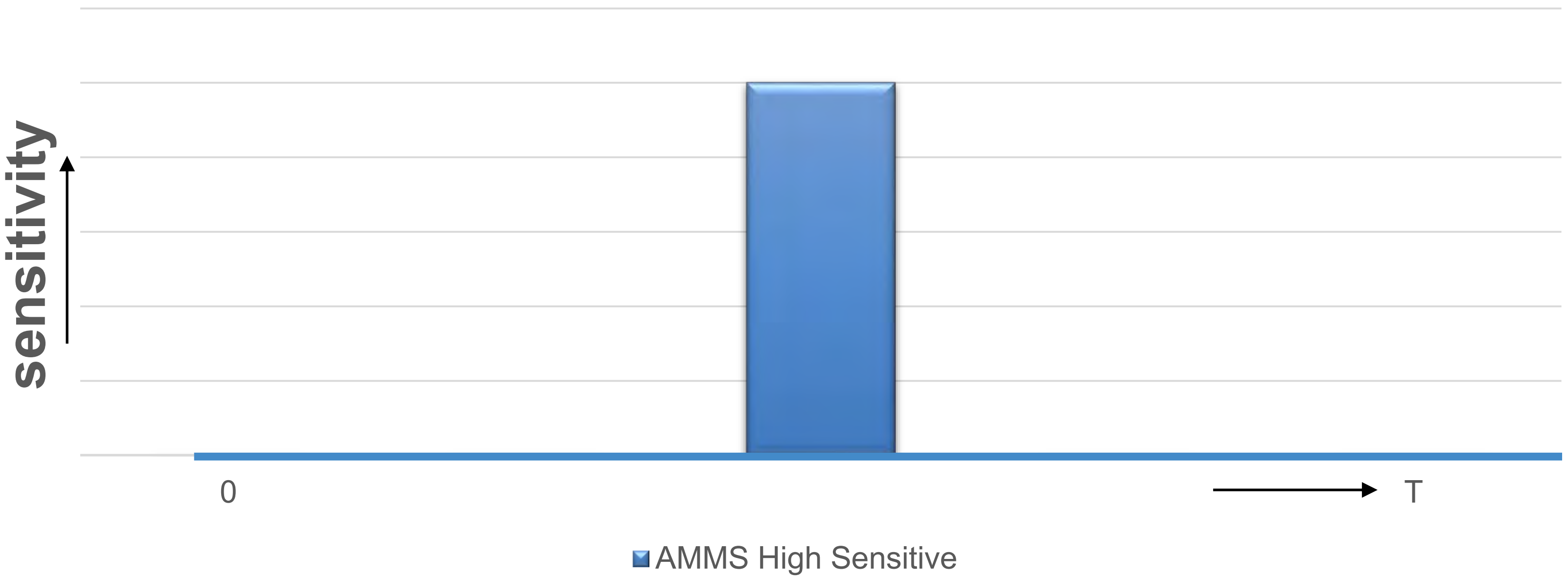


$T_3 = \frac{d3}{330} \pm \frac{50}{330}$

$T_2 = \frac{d2}{330} \pm \frac{50}{330}$

Dynamic sensitivity of sensor nodes

The individual sensor nodes obtain high sensitivity in a certain time window after a round has been fired.



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Resulting time of flight

The time of flight is determined upon firing table data (example).

Charge Zone	Muzzle Velocity [m/s]	Range [m]	Time of Flight [sec]	Terminal Velocity [m/s]	Angle of Fall [˚]	Time of arrival blast/noise [sec]
0	73	518	10.4	69.7	-46.0	1.5
1	110	1115	15.4	99.8	-47.5	3.3
2	137	1649	18.9	118.9	-48.7	4.8
3	162	2197	22.1	134.6	-50.0	6.5
4	195	2969	26.0	152.7	-51.6	8.7
5	224	3673	29.3	166.3	-53.0	10.8
6	250	4312	32.1	177.0	-54.2	12.7

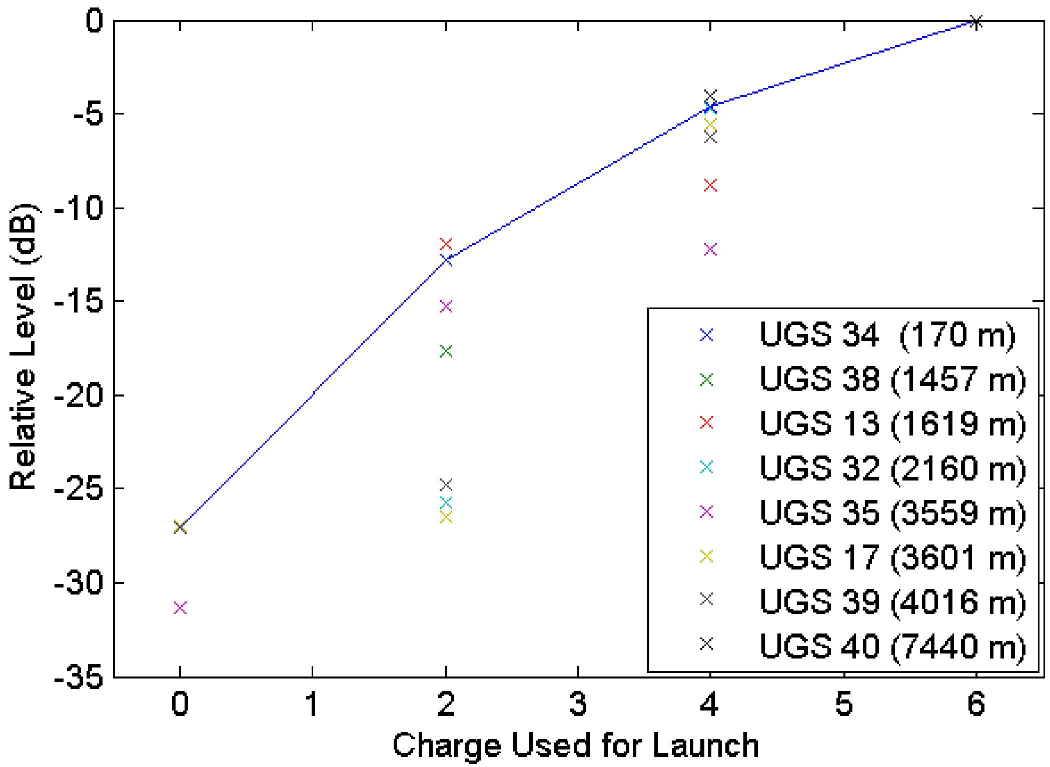
Target coordinates/ammunition data

Dynamic information needs to be considered as well:

- target coordinates
- ammunition data
  - o weapon system (60, 81, 120 ,155 mm)
  - o projectile (e.g. High Explosive, Excalibur)
  - o fuze (e.g. PD M 572)
  - o cargo charge (e.g. 4, 5M4)

Launch noise level depends upon cargo charge

Analyzing measurement data 8 sensor nodes during test Denmark



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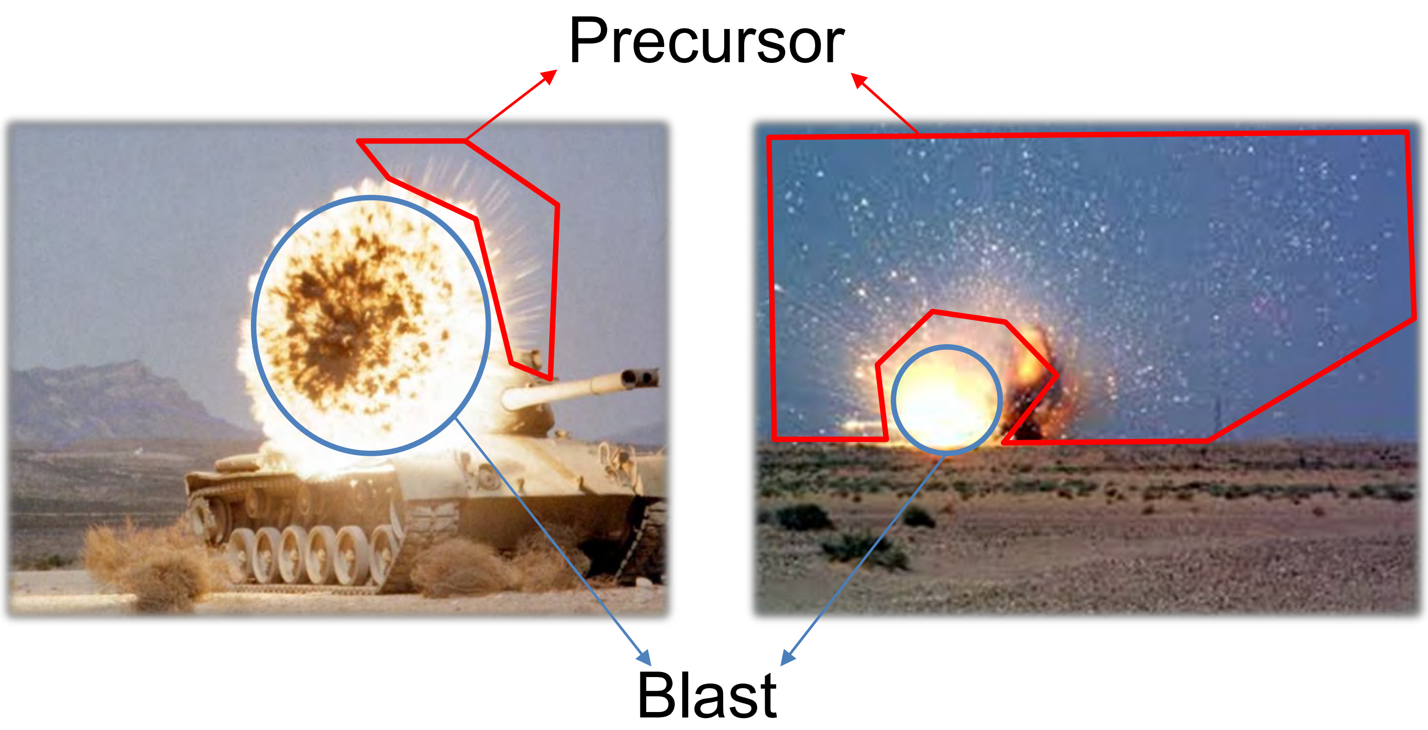
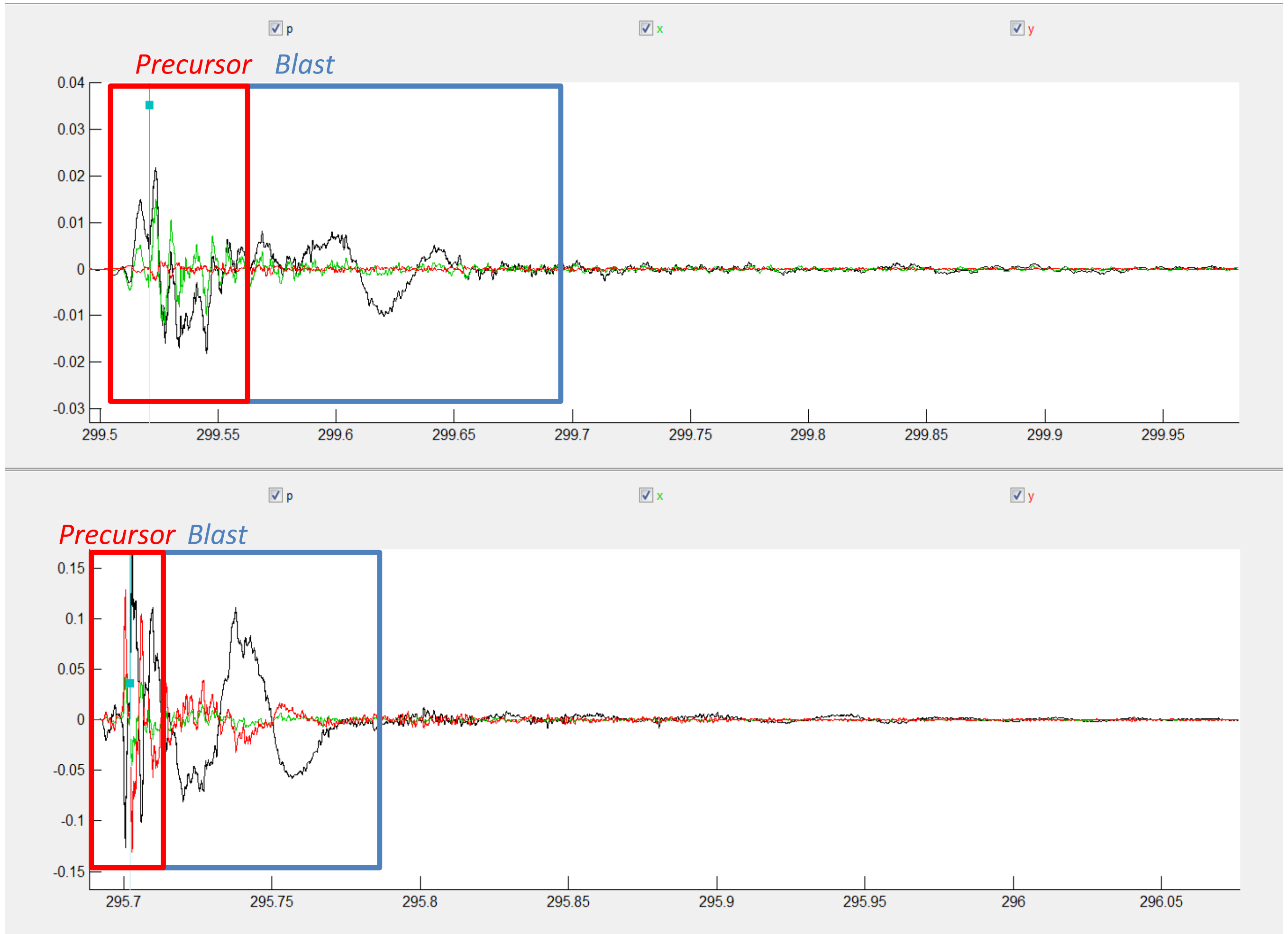
Impact signatures will differ per weapon

Pictures of actual impacts showing the *precursor* and the *blast*



Signatures of impacts



Time signals of the acoustic signature of an impact of a 122mm Howitzer recorded by AMMSs around 14 km (top) and 7 km (bottom)

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Specifications Perch & Listen AMMS

Specifications:

- total weight (incl. AMMS) around 10 kg
- arm diameter: 110 cm
- propellor diameter : 73,6 cm
- total flying time: 21 minutes
- total flight distance: 15 km
- standby: 48 hrs

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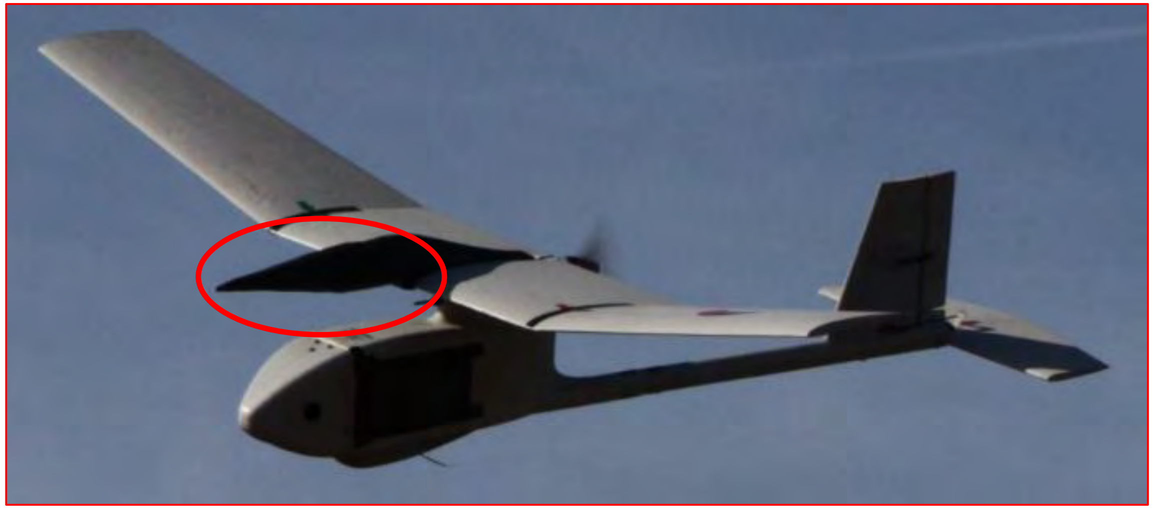
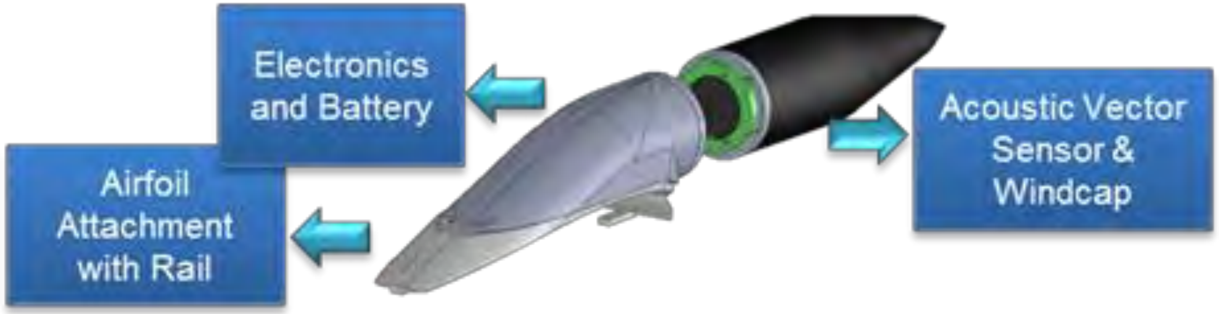
Acoustic Pointer on Dutch Raven





Acoustic Pointer

Final design in May 2016 - Standard sensor tip and housing (ITAR free)

Acoustic Pointer
passed airworthiness tests in the NL for, a.o:

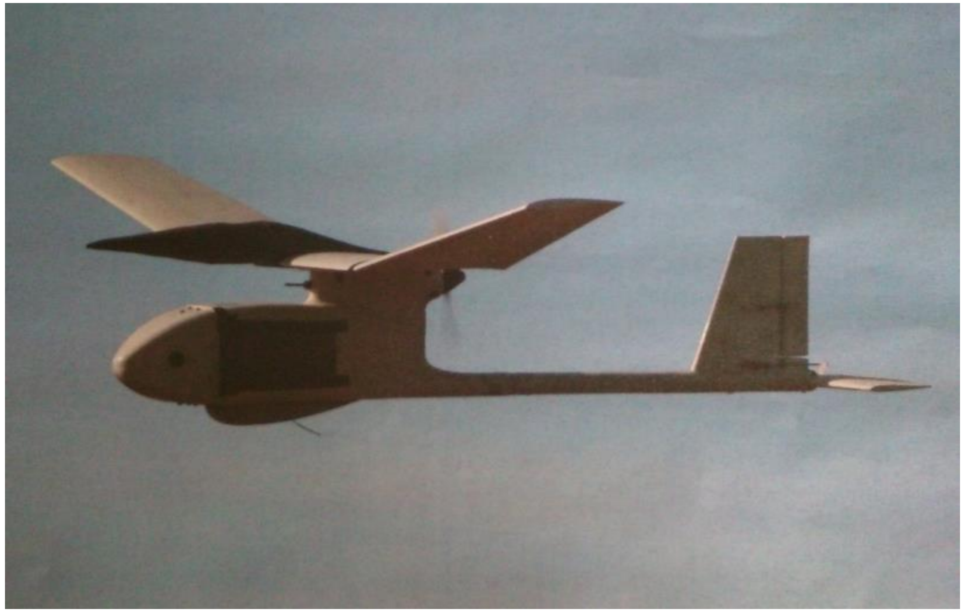
- center of gravity
- weight and balance

Electronics powering	5
VARTA battery (1200mAh)	25
Electronics (Zigbee) communication, 868 Mhz	27
Inertial sensors (VectorNav VN-200)	19
Electronics signalprocessing	18
GPS Antenna	9
3D printed housing (180x48mm)	38
3D sensor with windcap (220x48mm)	43
Clip-on mount	36 +
Total weight:	220 grams

First Acoustic Pointers to be acquired in 2017

Acoustic Pointer passed first airworthiness tests in the NL for, a.o:

- center of gravity
- weight and balance



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Prototyping of Twin Dagger on artillery drone

Two Acoustic Pointers, offering more, spatially distributed, channels, will improve substantially the performance:

- increasing the range of the detection/localization bubble
- reducing the background noise of the platform itself
- allowing the separation of various tonal sound sources at the same time

Elevated Sensor Posts were tested in Finland

Brings acoustic benefits:

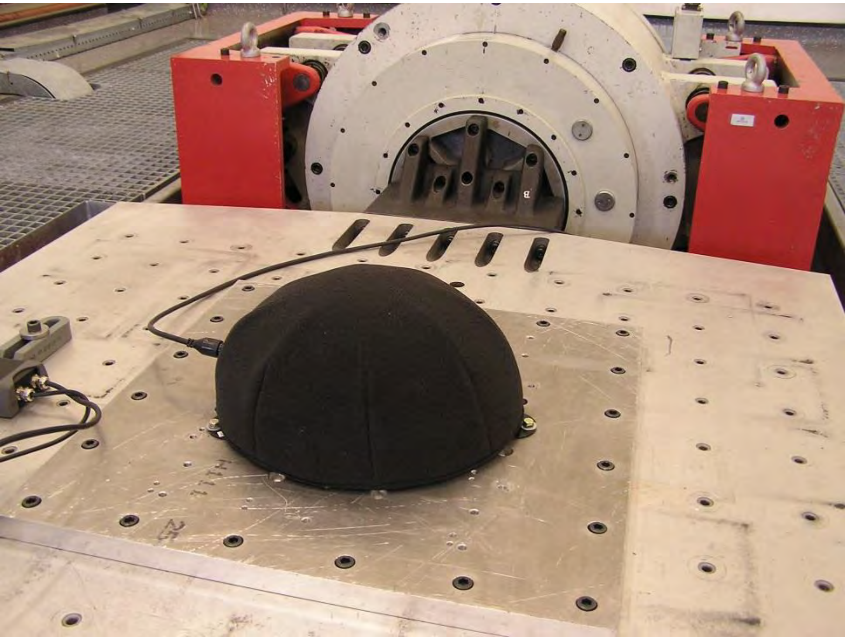
- line of sight to the acoustic event (due to better propagation)
- line of sight to the command post (larger radio distance)

AMMS on rubber tracked CV90 in Sweden

In CW 46/2015, first audio recordings were done with an AMMS on a rubber tracked CV 90, reducing the platform noise significantly. It allows the AMMS to be used:

- as part of a self defense suite
- as a sensor node in the networked array.

Current testing according to MIL-spec. standards



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Need for further testing/1

Microflown AVISA needs access to artillery ranges:

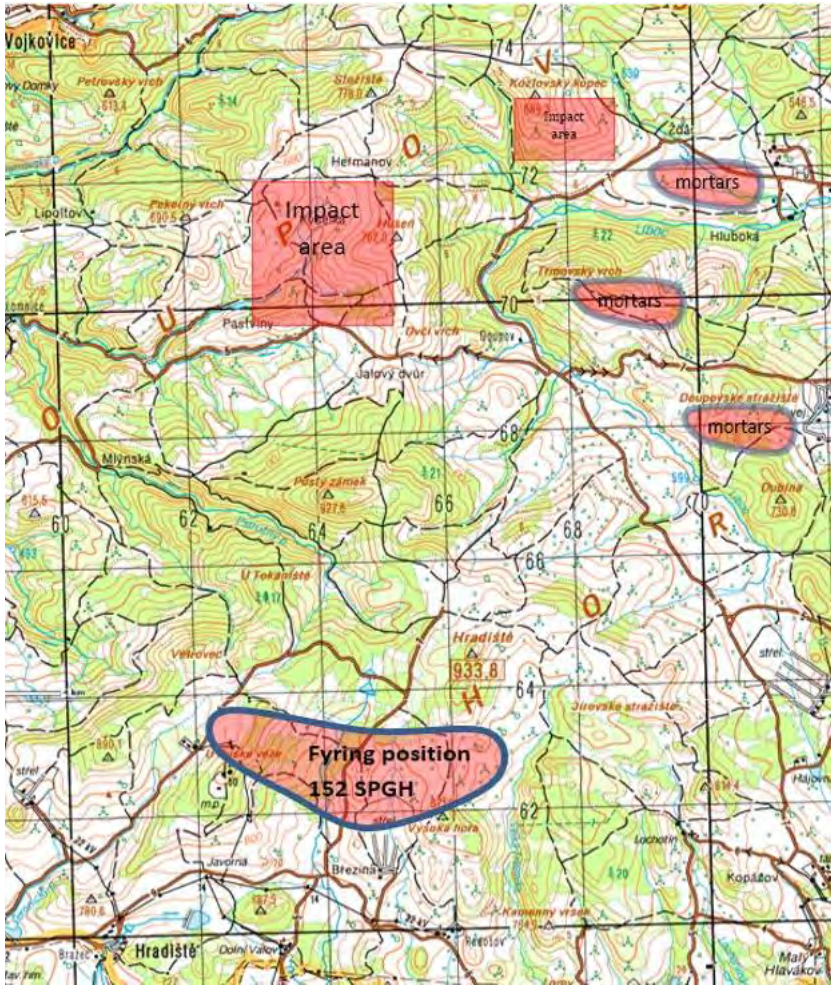
- testing long range weapons (with high cargo charge)
- allowing long distances (+- 30 km) for sound ranging
- above all maneuverable missiles (rather than ballistic ordinance)
- with various topographies (open, hilly, forest, snow)
- under different weather conditions
- various sorts of rounds:
    - NATO rounds, eg Excalibur (impacts and launches)
    - Russian make rounds

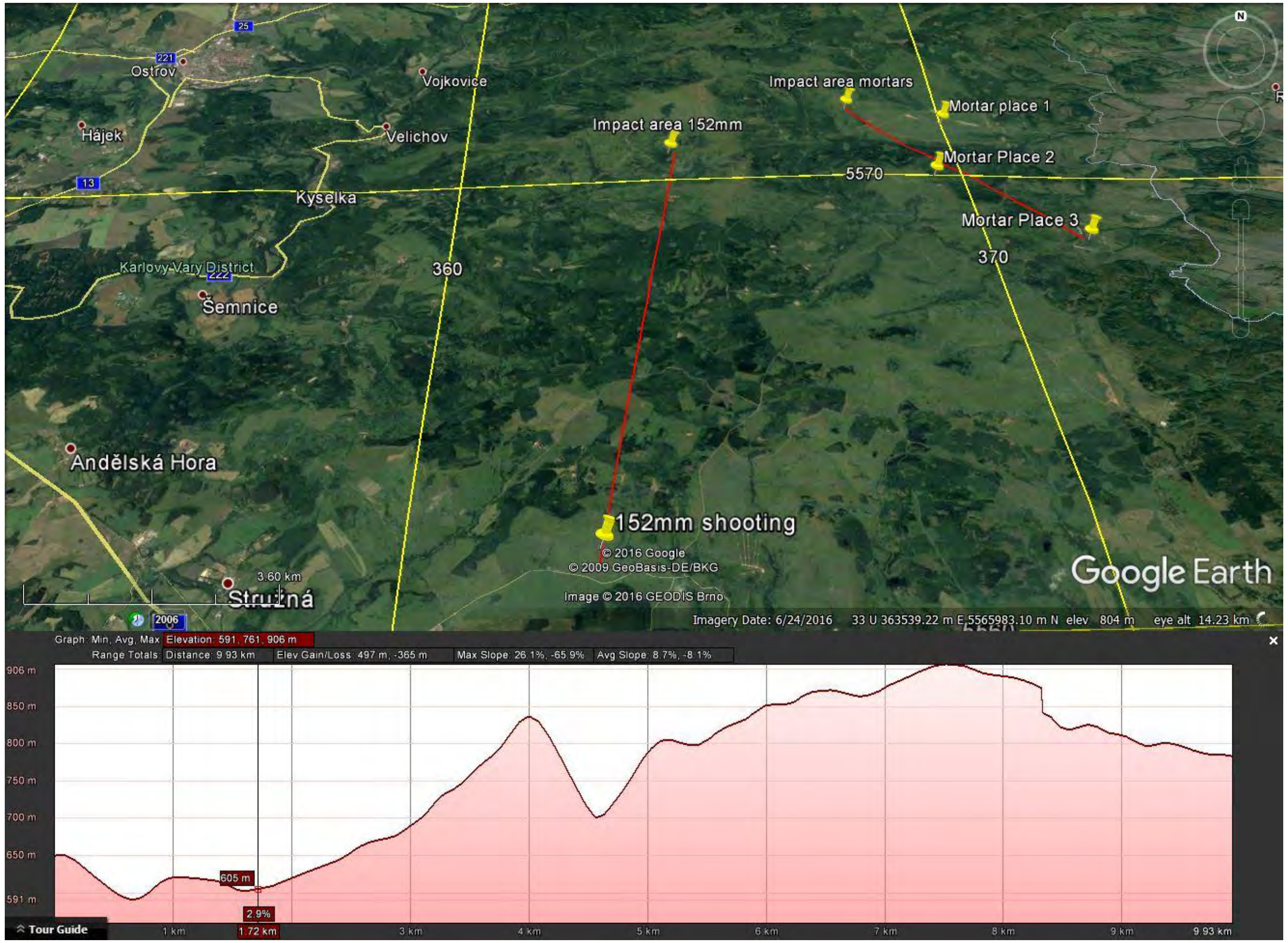
Need for further testing/2

Microflown AVISA is further in need of opportunities to test:

- Acoustic Pointers on local Raven drones
- AMMS on tracked vehicles (like CV90)
- AMMS against MILSPECs

Next exercise: April 2017, CZ, Hradiste





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