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A hybrid active-passive radar system concept for extending target detection range

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9th NATO Military Sensing Symposium
31st May 2017
Quebec City, Canada

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Introduction

- **ISR Concepts and Integration (ICI) Group:**
  - 5 Defence Scientists
  - 1 Computer Scientist
- **Mission (short version):**
  - develop and evaluate innovative and integrated ISR concepts in both the technical and human factors domains through a multi-disciplinary approach…
- **Activities:**
  - Development of analysis tools
  - Development of System-of-Systems (SoS) concepts to provide advice to military sponsors:
    - Includes examination of SoS surveillance concepts that could be used to extend the range of current radar assets, or as part of a Point Defence system (e.g. this study).

Hybrid Passive-Active Concept

- **Study Objective(s)**:
  - Initial study to examine the feasibility of using a network of (lower-cost?) passive RF sensors to extend the surveillance range of an active Primary Surveillance Radar (PSR) system.
  - **Two Concepts examined:**
    - Forward perimeter zone with limited tracking capability; and
    - Forward trip-wire
  - **Assumptions:**
    - The PSR is based on a the concept of a new Multifunction/Multimission Phased Array Radar (MPAR) system currently being developed in the U.S.; and
    - The passive multi-static receiver network will be based on the Time-Difference-Of-Arrival (TDOA) hyperbolic location algorithm.

MPAR Description

- **MPAR: Multifunction/Multimission Phased Array Radar**
  - **Objectives:**
    - To replace roughly 500 aging ATC and weather radars in the U.S. with ~330 MPAR
    - To be able to simultaneously perform aircraft tracking, wind profiling, and weather surveillance
  - **Variants:**
    - S-Band version being developed by US consortium (version our study is based on)
      - National Weather Radar Testbed (NWRT) at the NOAA's National Severe Storm Laboratory (NSSL)
      - Initial development testbed based on array face from (S-Band) US Navy SPY-1 (AEGIS) radar.
    - X-Band version being developed by Raytheon
  - **Advantages**
    - Solid-state so will have long MTBF (reduced life-cycle costs)
    - S-Band version leverages cell-phone tech & economy of scale to reduce risk/cost
    - Scalable
    - etc.

S-Band MPAR estimated parameters

Radar frequency, f_R	**3 GHz**
Peak power, P_T	158 kW
Antenna gain, G	46 dB (39800)
Pulse length, τ_p	1 µs
Pulse duty cycle, Ω_C	0.2%
Receiver filter bandwidth, β_r	1.1 MHz
Receiver noise density, η	-140 dBW/MHz

Pulse repetition frequency, PRF	**2 kHz**
Maximum unambiguous detection range, R_u	75 km
Radar beam width, θ_B	~1 degree
Azimuth field-of-view, FOV_{az}	100 degrees

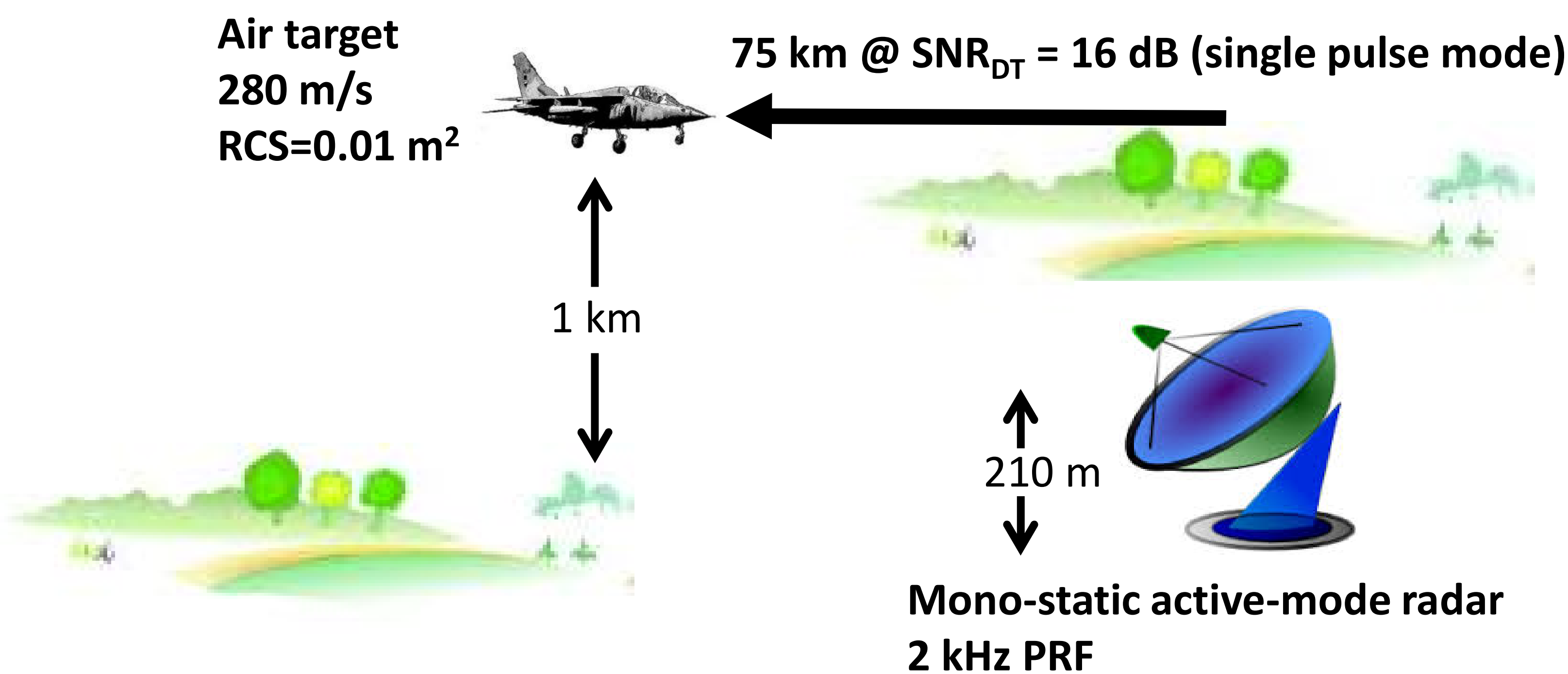
From https://www.ll.mit.edu/mission/aviation/publications/publication-files/atc-reports/Cho_2012_ATC-395_WW-24378.pdf

Stand-alone active radar (MPAR)

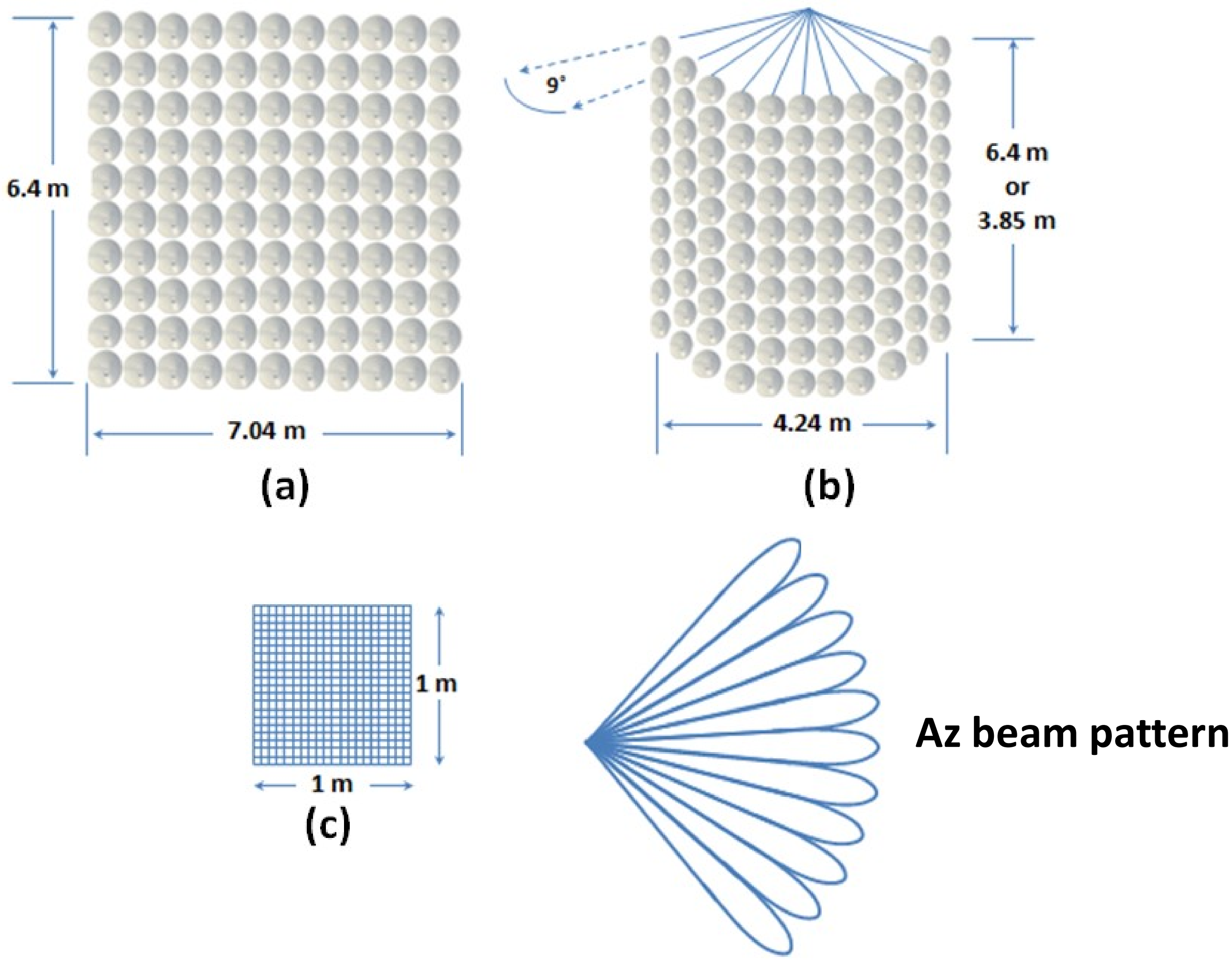
$$SNR = \frac{P_T G^2 \sigma \lambda^2}{(4\pi)^3 R_u^4 \eta \beta_r L} = 16dB$$

For the given radar parameters the 0.01 m^2 target is near the detection threshold for single pulse detections at 75 km

Single-pulse active radar mode for detecting and tracking small air targets



Passive receiver array options


6.4 m
7.04 m
(a)
9°
6.4 m
or
3.85 m
4.24 m
(b)
1 m
1 m
(c)
Az beam pattern

Extended detection and tracking range

$$SNR_{\min} = \frac{SNR_{DT}}{N_P} = 2$$

$N_P = 20$

$$R_{t2r} = \left(\frac{P_T G G_r \sigma \lambda^2}{(4\pi)^3 (RLOS)^2 \eta_r \beta\, SNR_{\min} L_{sys}} \right)^{1/2} = 13.2\, km$$

$RLOS = 190$ km

$\sigma = 0.01$ m^2

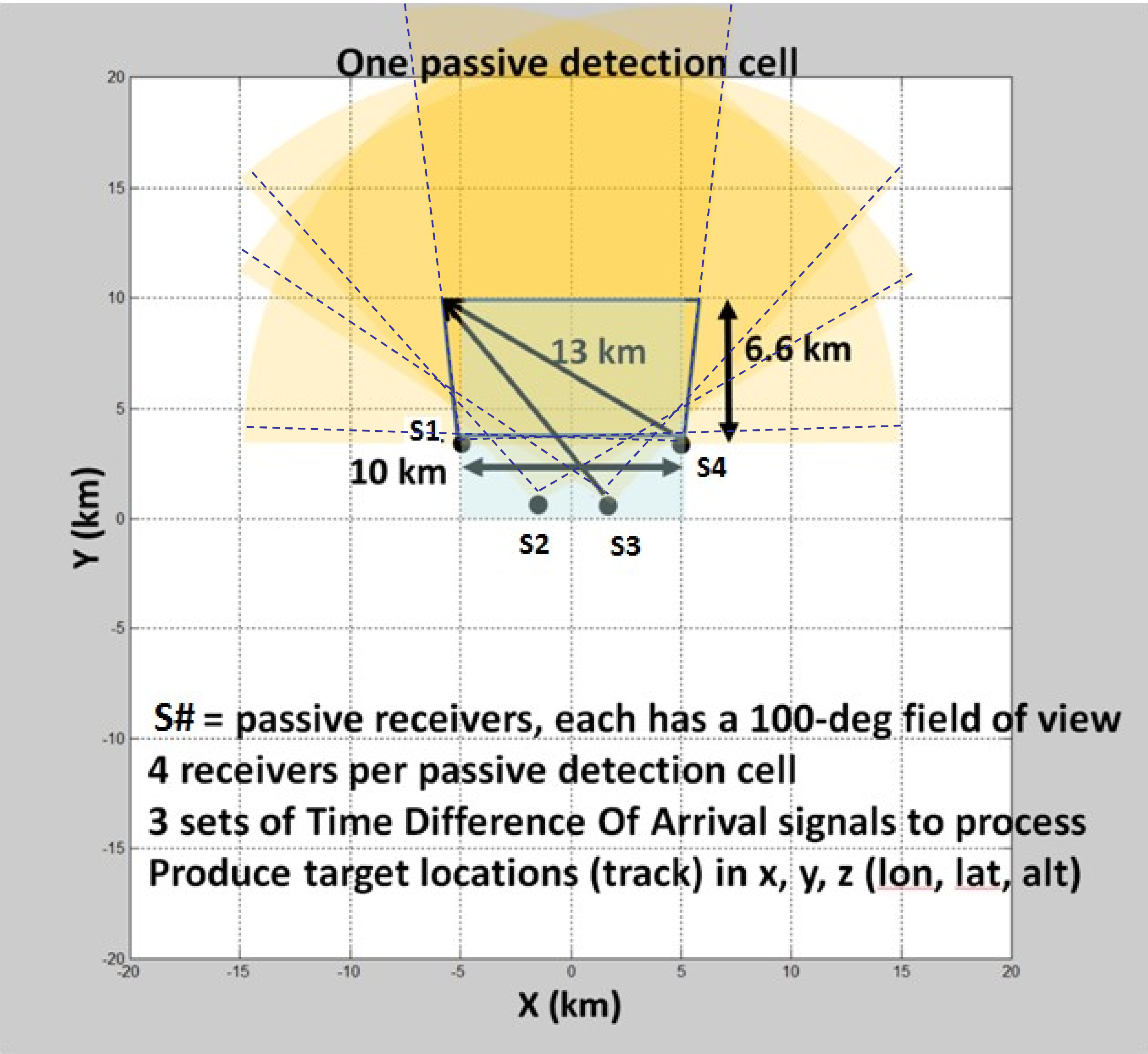
$\eta_r = kT = 5 \times 10^{-15}$ W/Mhz

$k = 1.38\text{x}10^{-23}$ W/K-Hz

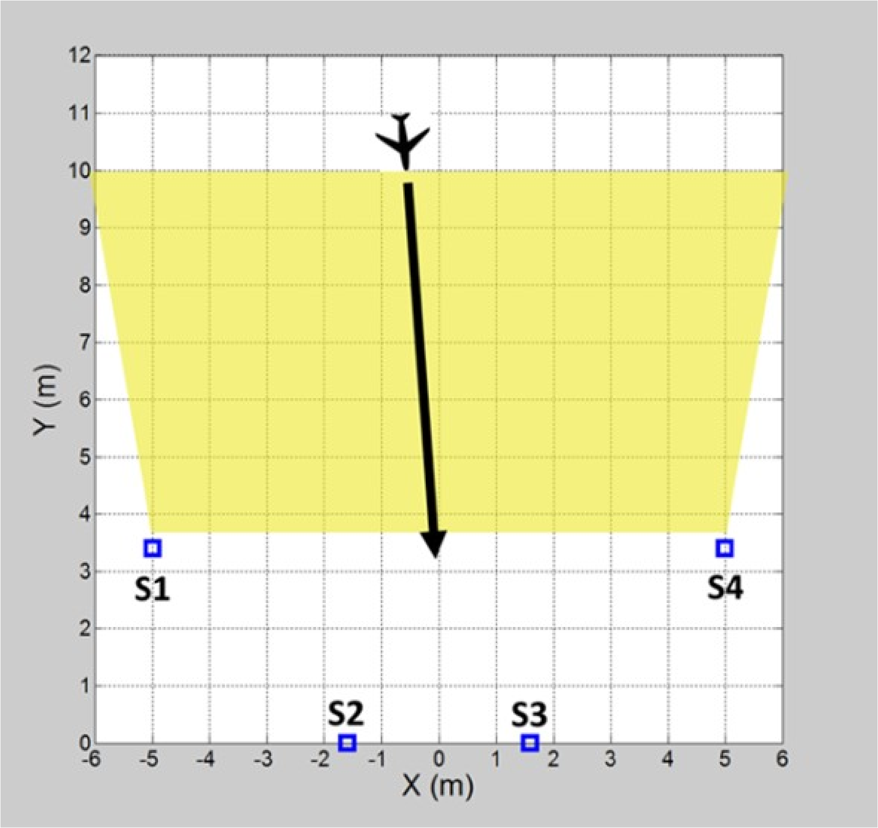
$T = 344$ °K

$G_r = 400$

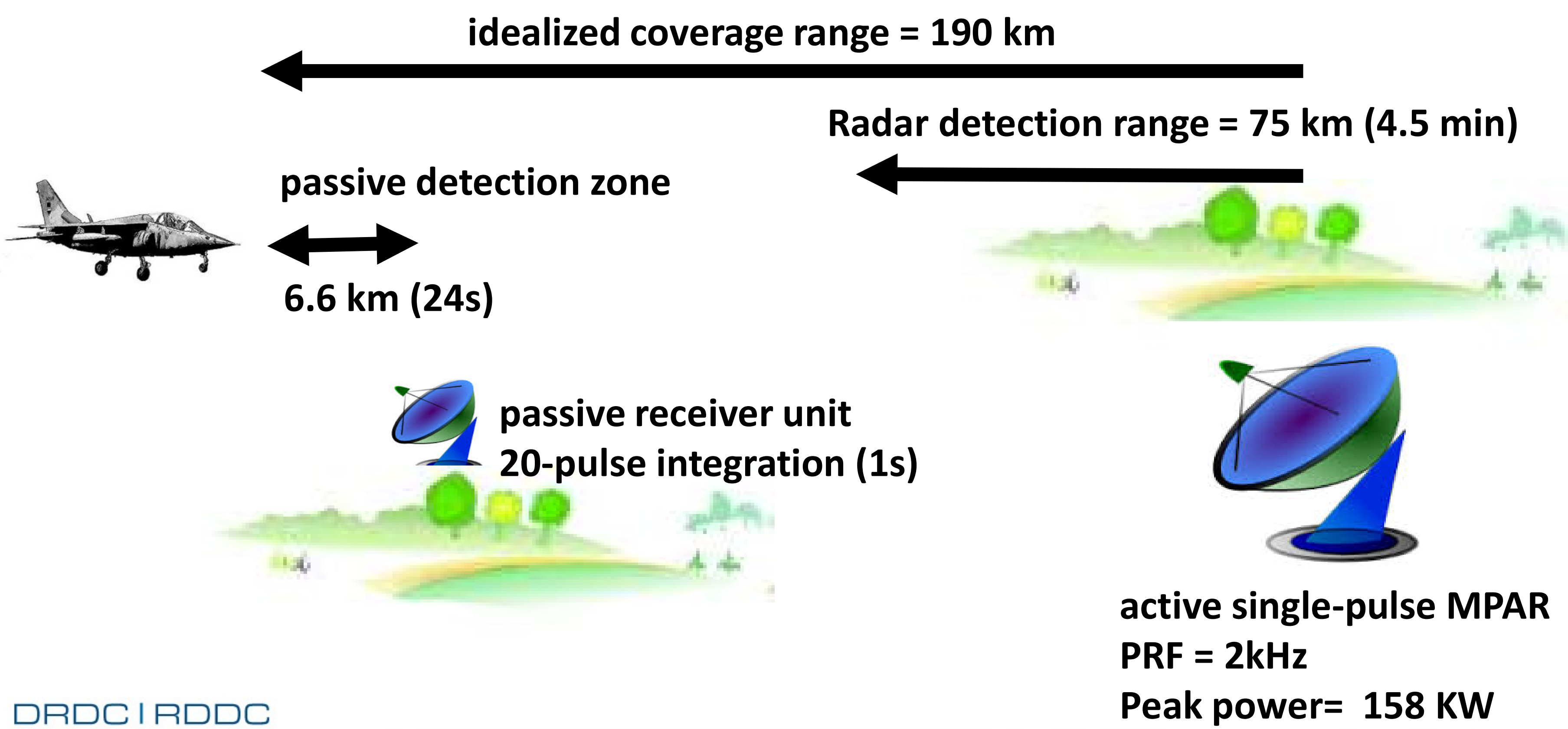
$L_{sys} = 2$ (3 dB)

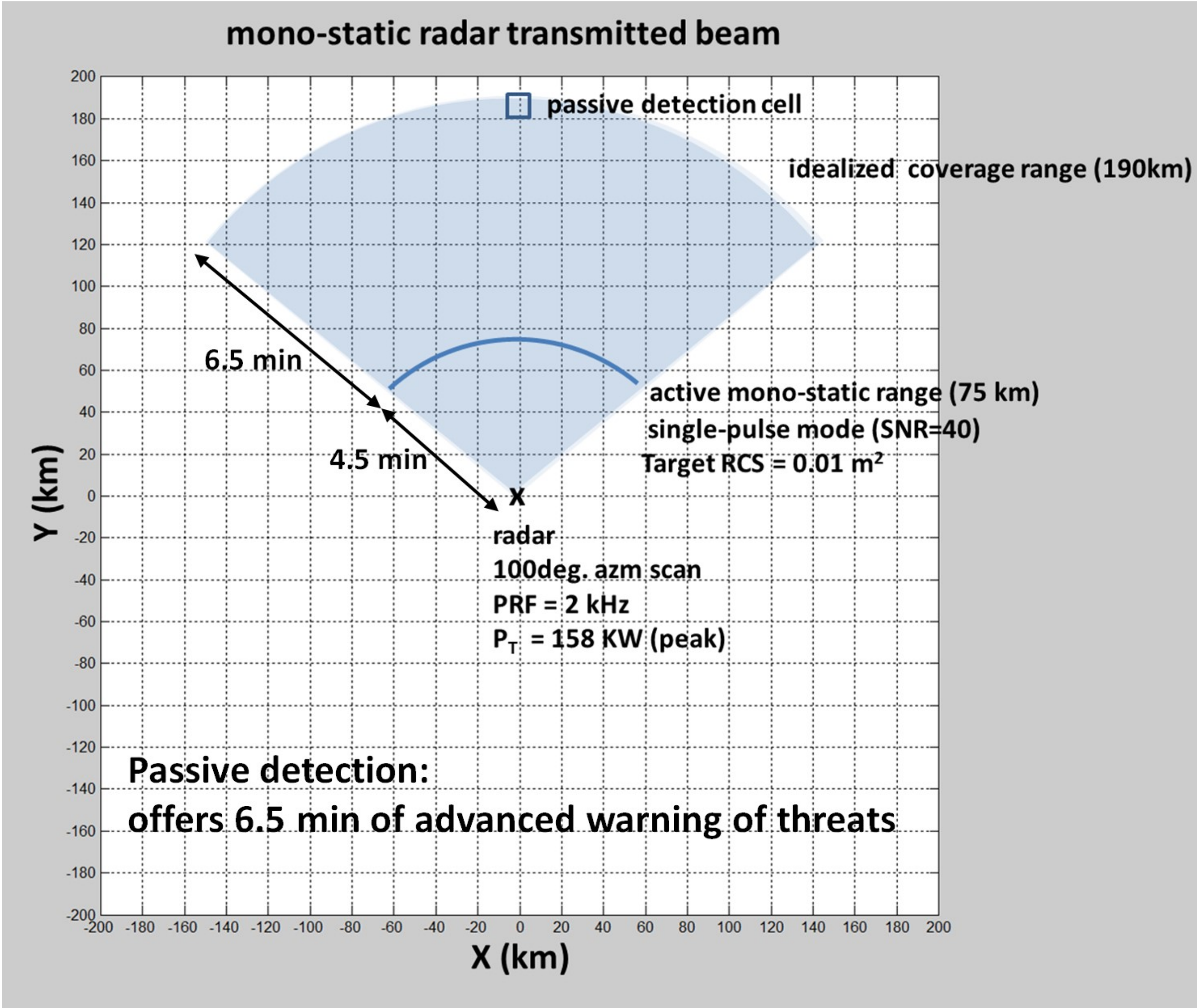

One passive detection cell
13 km
6.6 km
S1
S4
10 km
S2
S3
S# = passive receivers, each has a 100-deg field of view
4 receivers per passive detection cell
3 sets of Time Difference Of Arrival signals to process
Produce target locations (track) in x, y, z (lon, lat, alt)
Y (km)
X (km)
20
15
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10
15
20

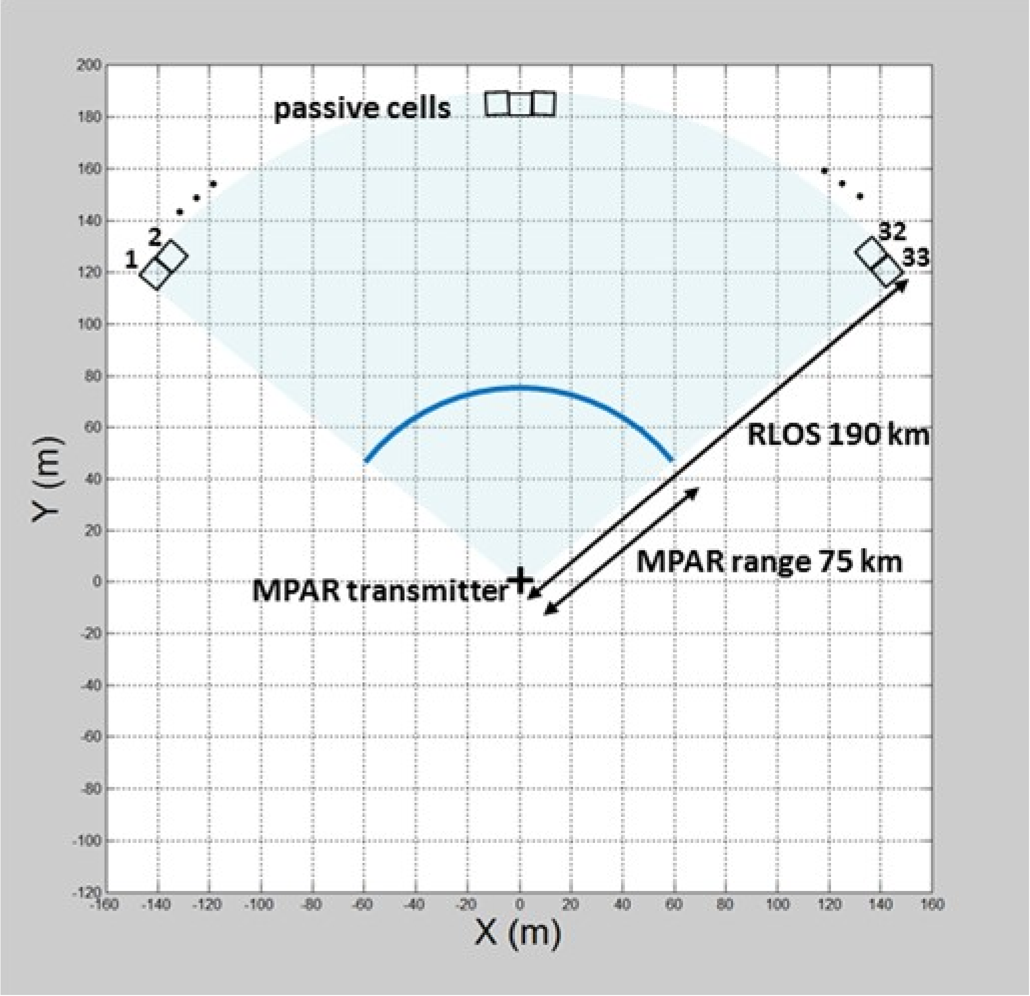
Extended range detection and tracking zone

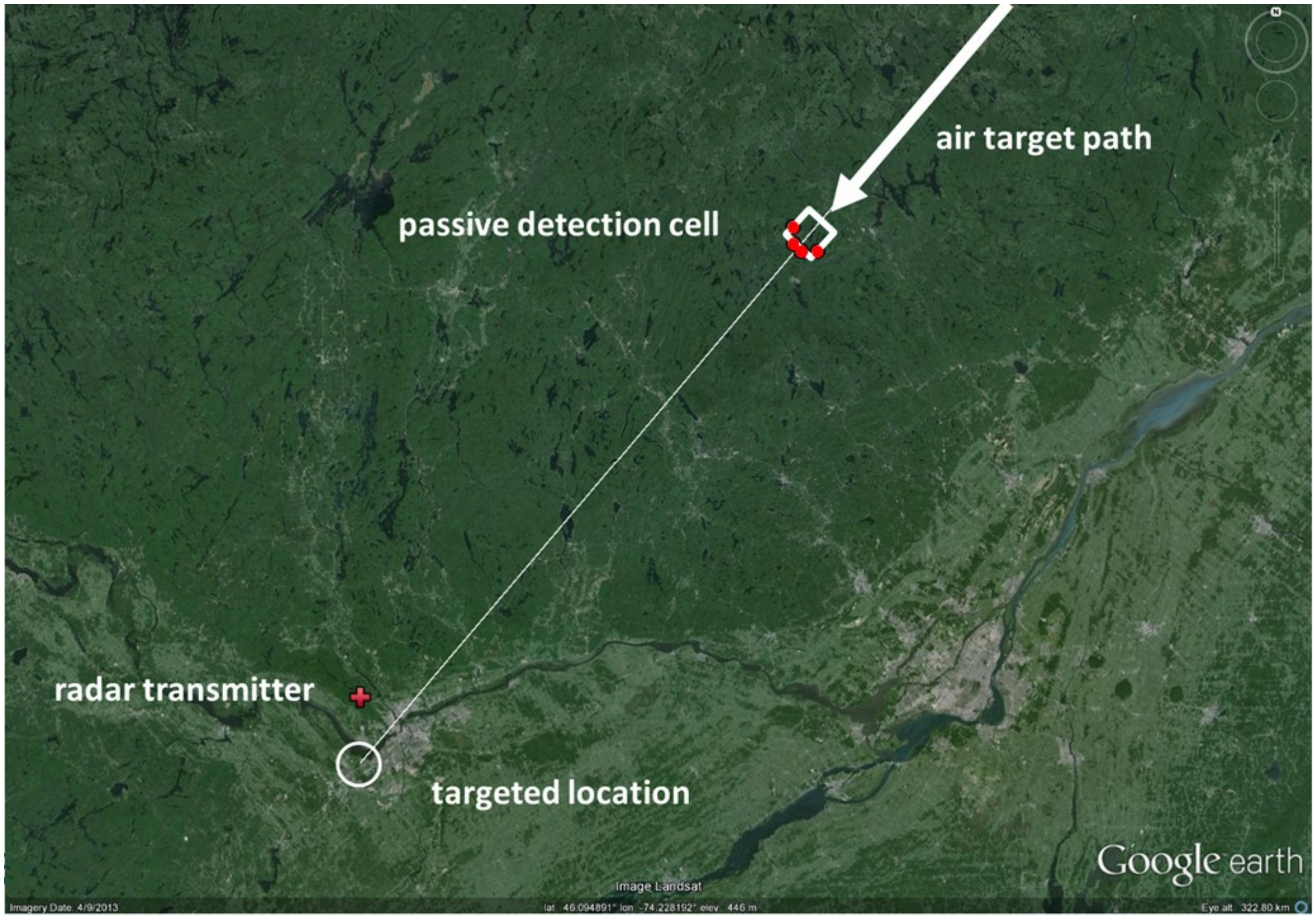


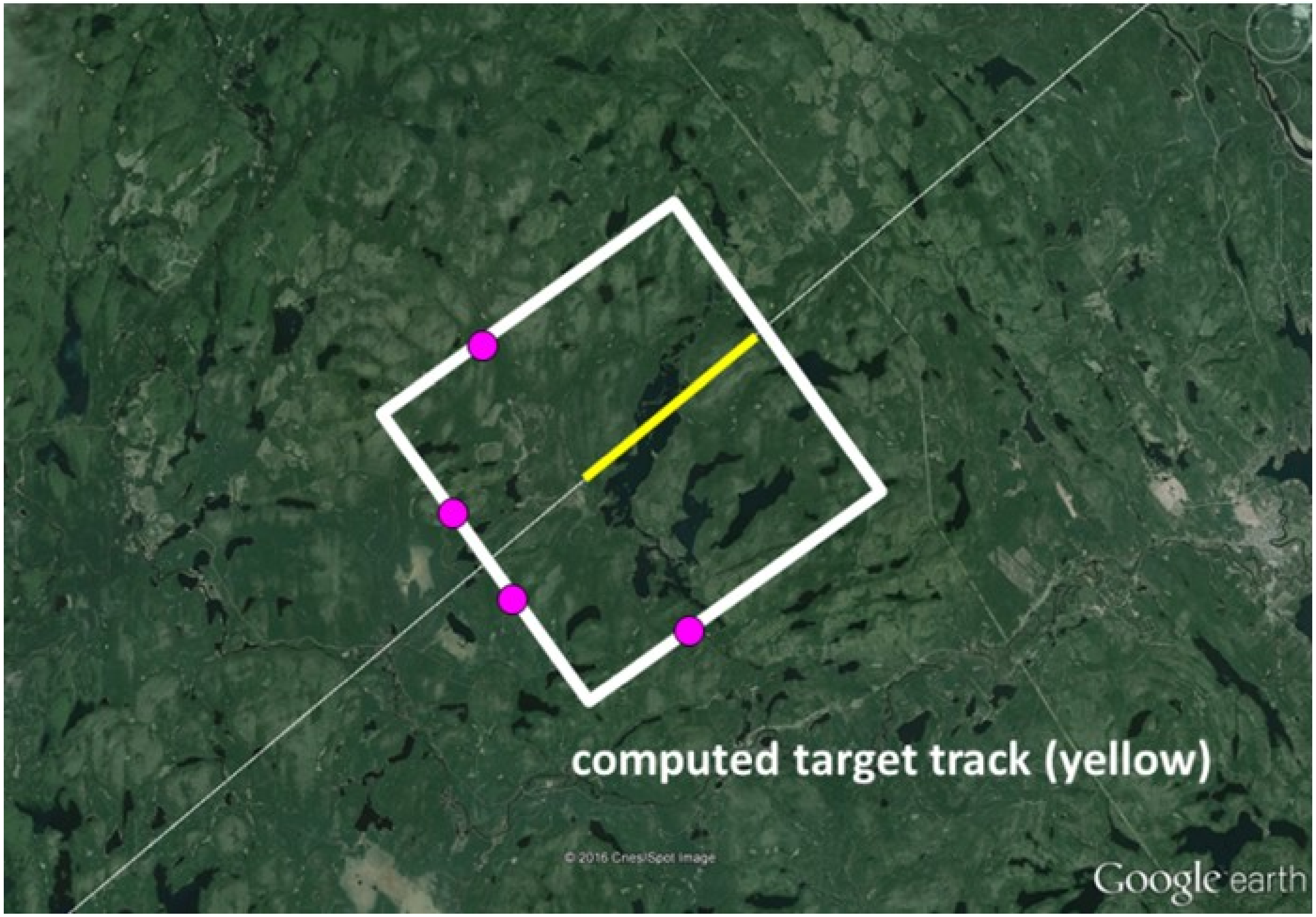
Hybrid active (single-pulse) – passive (multi-pulse) MPAR

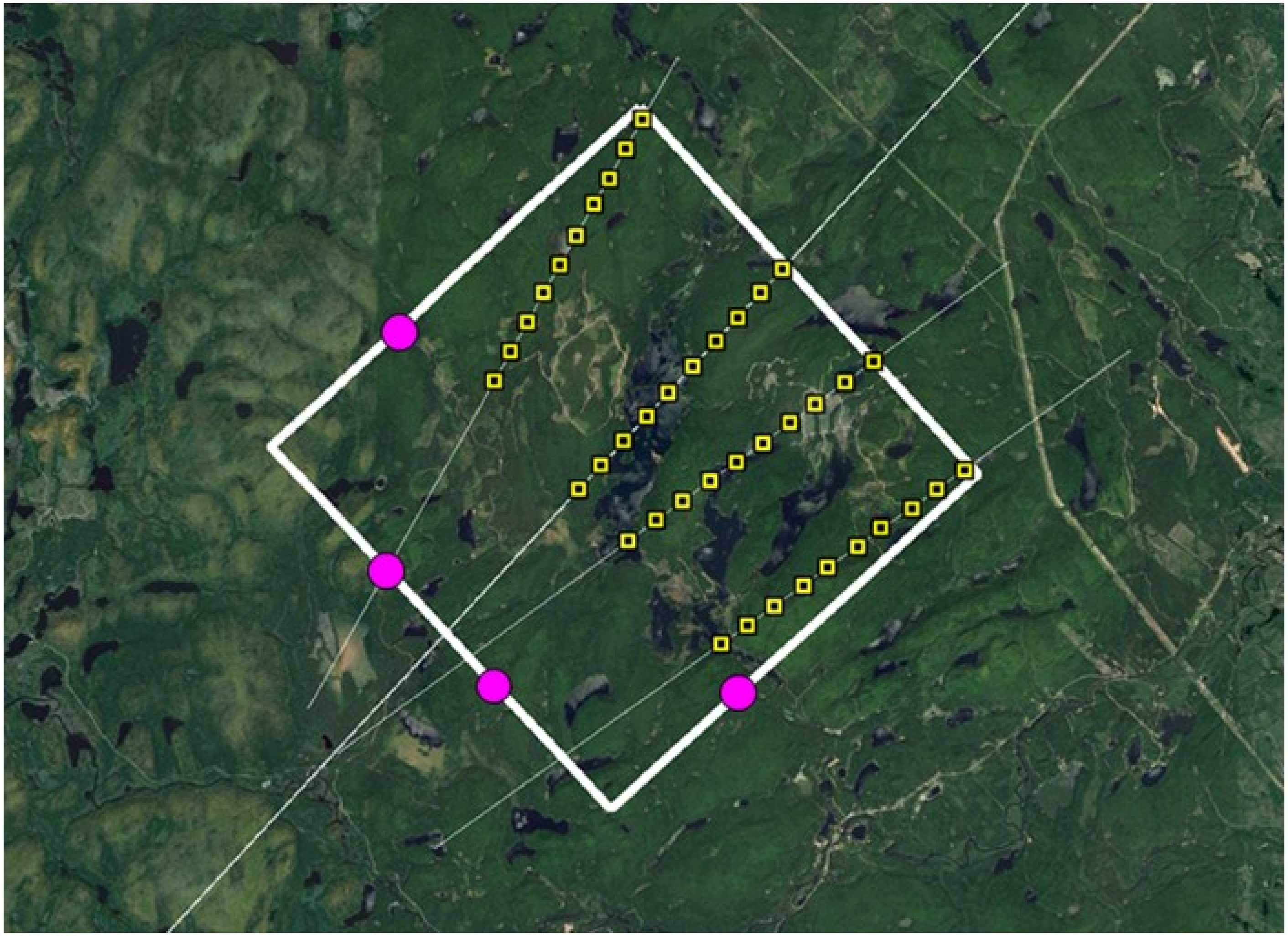



mono-static radar transmitted beam
passive detection cell
idealized coverage range (190km)
6.5 min
4.5 min
active mono-static range (75 km)
single-pulse mode (SNR=40)
Target RCS = 0.01 m²
X
radar
100deg. azm scan
PRF = 2 kHz
P_T = 158 KW (peak)
Passive detection:
offers 6.5 min of advanced warning of threats
Y (km)
X (km)


passive cells
1
2
32
33
RLOS 190 km
MPAR range 75 km
MPAR transmitter
Y (m)
X (m)


air target path
passive detection cell
radar transmitter
targeted location
Google earth
Image Landsat
Imagery Date 4/9/2013


computed target track (yellow)
© 2016 Cnes/Spot Image
Google earth

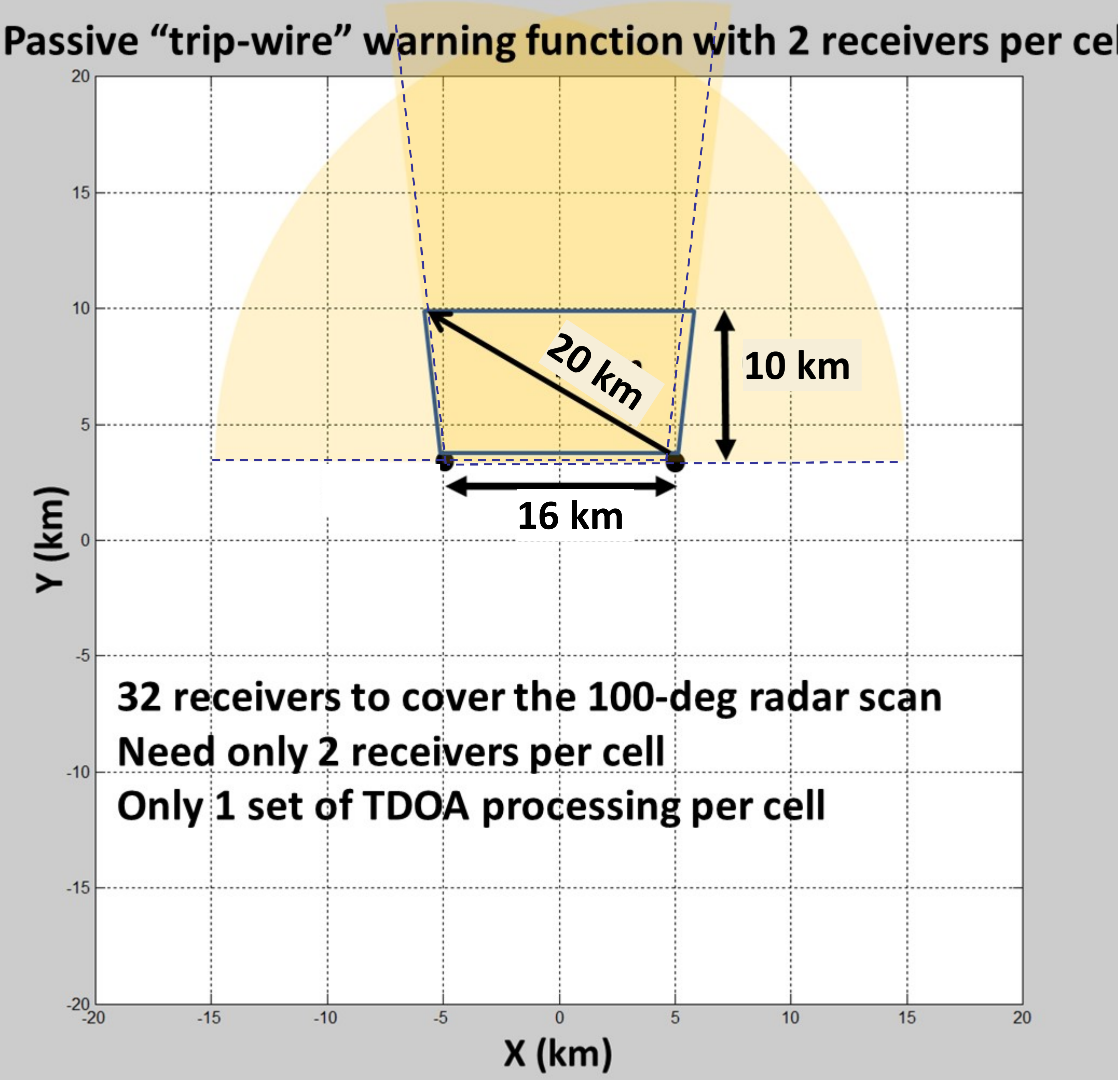


“Trip-wire” concept

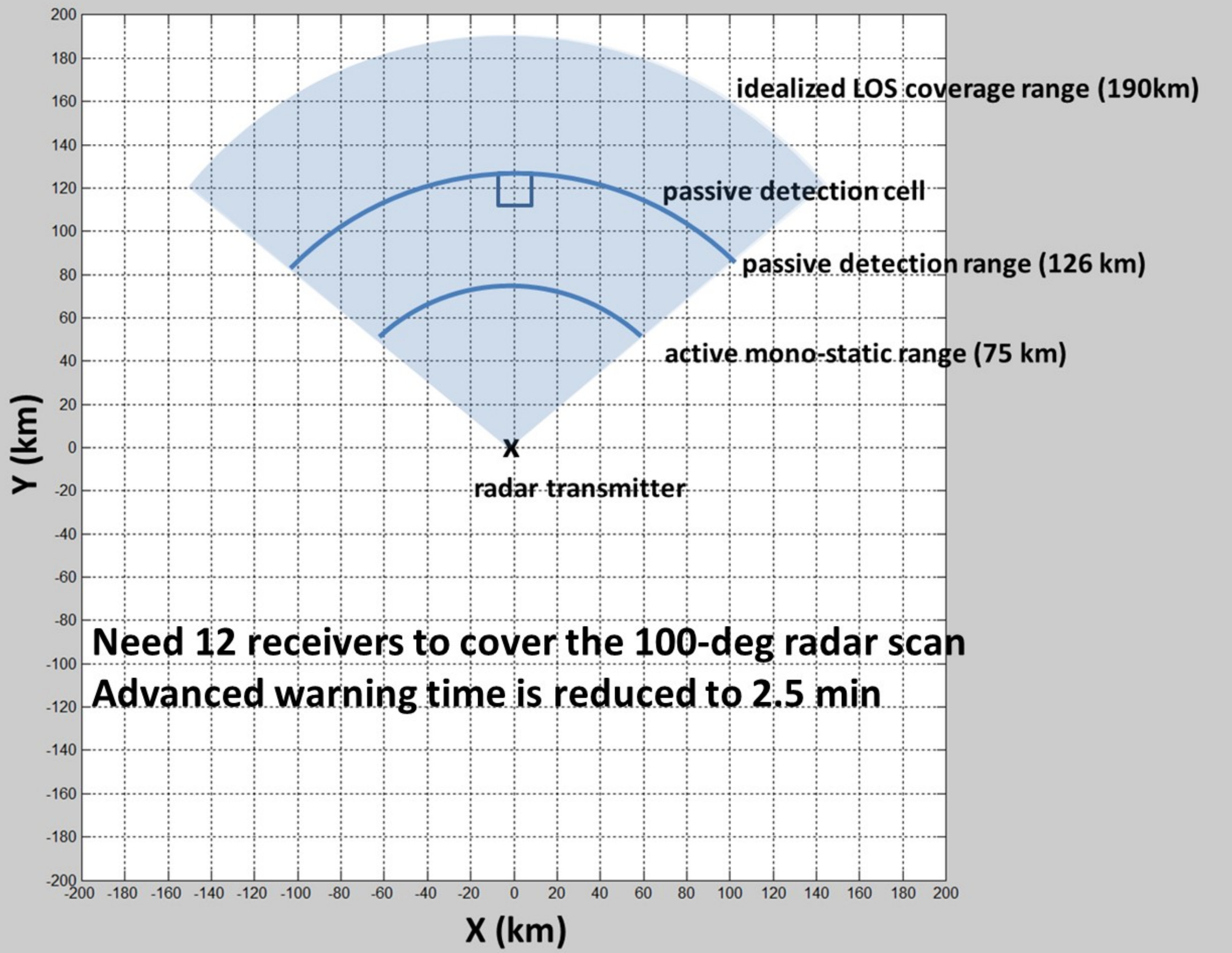
$$R_{t2r} = \left(\frac{P_T G G_r \sigma \lambda^2}{(4\pi)^3 (RLOS)^2 \eta_r \beta\, SNR_{\min} L_{sys}} \right)^{1/2} = 20\ km$$

$RLOS$=126 km

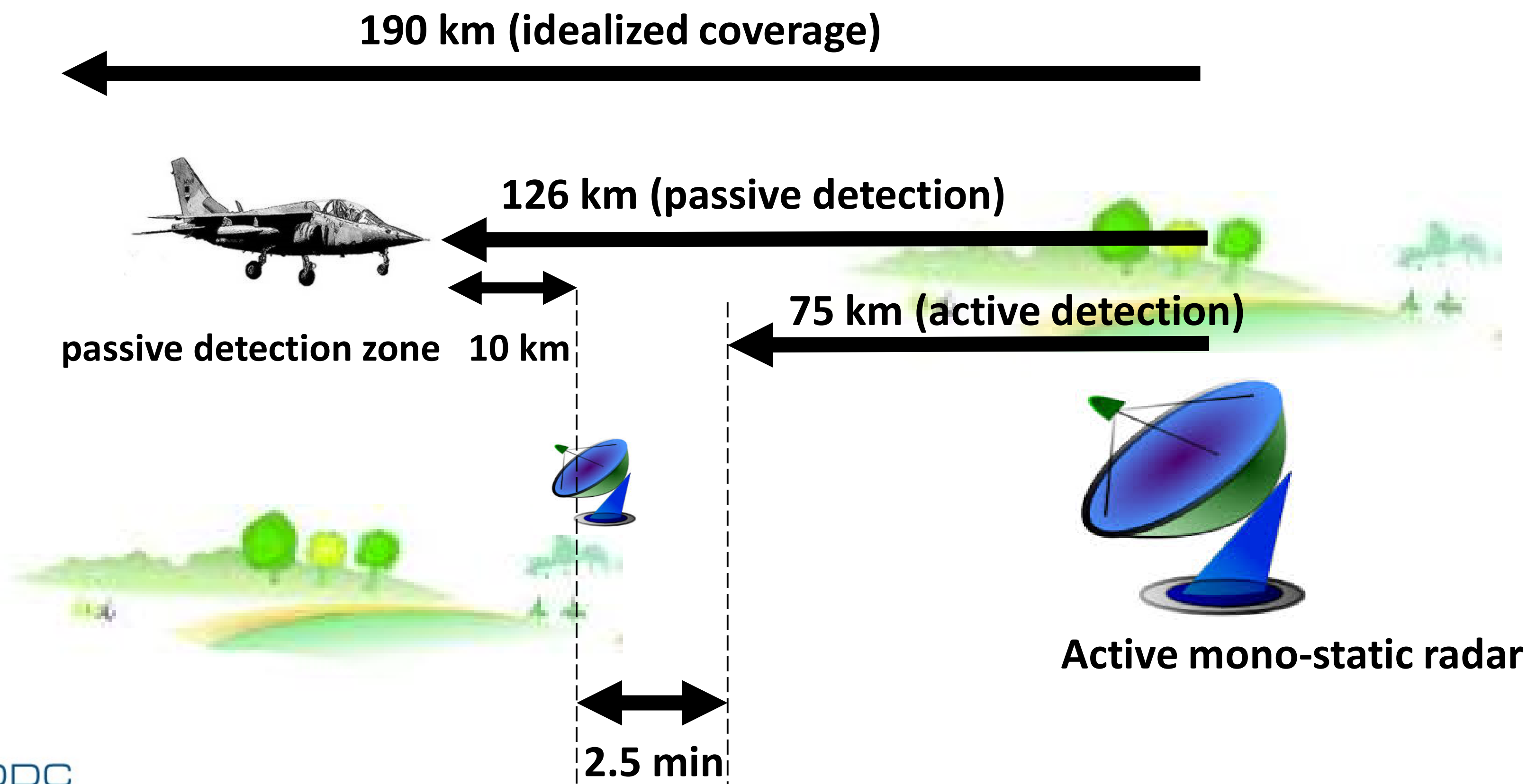
Passive "trip-wire" warning function with 2 receivers per cell

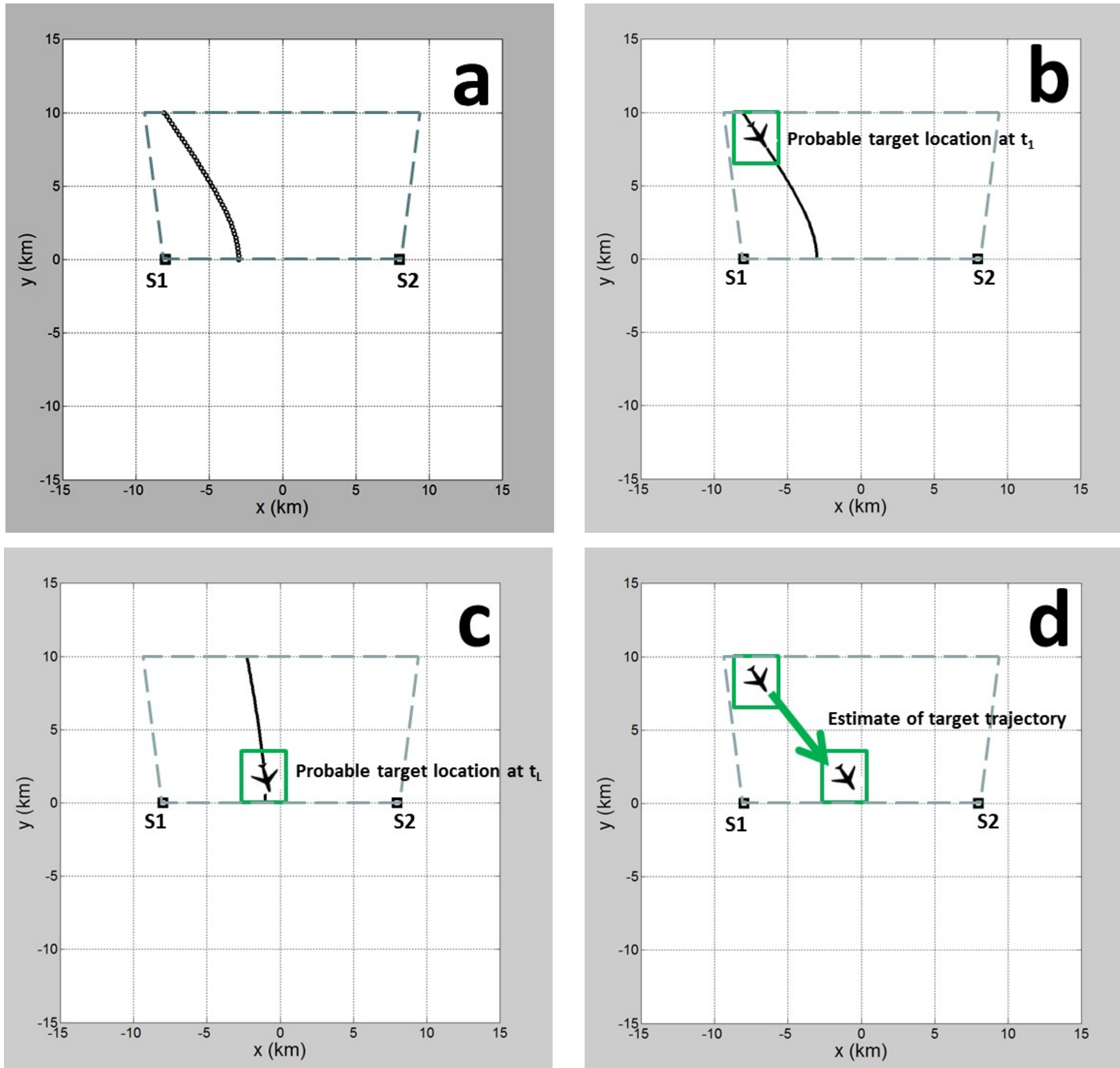


“trip-wire” detection with fewer passive receivers



Extended detection range with fewer passive receivers




a
b
c
d
S1
S2
Probable target location at t_1
Probable target location at t_L
Estimate of target trajectory
x (km)
y (km)

Thank You