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Alojz Gomola
21st January 2018

Emergency ACAS-XU implementation

Using Obstacle Avoidance Framework Based on Reach sets

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You can have nice weekend, but there is idea looming around ….

UAV wants To chat

Look at your phone

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A little chat with UAV…

Lojzo, I was thinking, that you should implement ***ACAS-XU avoidance mechanism*** into your framework ...

ACAS is using avoidance trajectory tree to avoid collisions ….

That is our REACH set right ?

Well, but we are using a ***different cost function for navigation*** …

Switching mode control will do …

Well, I propose to implement Switching mode control between:

1. ACAS custom reach set
2. Standard cost function reach set

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Idea in nutshell

Implement ACAS emergency avoidance in current Obstacle avoidance framework

But we need Rule Engine to do That ...

Some features like cost based decisions can be covered under current framework:

- ***ACAS avoidance tree*** – just favor vertical separation instead vertical.
- Other cost based avoidance rules…

Lets gather ingredients…

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Prefer the vertical separation …

<u>Cost function</u> – *go right and down preffered movement direction*

Let us take the *<u>Trajectory from Reach set</u>*:

$$Trajectory(initialState, Movements)$$

Then one can take $Movements$ and *<u>just count them</u>*:

$$Performance = \sum Right + \sum Down - \sum Left - \sum Up$$

But Lojzo, ACAS defines performance criterion

Then we can do it also:

$$ACAS(Performance, InitialPosition, FinalPosition)$$

But Lojzo, ACAS tree is defined differently

<u>Yes you are right, Let us define switching control</u>

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Switching control

<u>Condition:</u>

When you *<u>receive ADS-B in your action radius</u>*:

Switch to “ACAS Reach Set”

<u>Otherwise:</u>

Use “Navigation Reach Set”

That can do, what if different condition is given ?

<u>ACAS</u> *is still under <u>development,</u>* for this time let say that condition can be satisfied by hardcoded distance condition

$$distance(UAV, Intruder) \leq d_m\ [feet]$$

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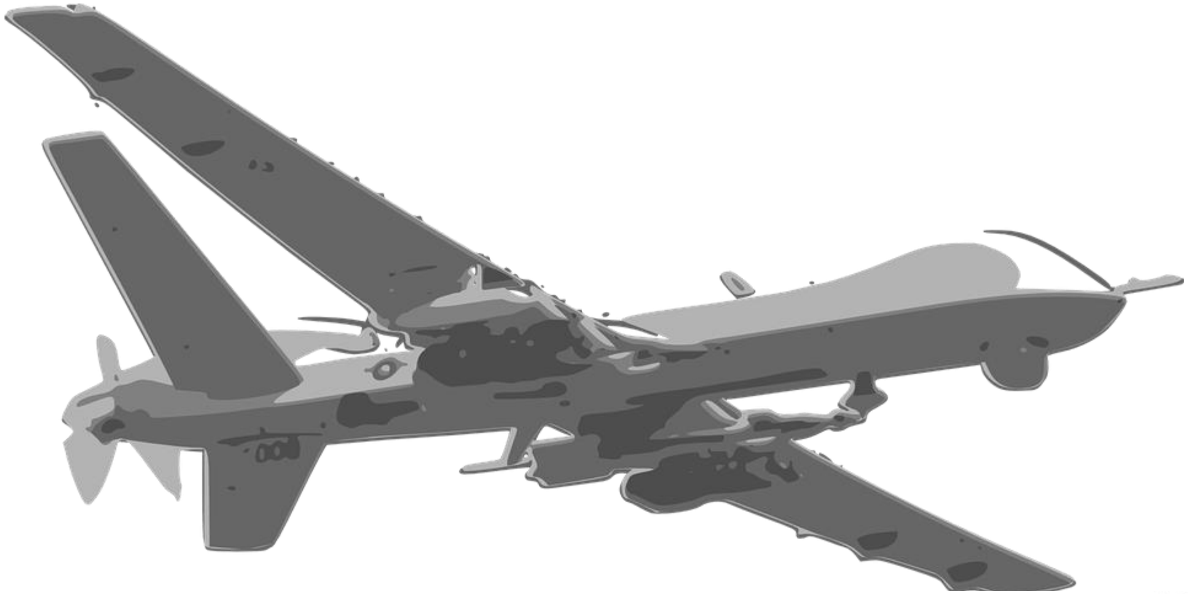
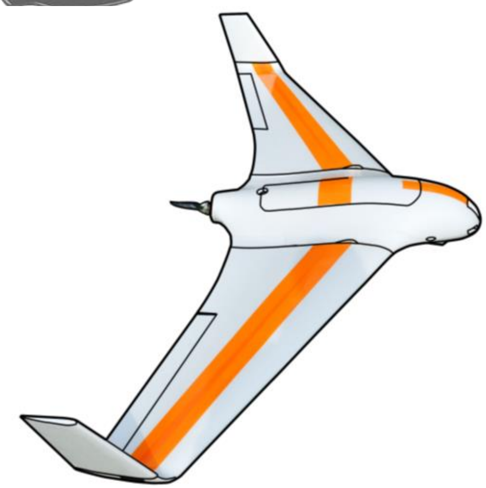
ACAS-Xu (Next generation safety framework)





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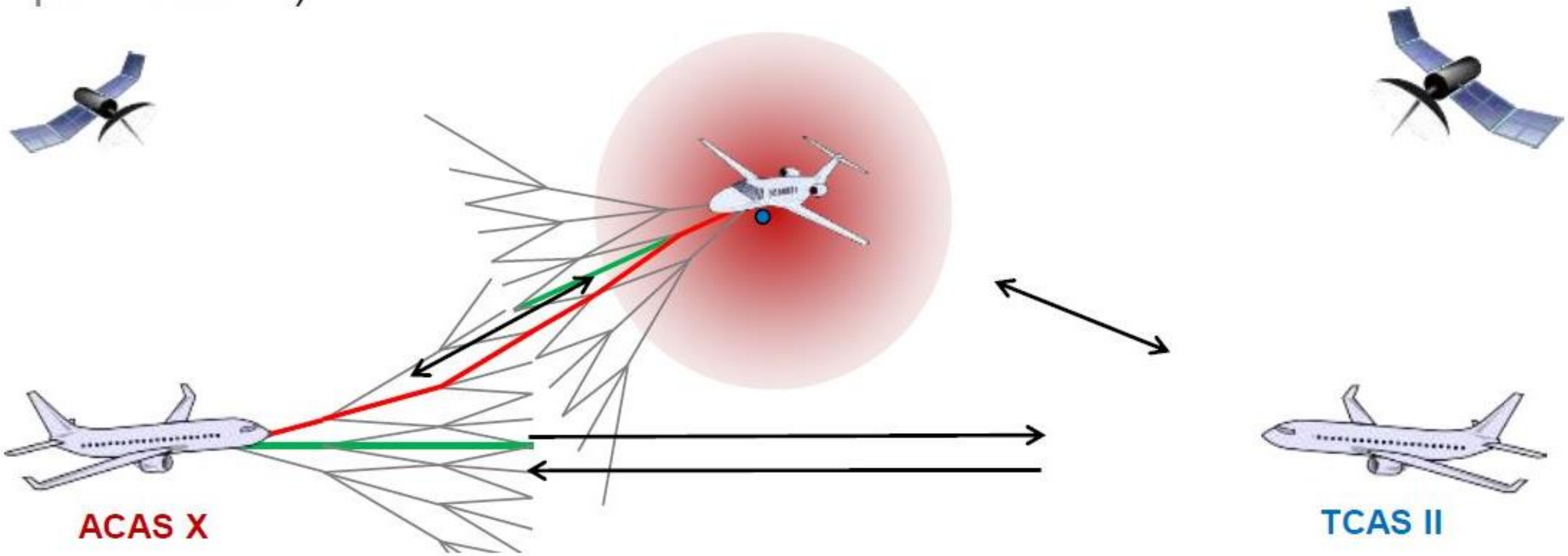
What is this ACAS ?

- New logic (interoperable with TCAS II) and system architecture
- ADS-B (automatic dependent surveillance – broadcast) track can be used also for threat resolution (active validation)
- New trackers allow to estimate not only the position of the intruder, but also **the error of this estimate**
- Improved robustness due to accounting for relative likelihood of all possible future trajectories (nominal used by TCAS, worst case, probabilistic)



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ACAS X_A vs. ACAS X_U

	 ACAS X_A	 ACAS X_U
Cooperative Surveillance	• ADS-B validated by active surveillance	• ADS-B validated by active surveillance
Non-cooperative Surveillance	• Does not provide protection for non-transponder equipped intruders	• Tracked output from primary radar, EO, IR or other sensor
Threat logic	• Tuned for aircraft meeting TCAS performance assumptions (2,500 fpm climb/descent)	• Accommodates range of vehicle vertical performance • "Nucleus" function switches between vertical and horizontal tables based on surveillance quality and vehicle performance
Advisories	• Traffic Alerts • Standard TCAS Vertical RAs • Either manual or automated RA response	• TA or Self Separation Alert • Vertical Resolution Advisories • Horizontal Resolution Advisories • Automatic RA response
Coordination	• Standard TCAS coordination over 1030 MHz	• Supports • TCAS coordination over 1030 MHz • Responsive coordination over 1030 MHz • Active Coordination over 1090 MHz ADS-B

RTCA, SC−147, ACAS Xu WG Kick−off, January 12, 2016

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Automatic response downfall

Depending on the communication link, it is expected that *there may be significant latency associated with RA data transmission* to a ground-based flight crew and subsequent pilot aircraft control commands back to the aircraft in response to the RA

Loss of uplink or downlink communications with the UAS would entirely prevent ground-controlled collision avoidance, and may also degrade collision avoidance effectiveness on other aircraft in coordinated encounters

UAS may also *lack additional outside information*, such as visual identification of intruders, which allows pilots in manned aircraft to make real-time decisions regarding RA response.

The pilot has *the ability to override auto-response* at any time before or after the aircraft has started maneuvering

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TCAS/ACAS RA advisories (!Horizontal only!)

Table 3. Possible Initial RAs for Single Threat

RA Type	Upward Sense		Downward Sense	
	RA	Required Vertical Rate (fpm)	RA	Required Vertical Rate (fpm)
Positive (Corrective)	Climb	1500 to 2000	Descend	-1500 to -2000
Positive (Corrective)	Crossing Climb	1500 to 2000	Crossing Descend	-1500 to -2000
Positive (Corrective)	Crossing Maintain Climb	1500 to 4400	Crossing Maintain Descend	-1500 to -4400
Positive (Corrective)	Maintain Climb	1500 to 4400	Maintain Descend	-1500 to -4400
Negative (Corrective)	Reduce Descent	0	Reduce Climb	0
*Negative (Corrective)	Reduce Descent	> -500	Reduce Climb	< 500
*Negative (Corrective)	Reduce Descent	> -1000	Reduce Climb	< 1000
*Negative (Corrective)	Reduce Descent	> -2000	Reduce Climb	< 2000
Negative (Preventive)	Do Not Descend	> 0	Do Not Climb	< 0
Negative (Preventive)	Do Not Descend > 500 fpm	> -500	Do Not Climb > 500 fpm	< 500
Negative (Preventive)	Do Not Descend > 1000 fpm	> -1000	Do Not Climb > 1000 fpm	< 1000
Negative (Preventive)	Do Not Descend > 2000 fpm	> -2000	Do Not Climb > 2000 fpm	< 2000

* These Initial RAs cannot occur in Version 7.1

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ACAS Xu Summary

- Safety – weather avoidance, mid air collisions
  - Strategic layer – flight planning (Hours/10ths of minutes) [Mission plan]
  - Tactical layer – separation (10ths of minutes/minutes) [Other systems]
  - Emergency layer – Collision avoidance (10ths of seconds/seconds) (ACAS)
- ACAS X merits to TCAS II limitations
  - Reducing nuisance alert rate while improving safety
  - New classes of users/Adaptation to new operations
  - Adaptable system allowing different sensors configuration
  - Backward compatibility with TCAS II
- ACAS Xu should guarantee that UAV system does not enter RA zone of manned aviation
- ACAS Xu provides look-up table for avoidance maneuvers on horizontal/vertical separation level, which determines vehicle behavior during avoidance
- ACAS Xu is designed for big UAVs which are equipped with Transponder

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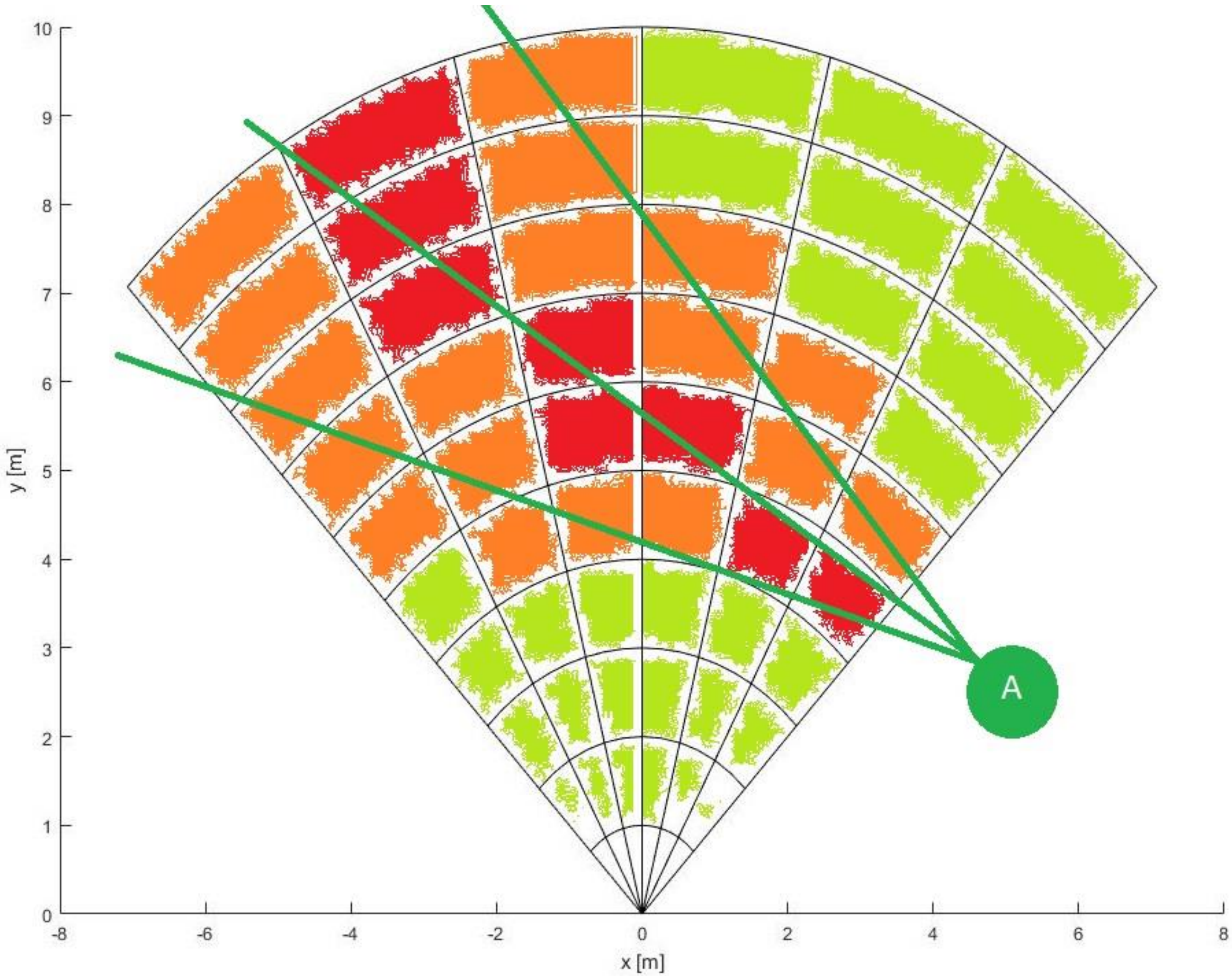
Intruder Intersection (Body volume, Spread)



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Body volume intersection

Intruder *can have body volume*,

- Obstacle probability using polygon intersection
- Cell radius search is implemented as spread algorithm to address time deviation intersection issues
- Intruder body volume can be only applied to direct intersection cells
- Example considers body radius of 1 m

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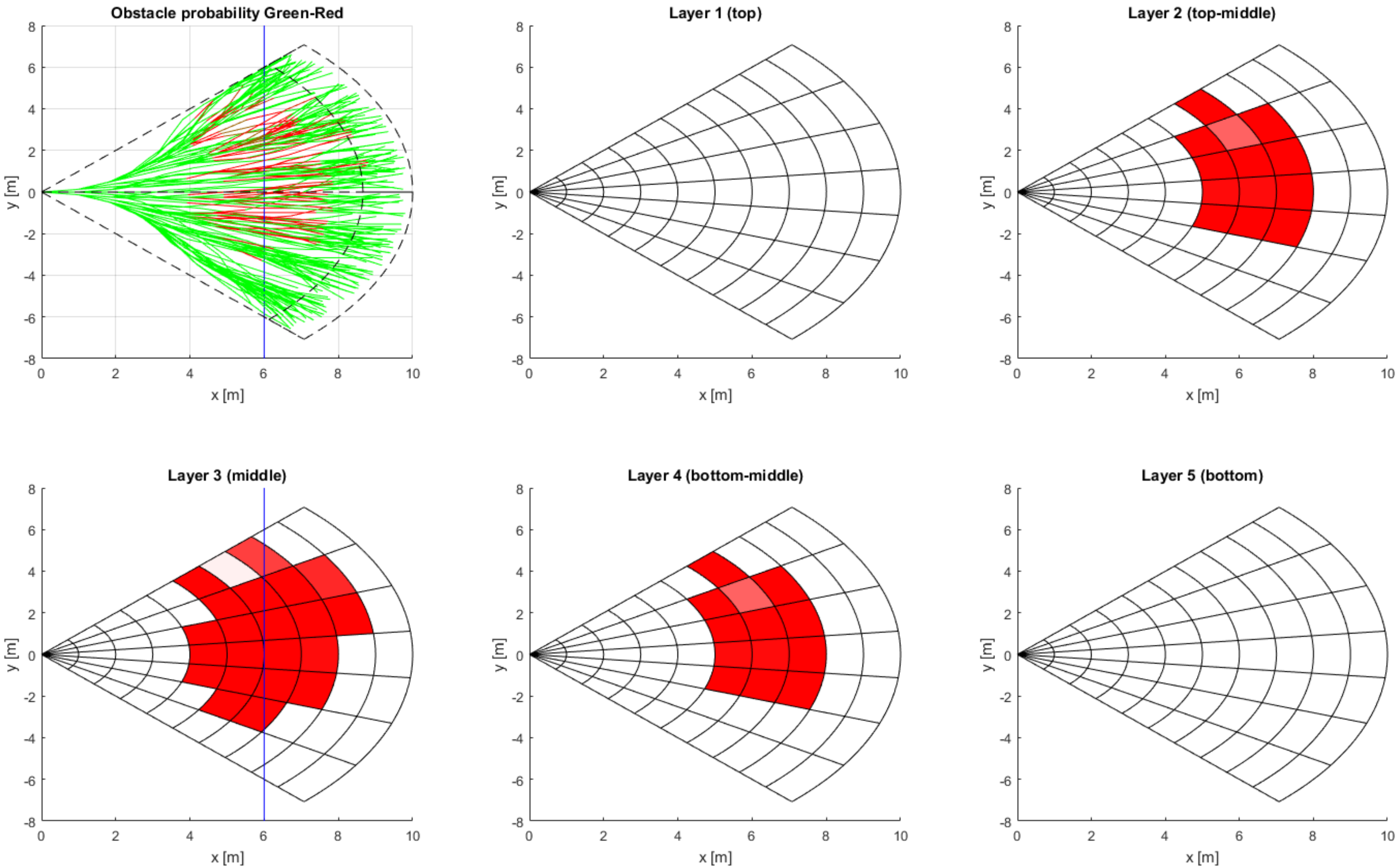
Obstacle space - Intruder body



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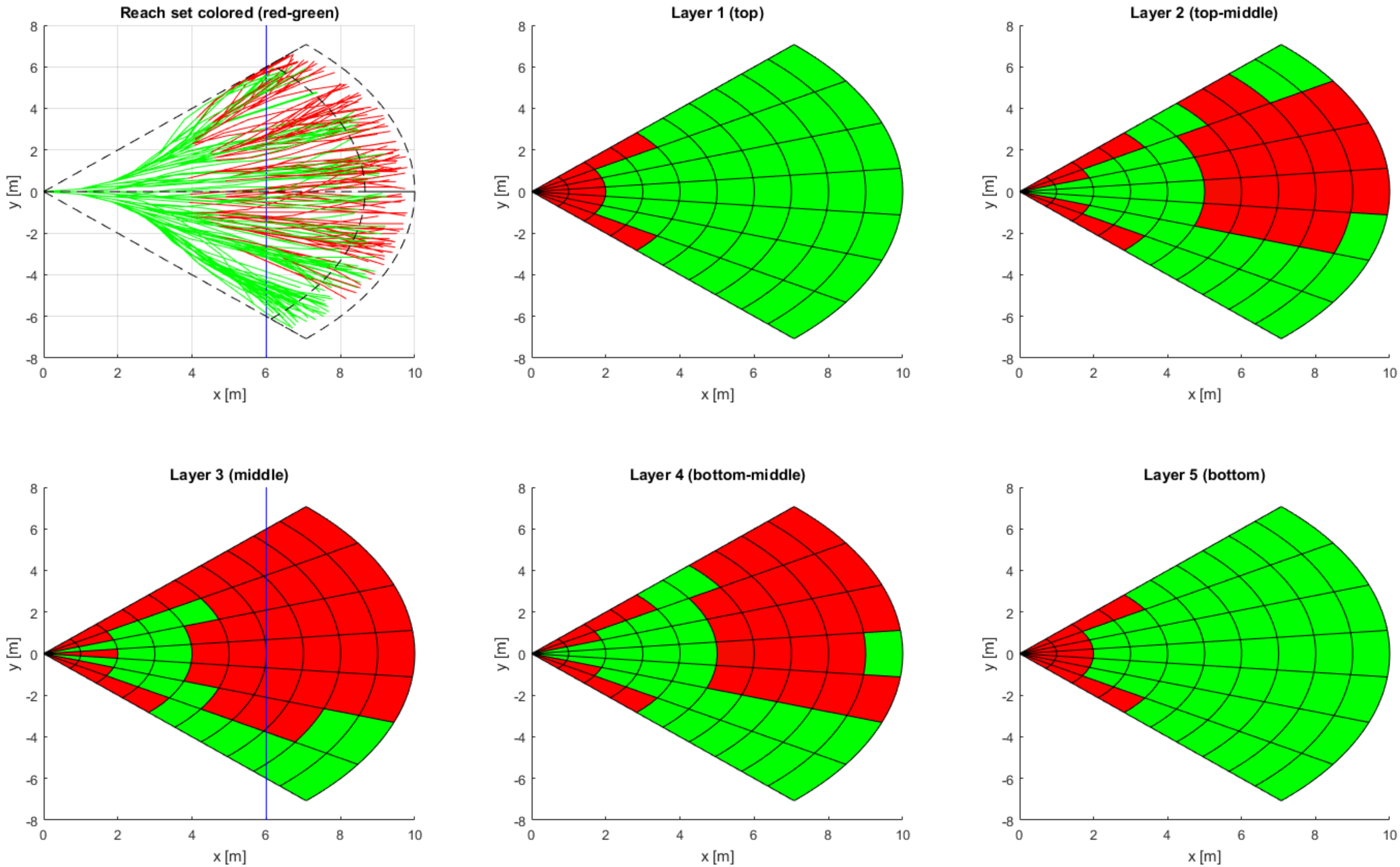
Reach set approximation - Intruder body



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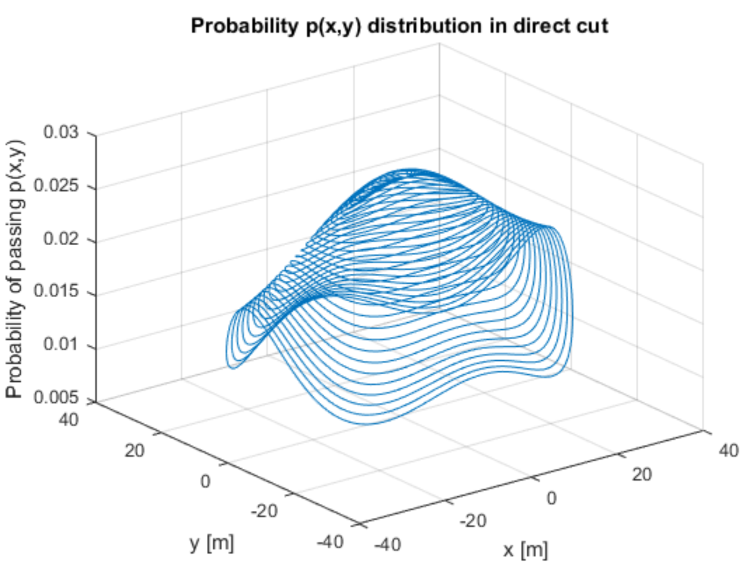
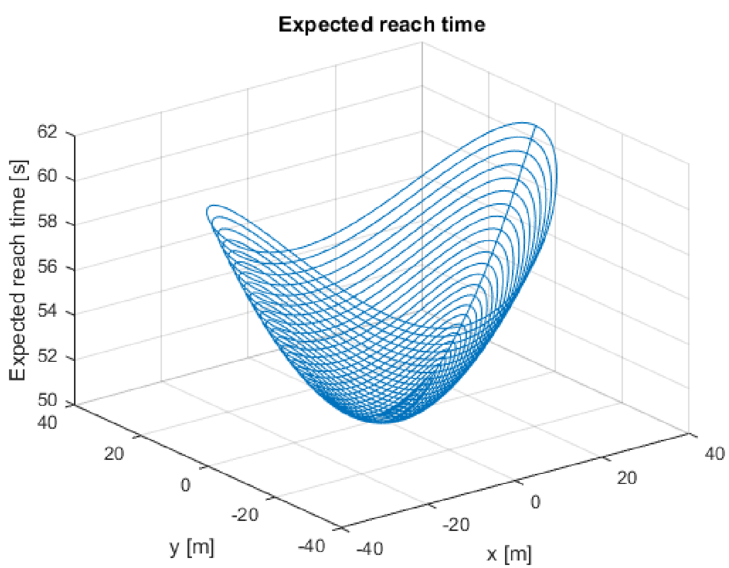
Intruder Trajectory Deviation Model

Intruder usually *do not follow determined linear route* and have some maneuverability, in this case this property is modeled as:

- Horizontal angle deviation θ- spread $[\pi/12]$
- Vertical angle deviation φ- spread $[\pi/16]$

Obstacle probability is spread trough conic intersection via standard Gaussian spread $\mathcal{N}(\mu,\sigma^2)$ in following manner:





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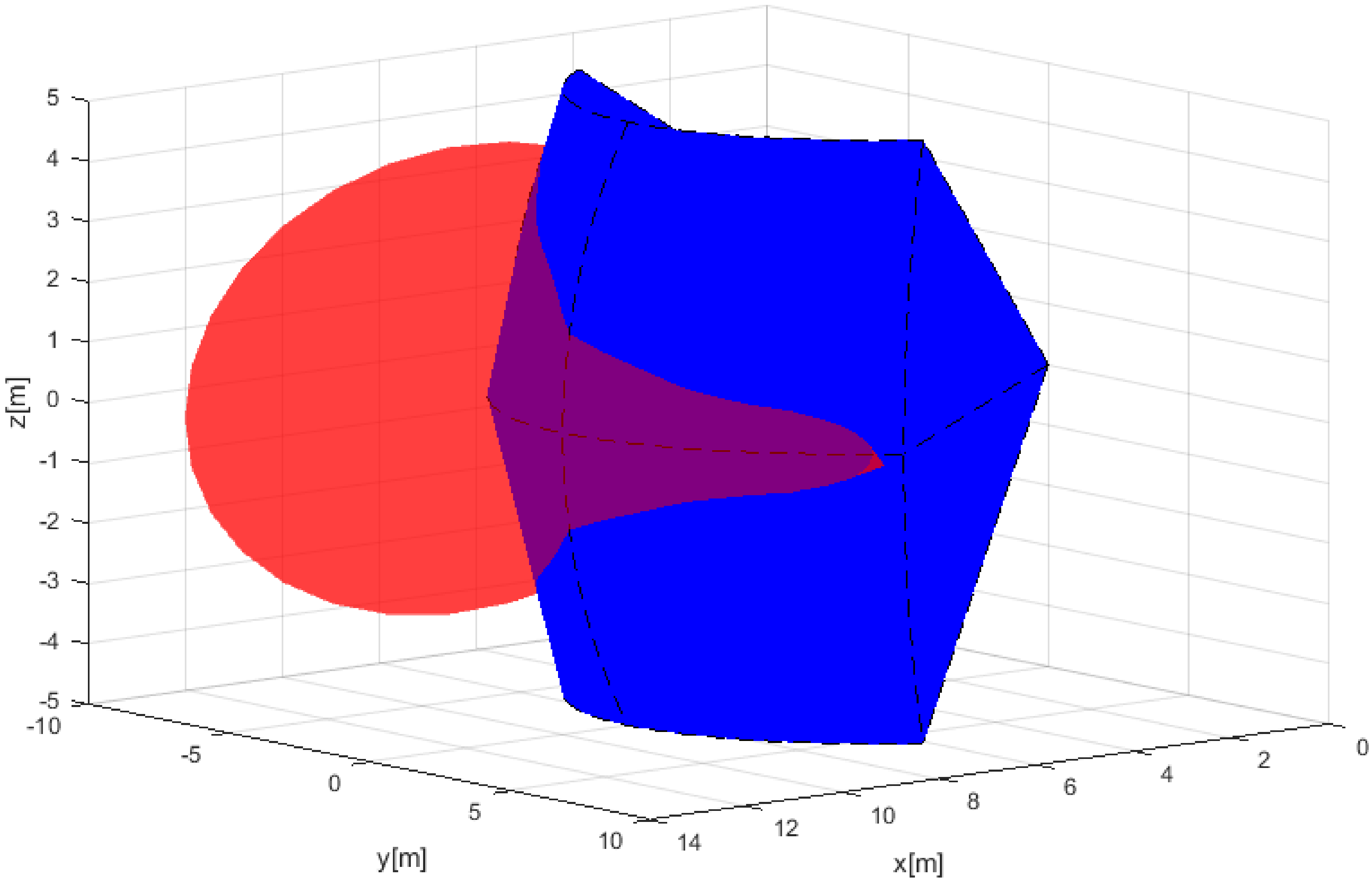
Spread Intersection Examples



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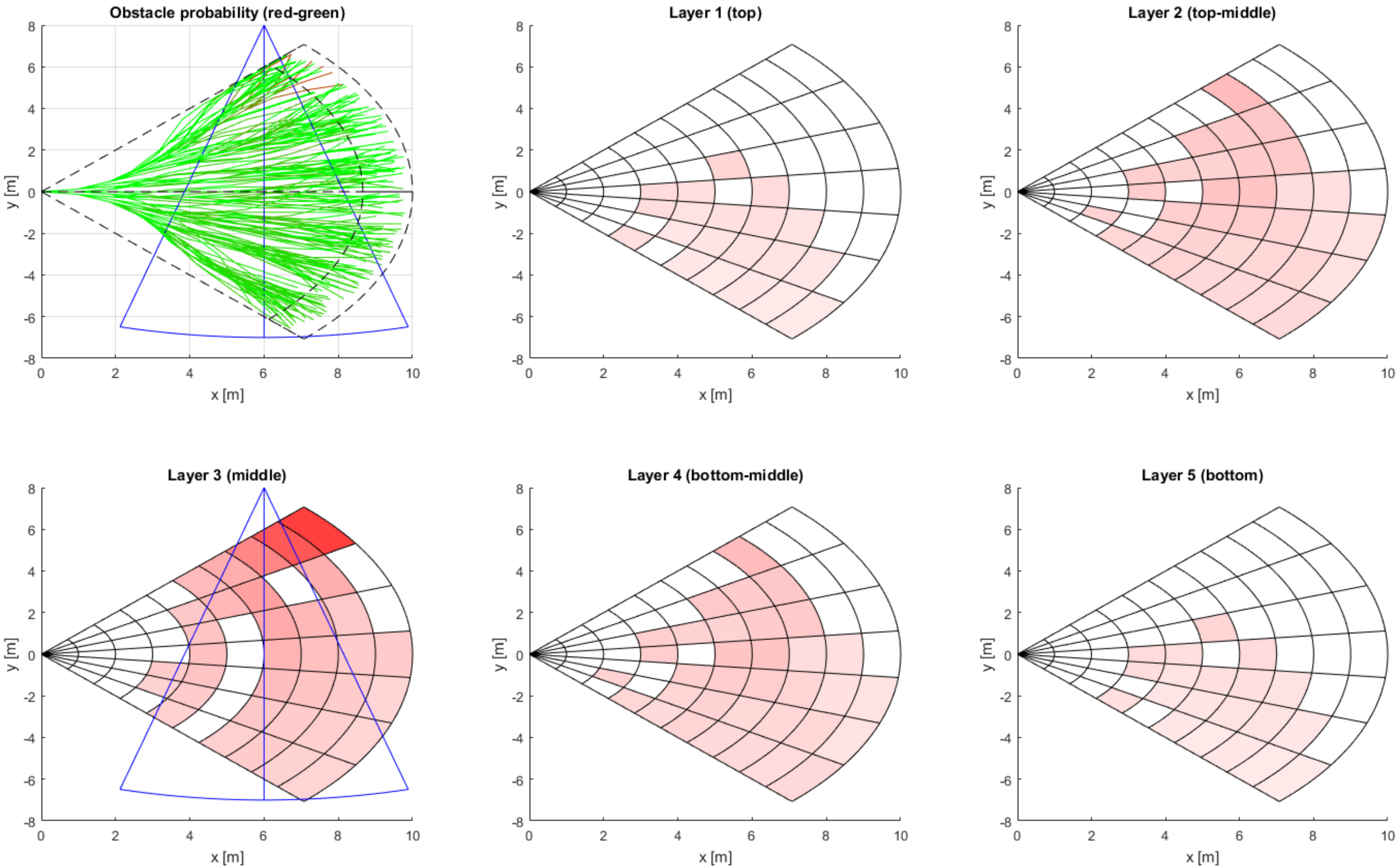
Obstacle space - Intruder spread (Static)



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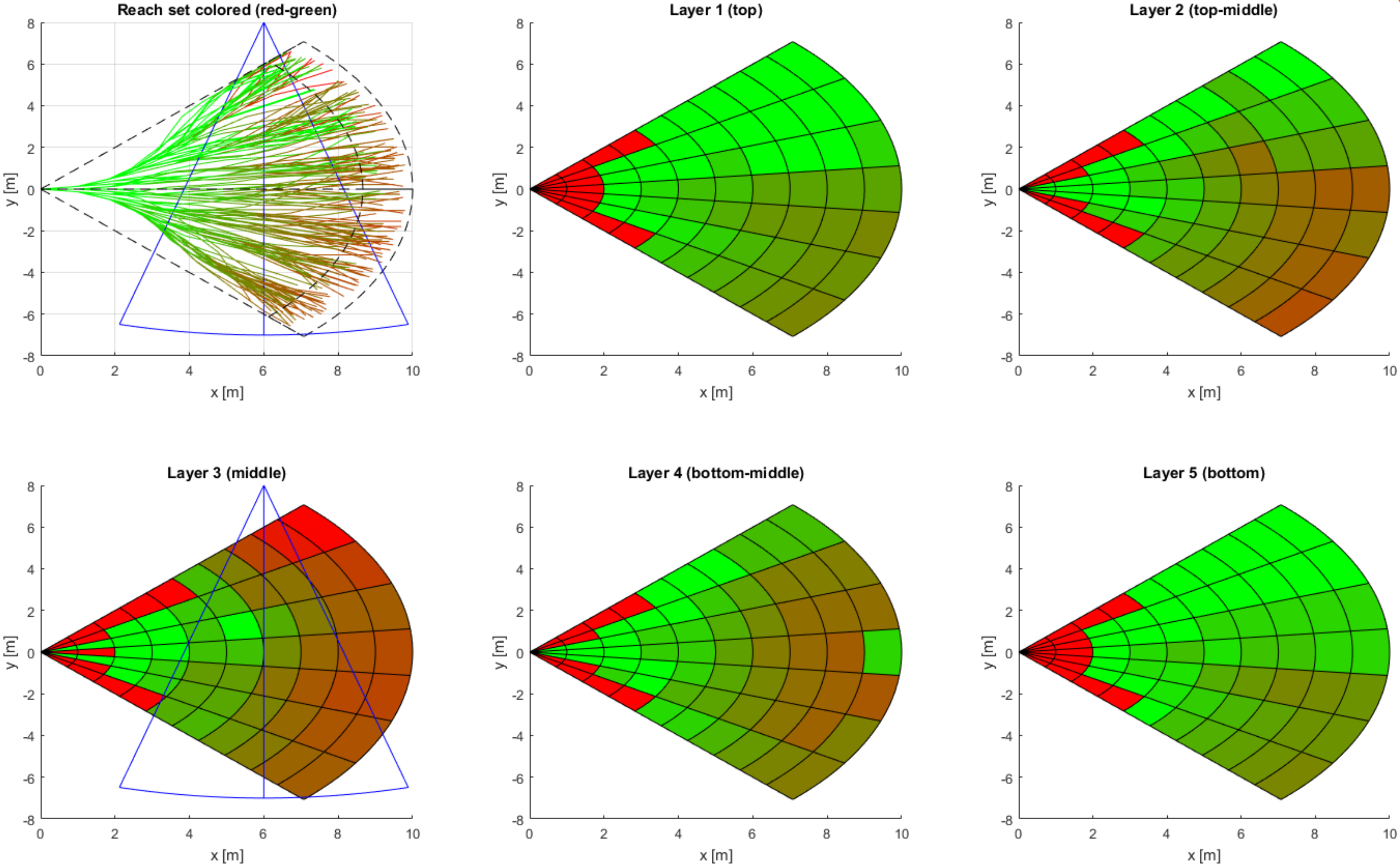
Reach set – Intruder spread (Static)



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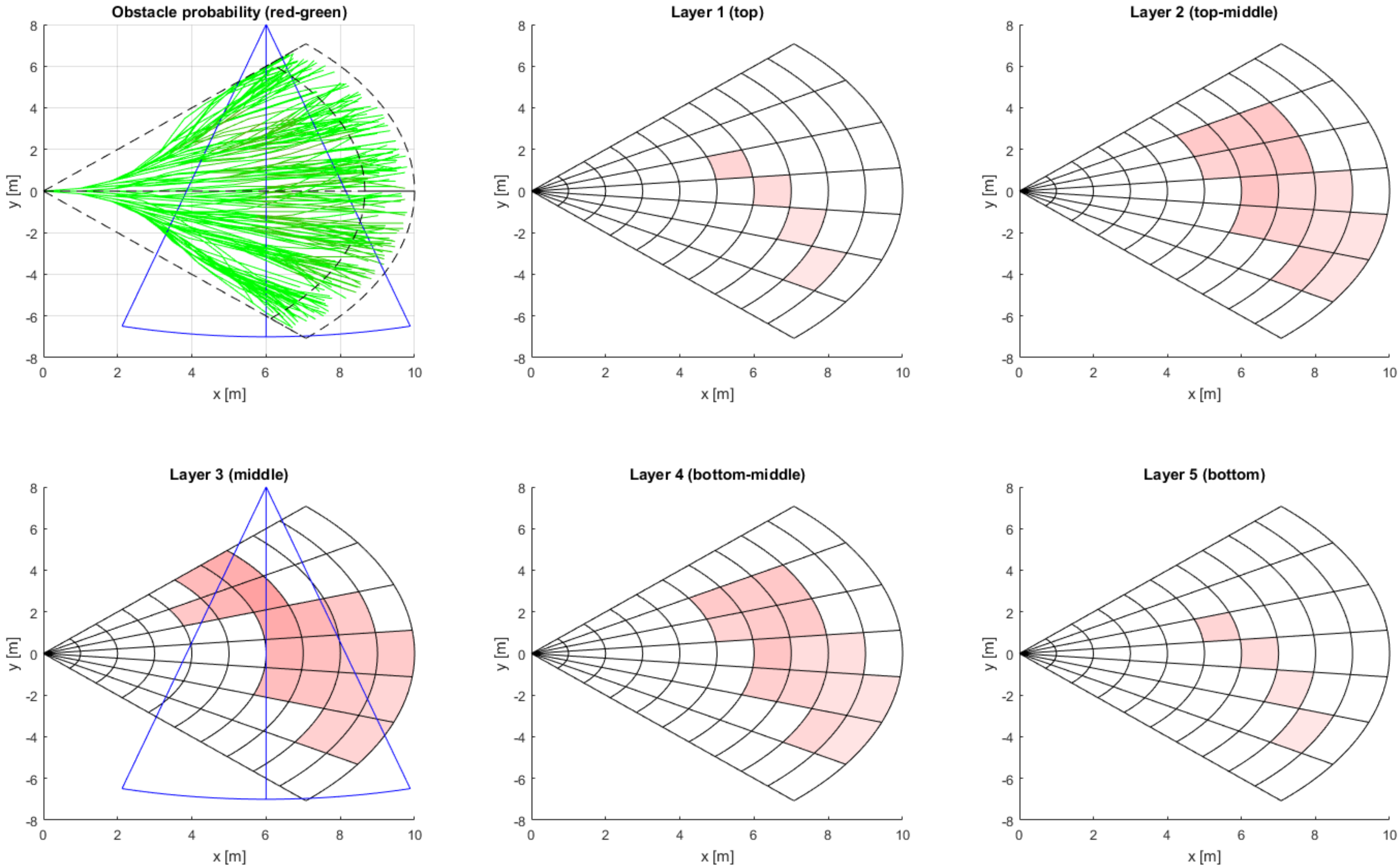
Obstacle space - Intruder spread (Timed)



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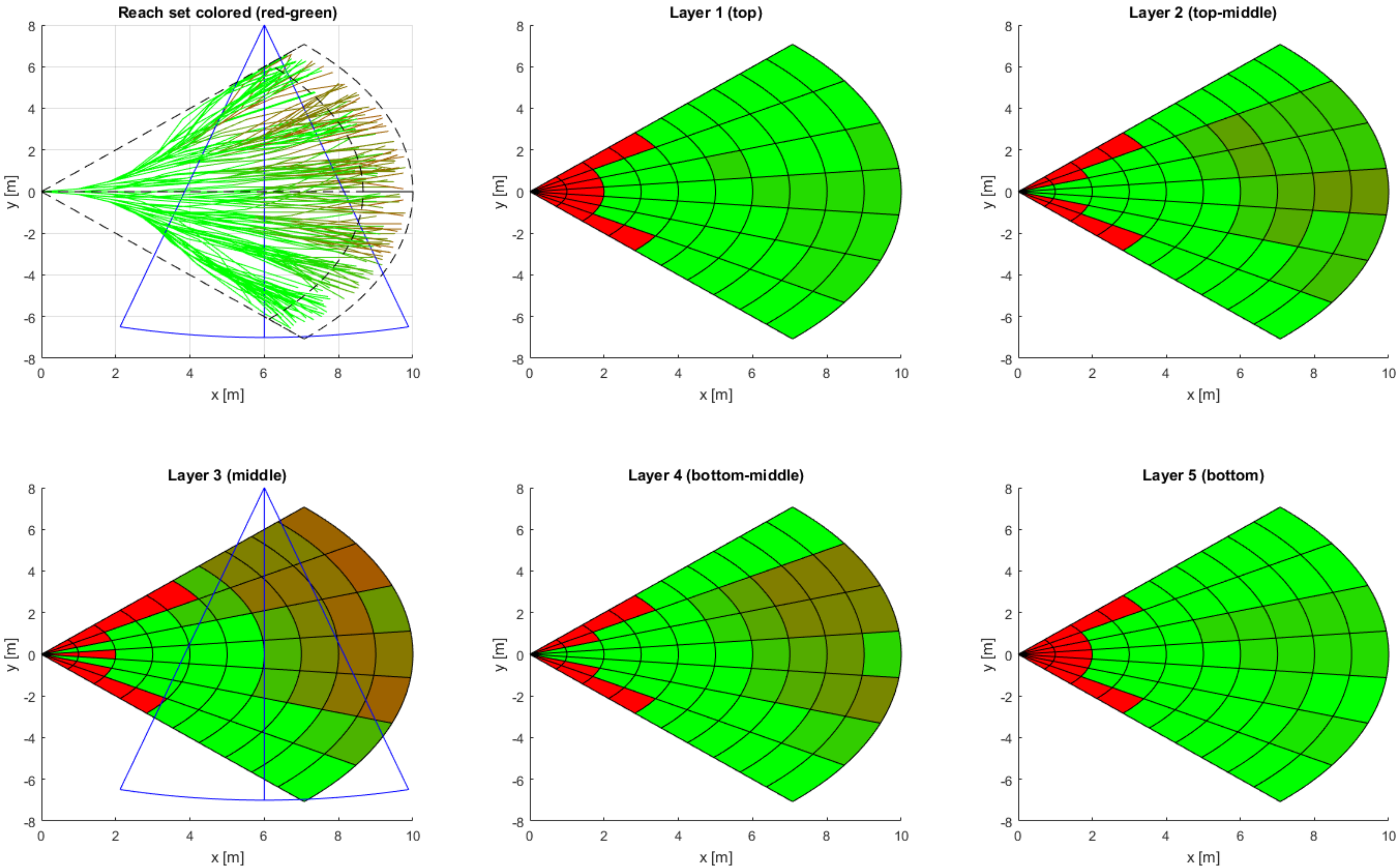

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Intruder probability calculation

In case of multiple intruders:

- Each intruder I_1 ... I_n can use own fusion settings with avoidance grid $\mathcal{A}(t_i)$
  - Time fusion [static/timed],
  - Propagation [line future movements/body/spread]

Intruder probability for cell $c_{i,j,k}$ and multiple I_1 ... I_n is:

$$P_{O_I}(c_{i,j,k}) = 1 - \prod_{I_i \in I_1 \ldots I_n} \left(1 - P_O(c_{i,j,k}, I_i)\right)$$

Total obstacle probability is combination of:

- Intruder obstacle probability P_{O_I}
- Detected static obstacle probability P_{O_D}
- Map obstacle probability P_{O_M}

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Simulations

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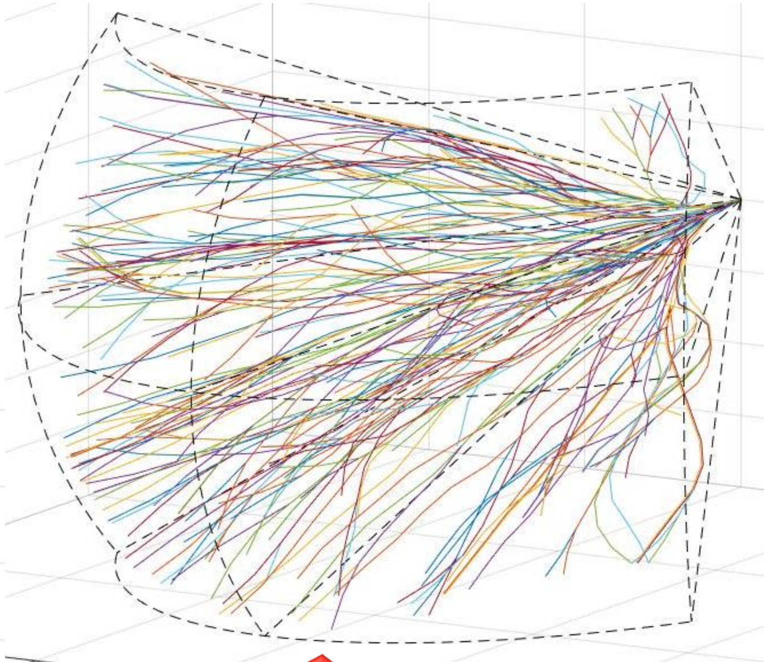
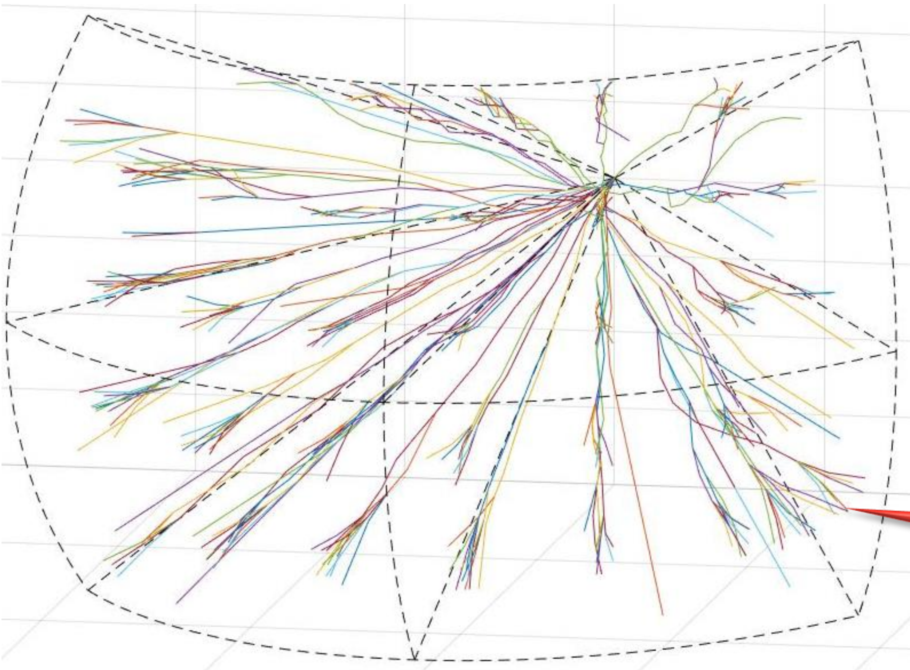
Avoidance Framework Setup

Defender (Blue(Red))

- Speed $1\,ms^{-1}$, Decision every $1\,s$,
- Avoidance grid [Effective ACAS-XU]
- Navigation grid [Effective trajectory]
- Used modes: [Effective ACAS-XU]





Effective **Trajectory**

Effective ACAS-XU

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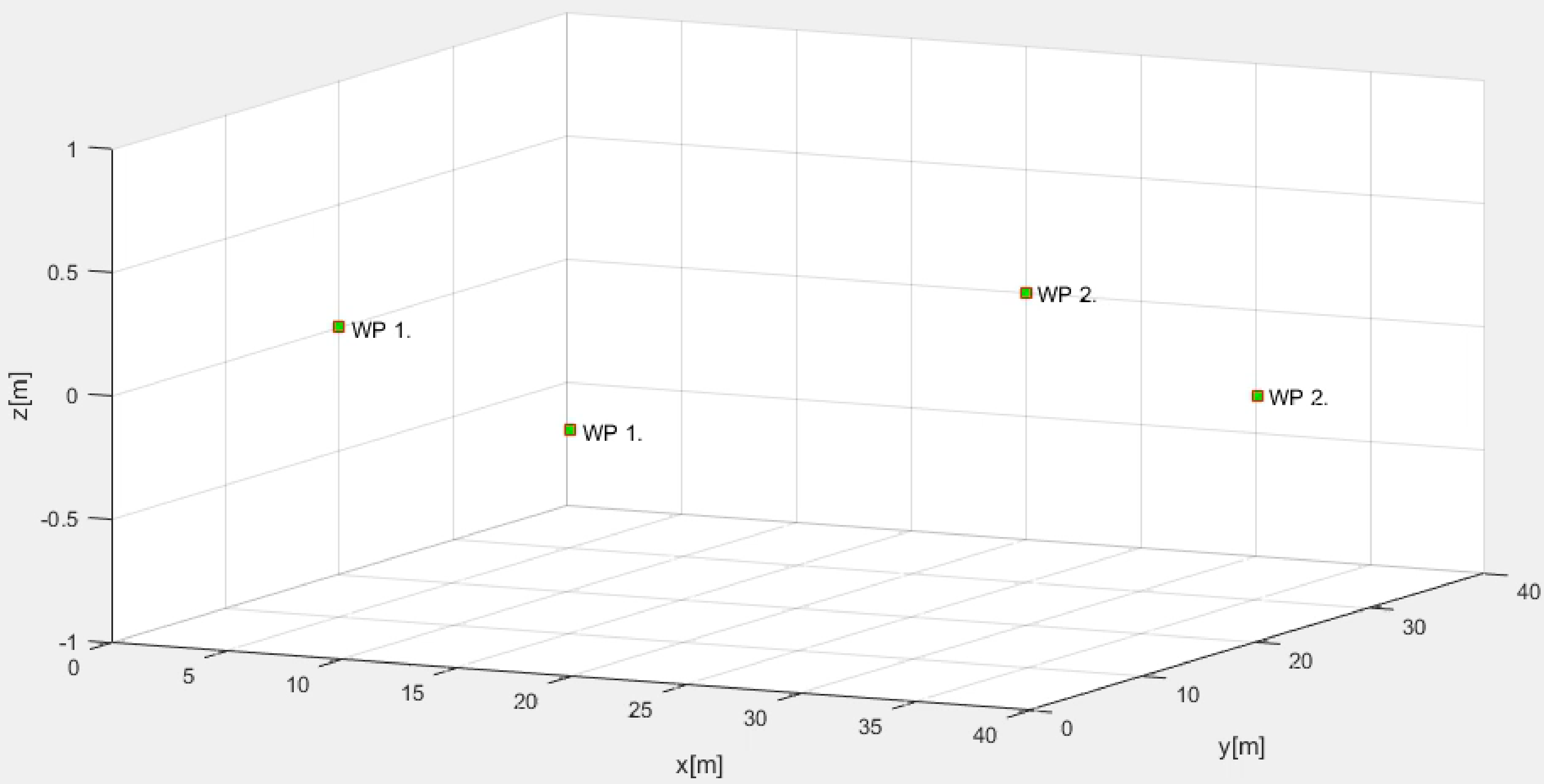
Same speed as intruder with “Right of the way”



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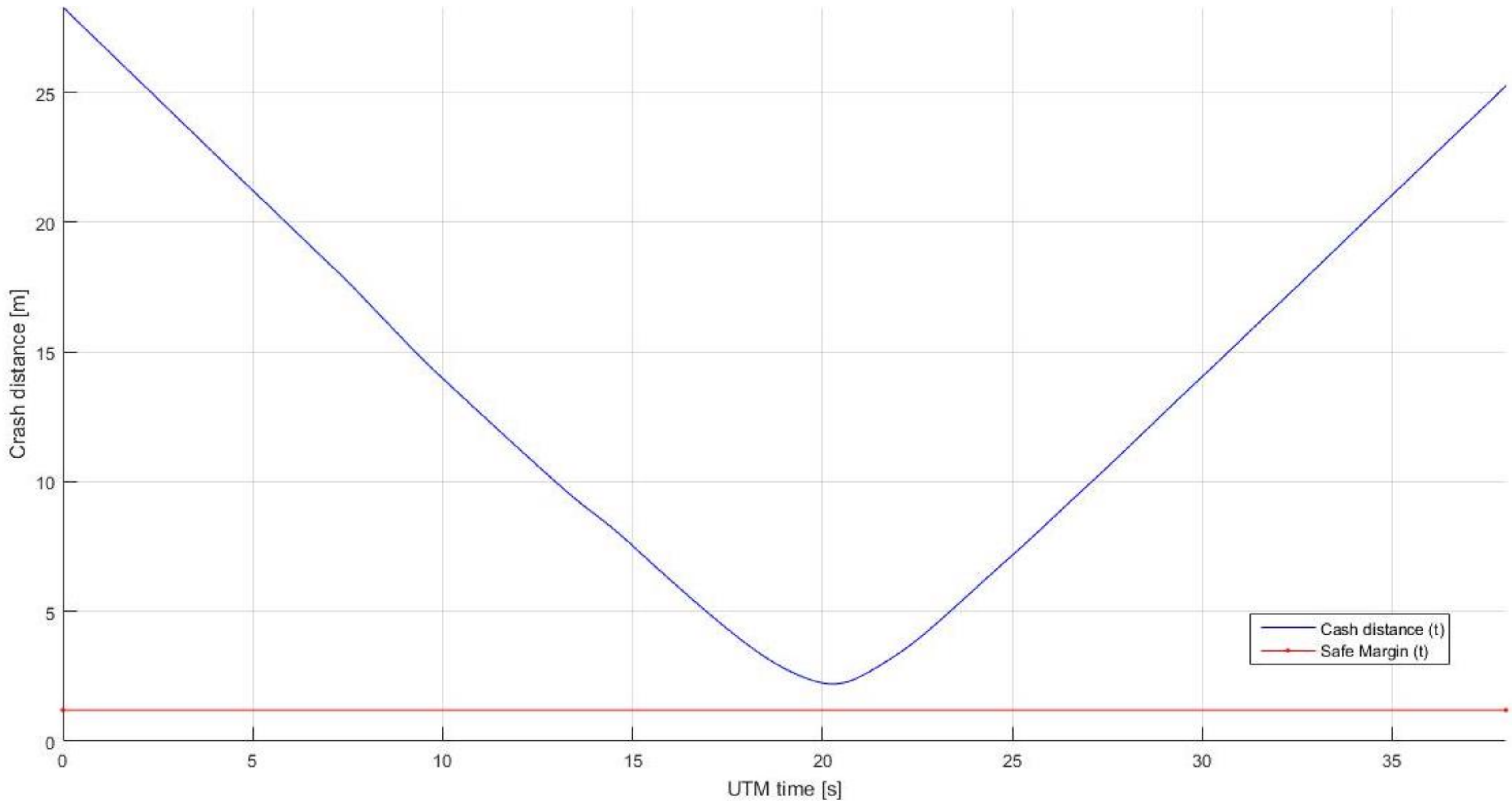
Crash distance $d_c(t)$ evolution (Normal ACAS)



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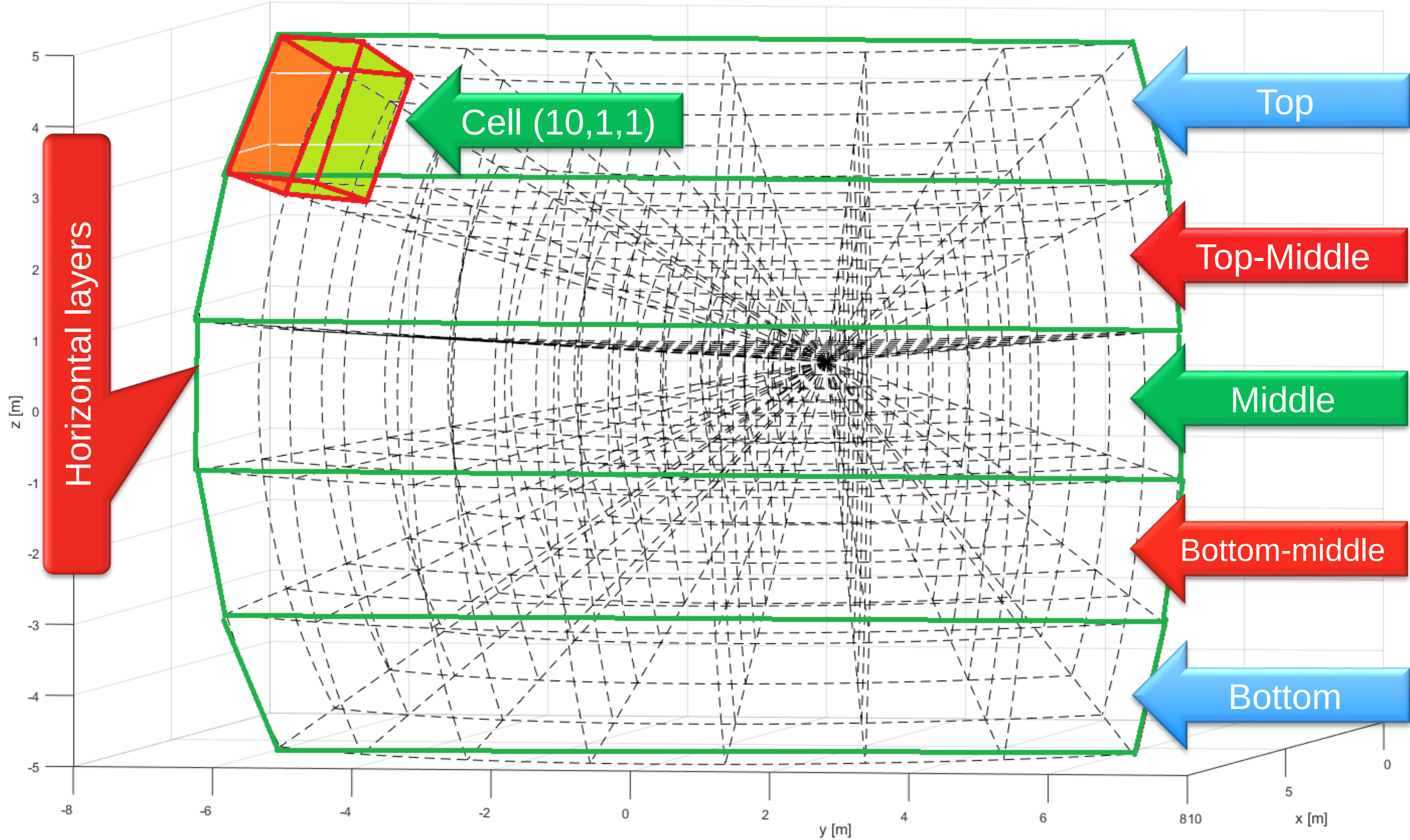
Avoidance Grid Setup



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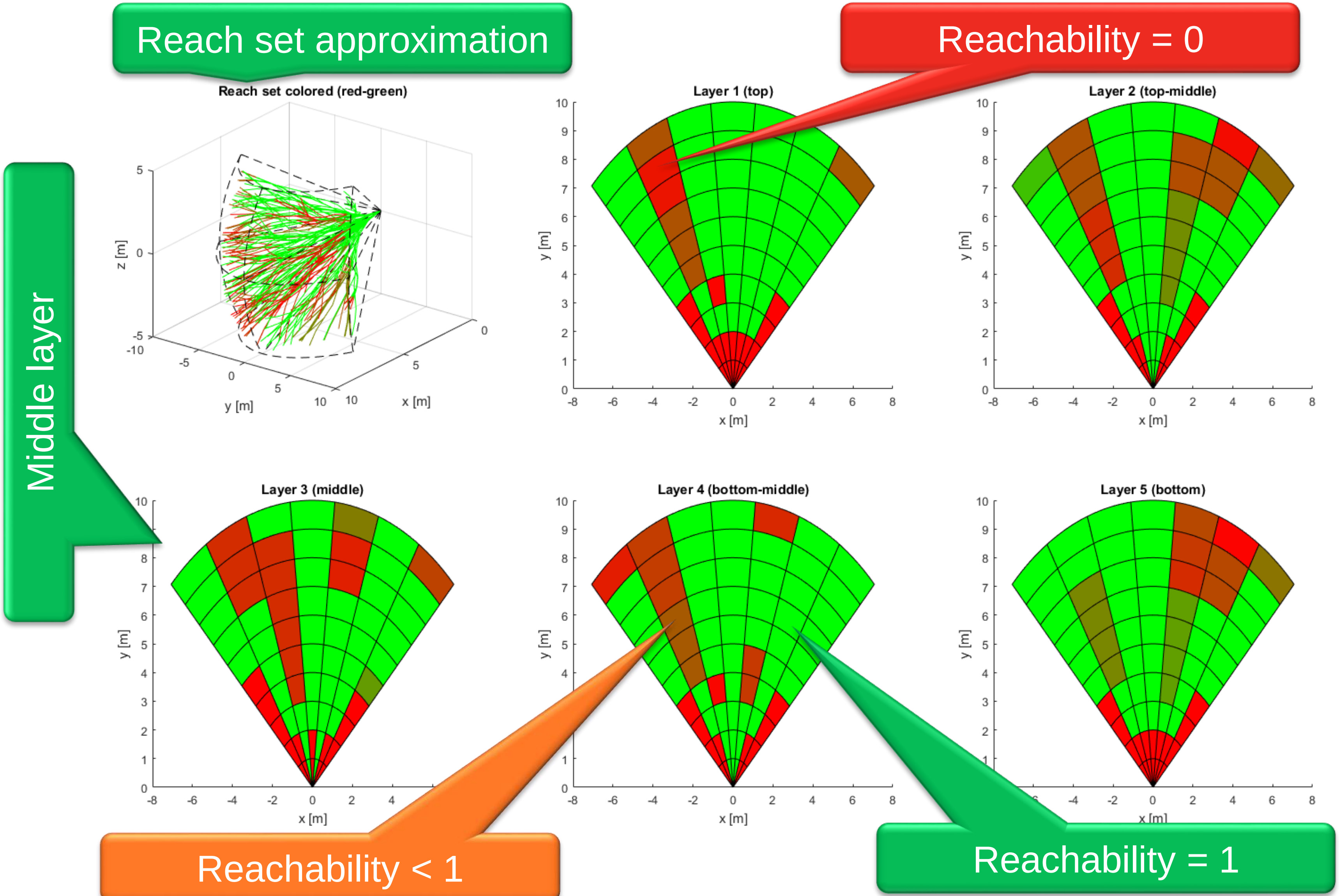
Avoidance Grid - Legend



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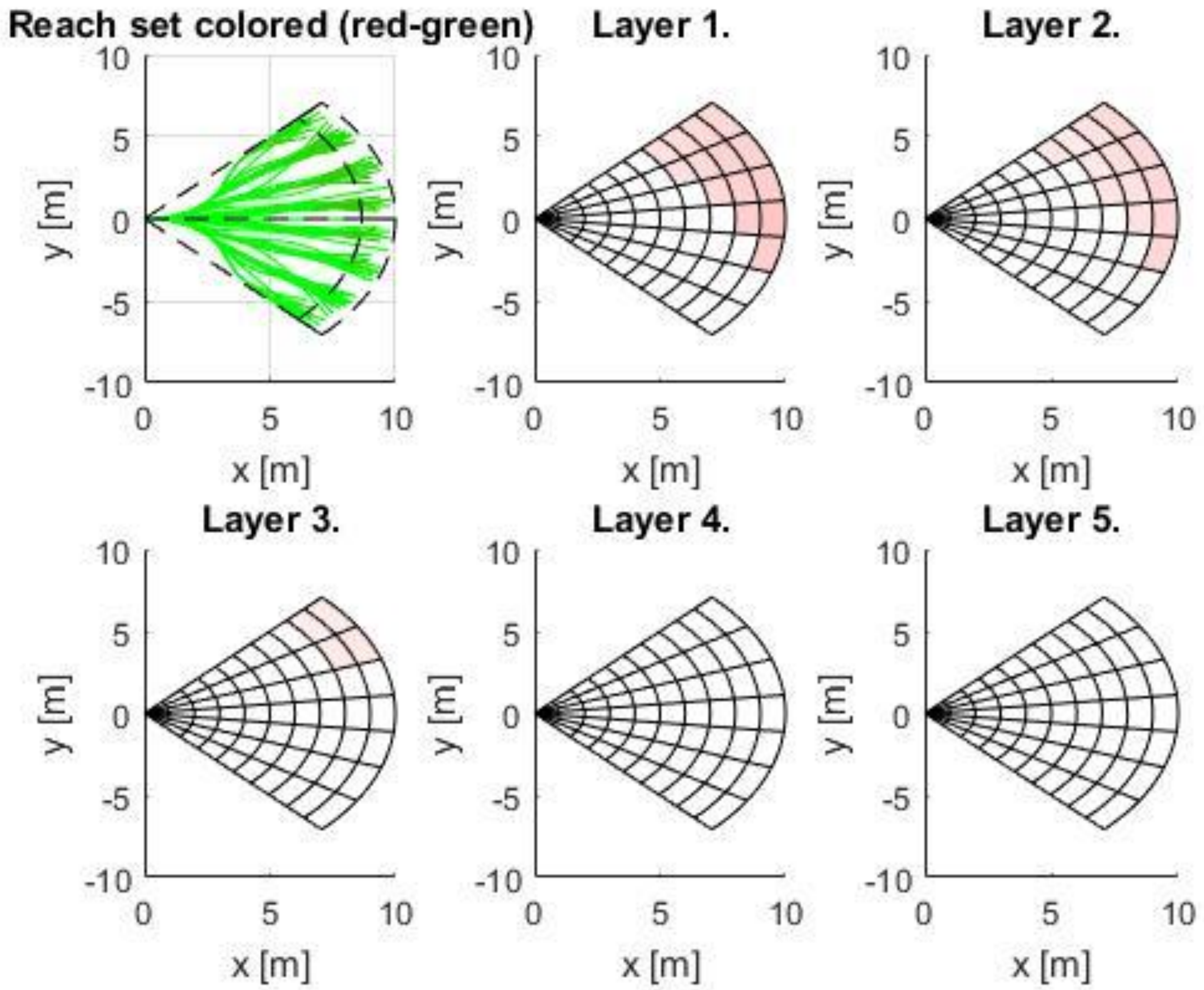
Decision Frame 5 (Obstacle Space)



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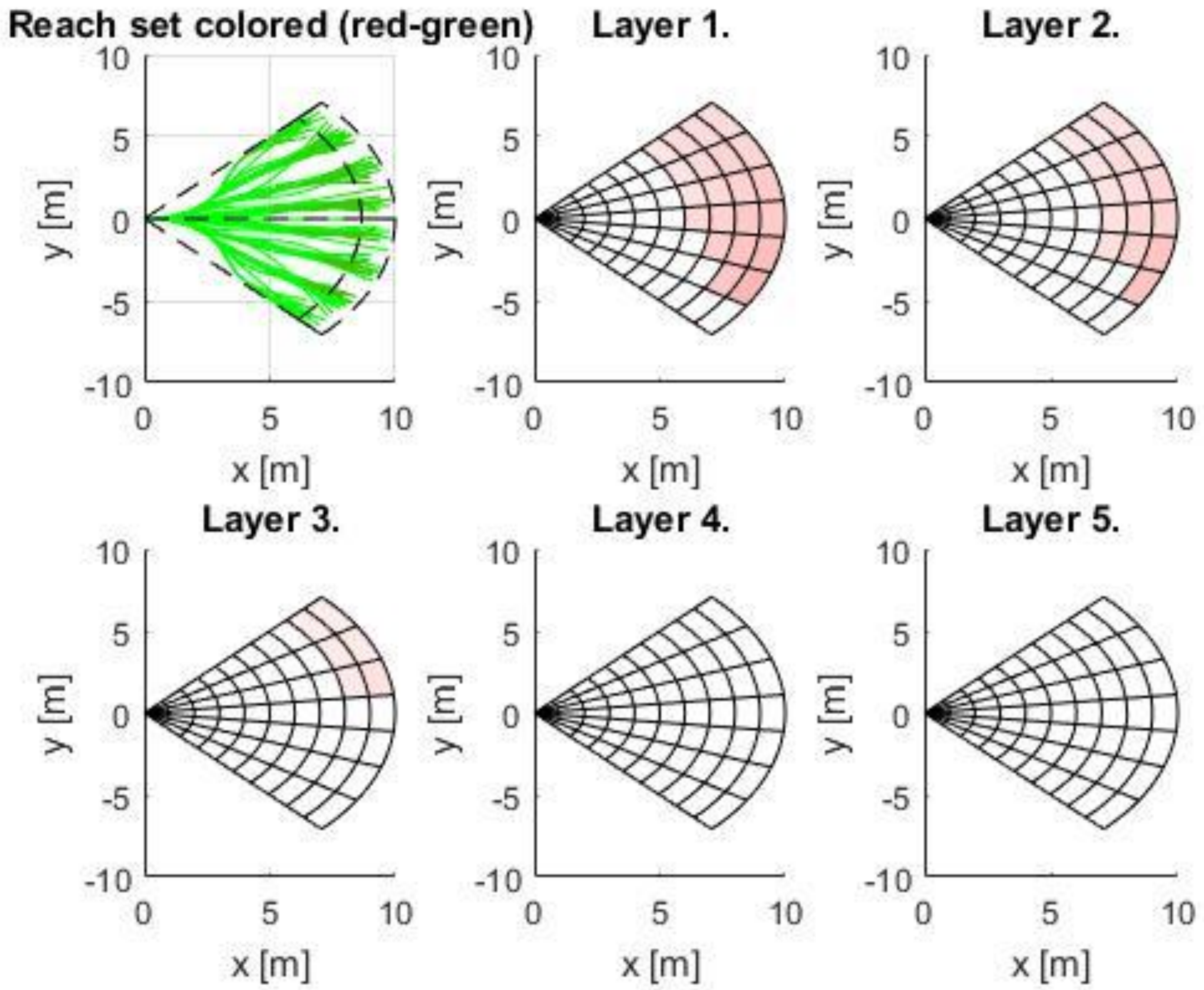
Decision Frame 6 (Obstacle Space)



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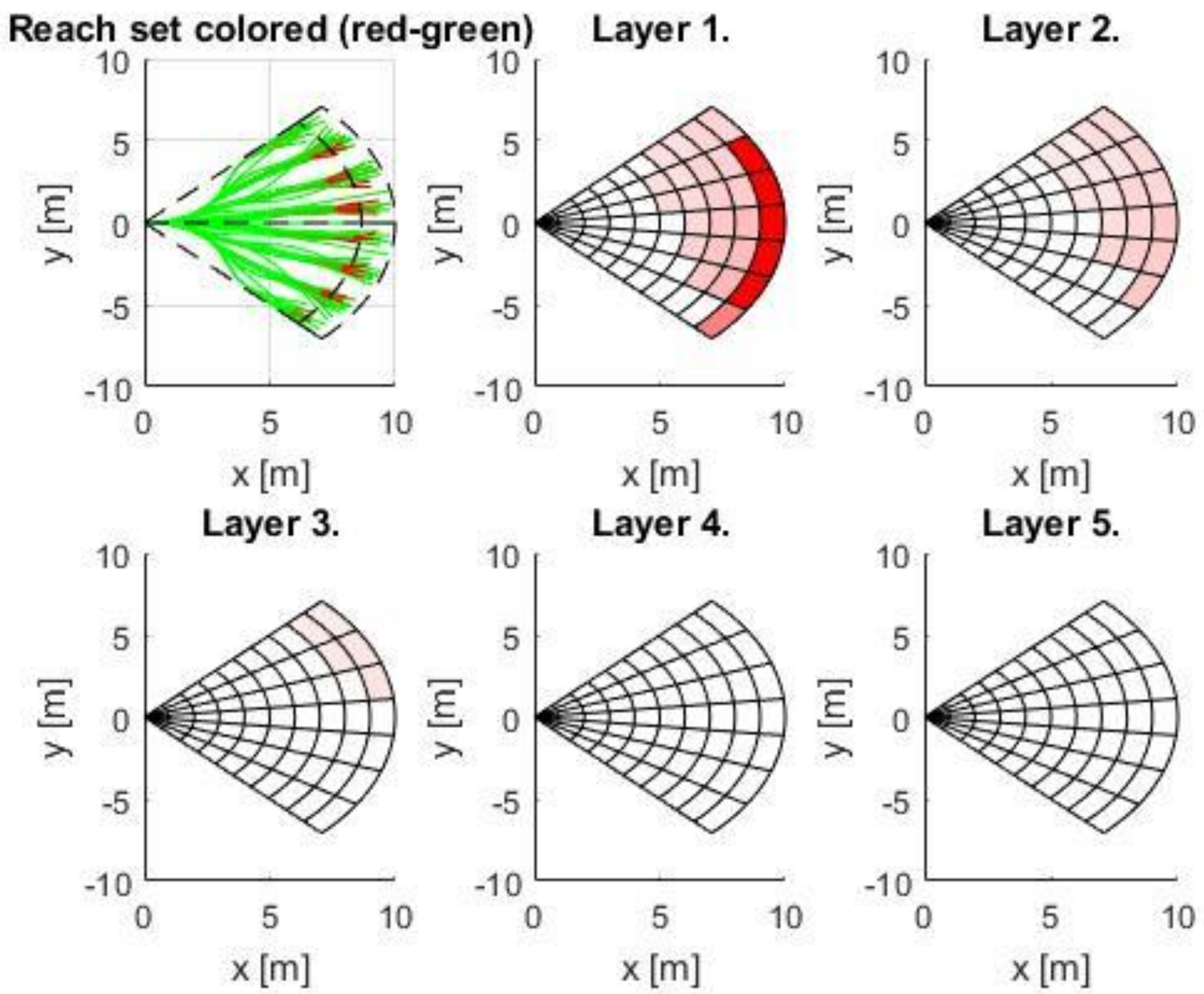
Decision Frame 7 (Obstacle Space)



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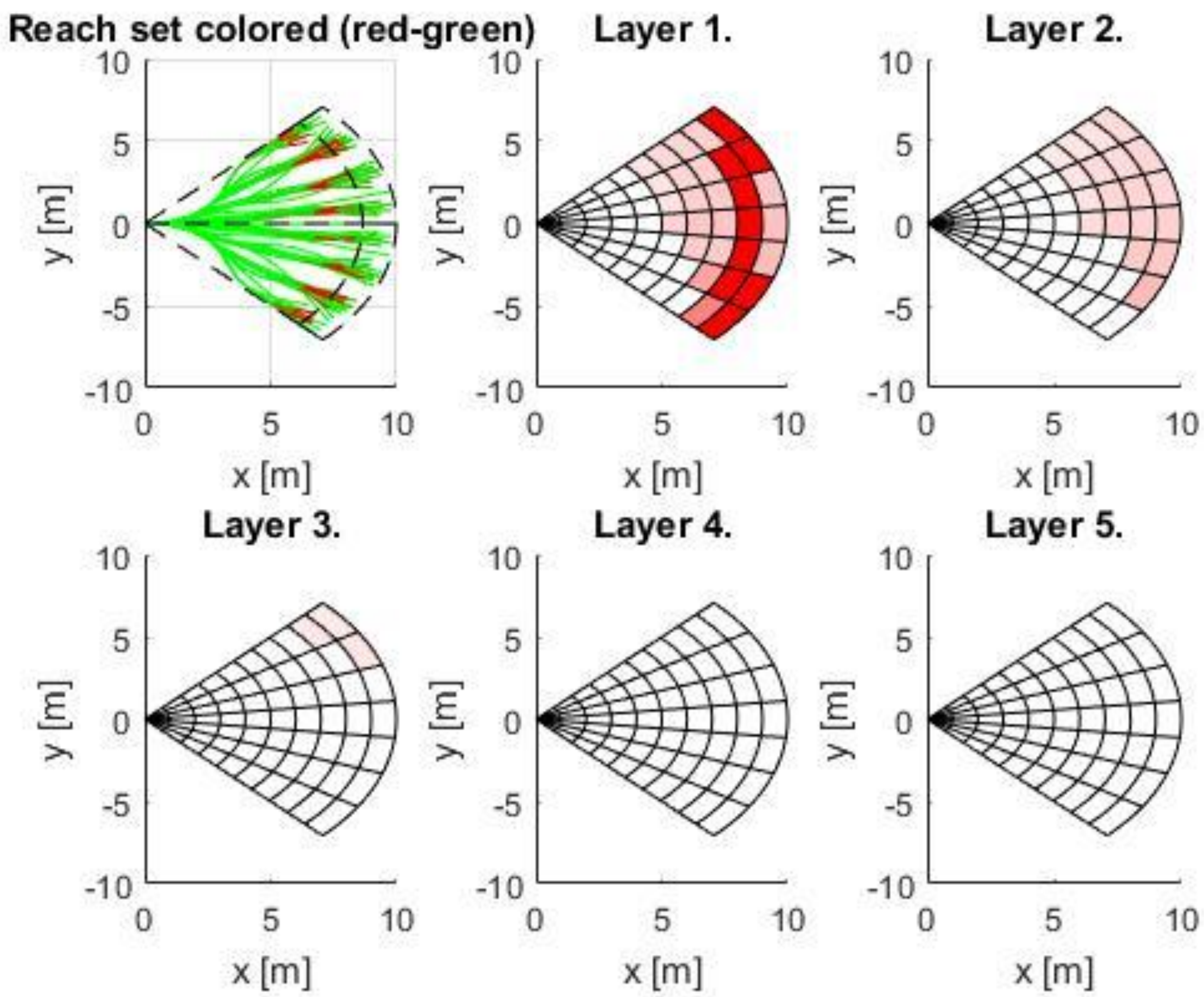
Decision Frame 8 (Obstacle Space)



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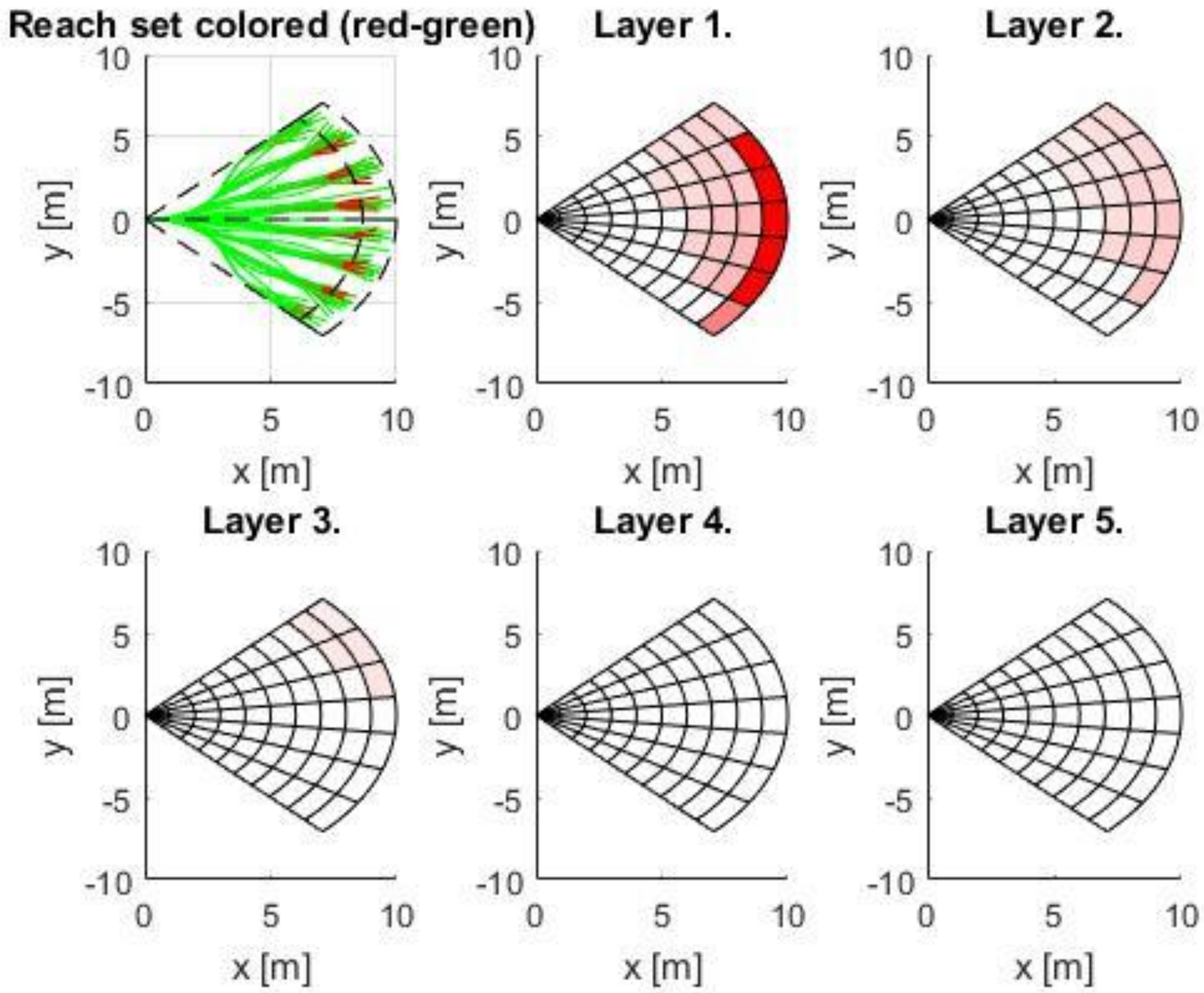
Decision Frame 9 (Obstacle Space)



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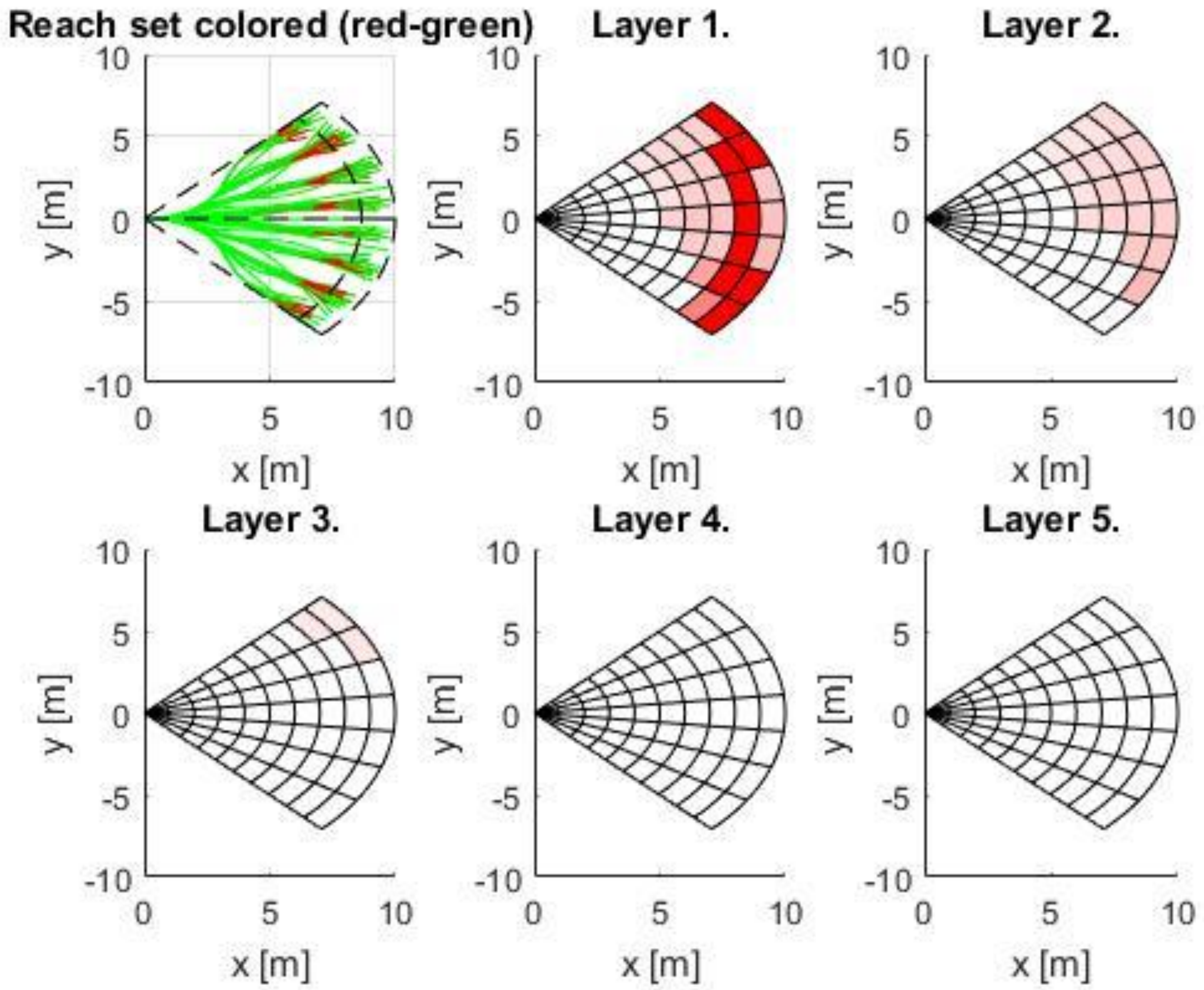
Decision Frame 10 (Obstacle Space)



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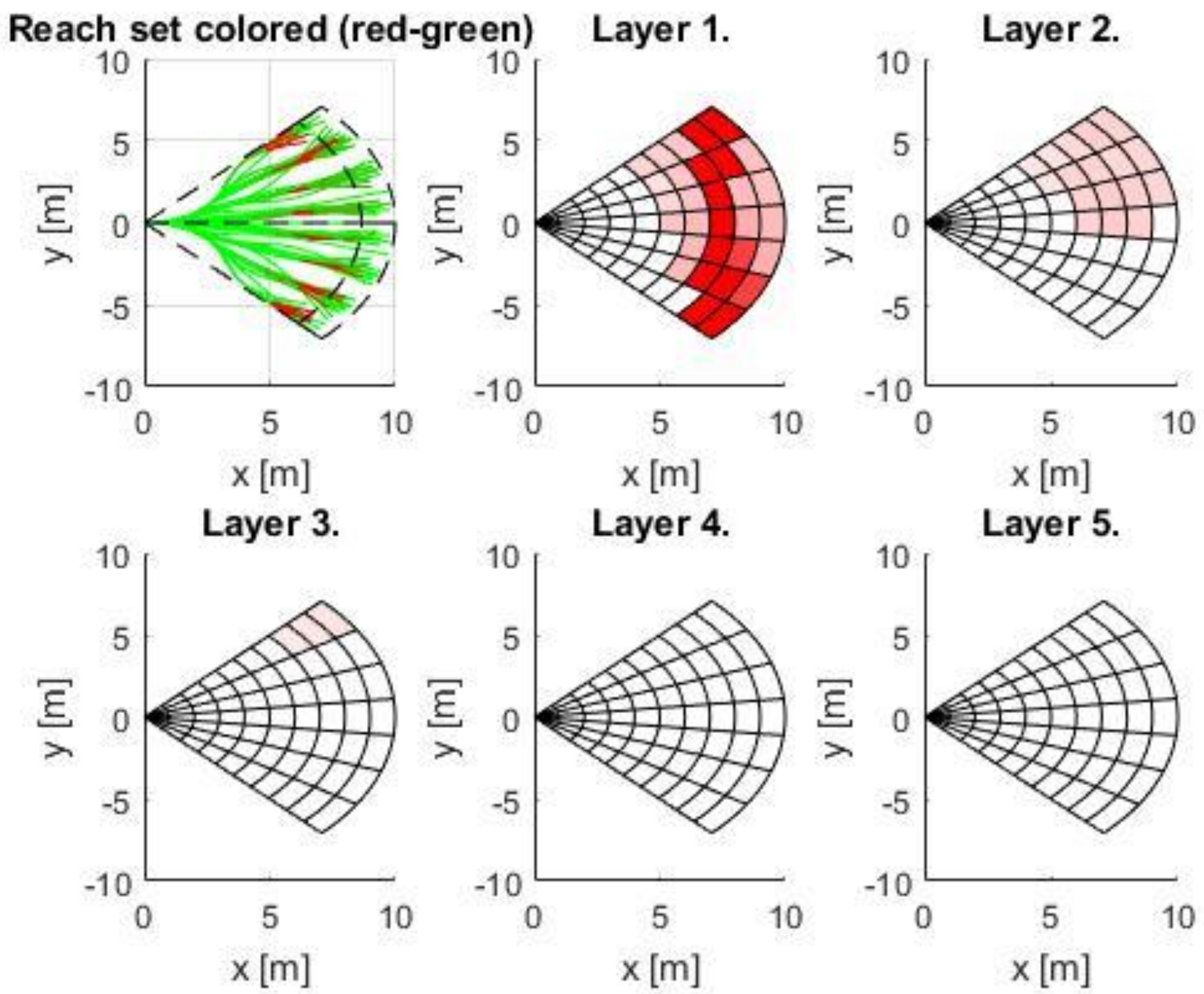
Decision Frame 11 (Obstacle Space)



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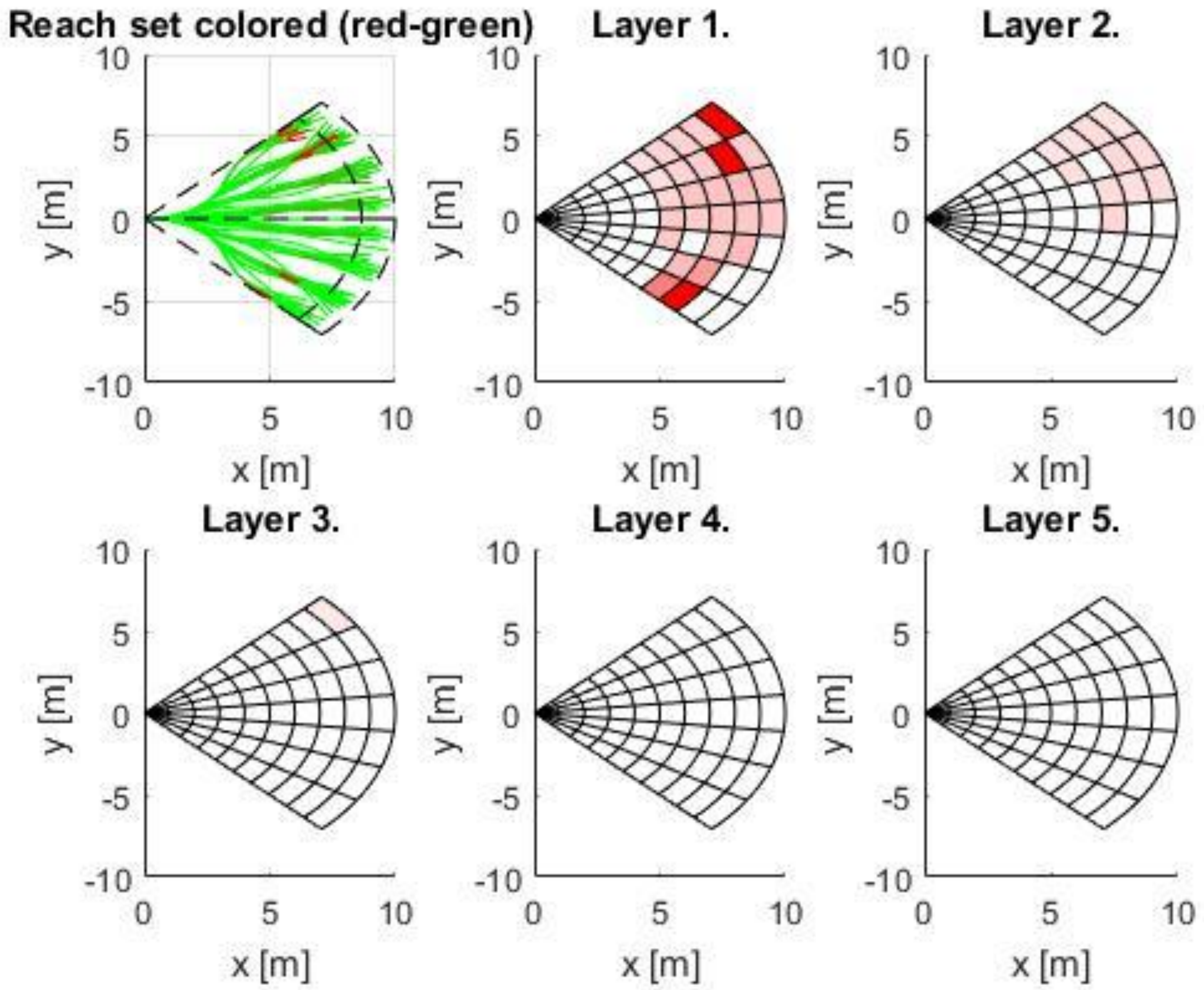
Decision Frame 12 (Obstacle Space)



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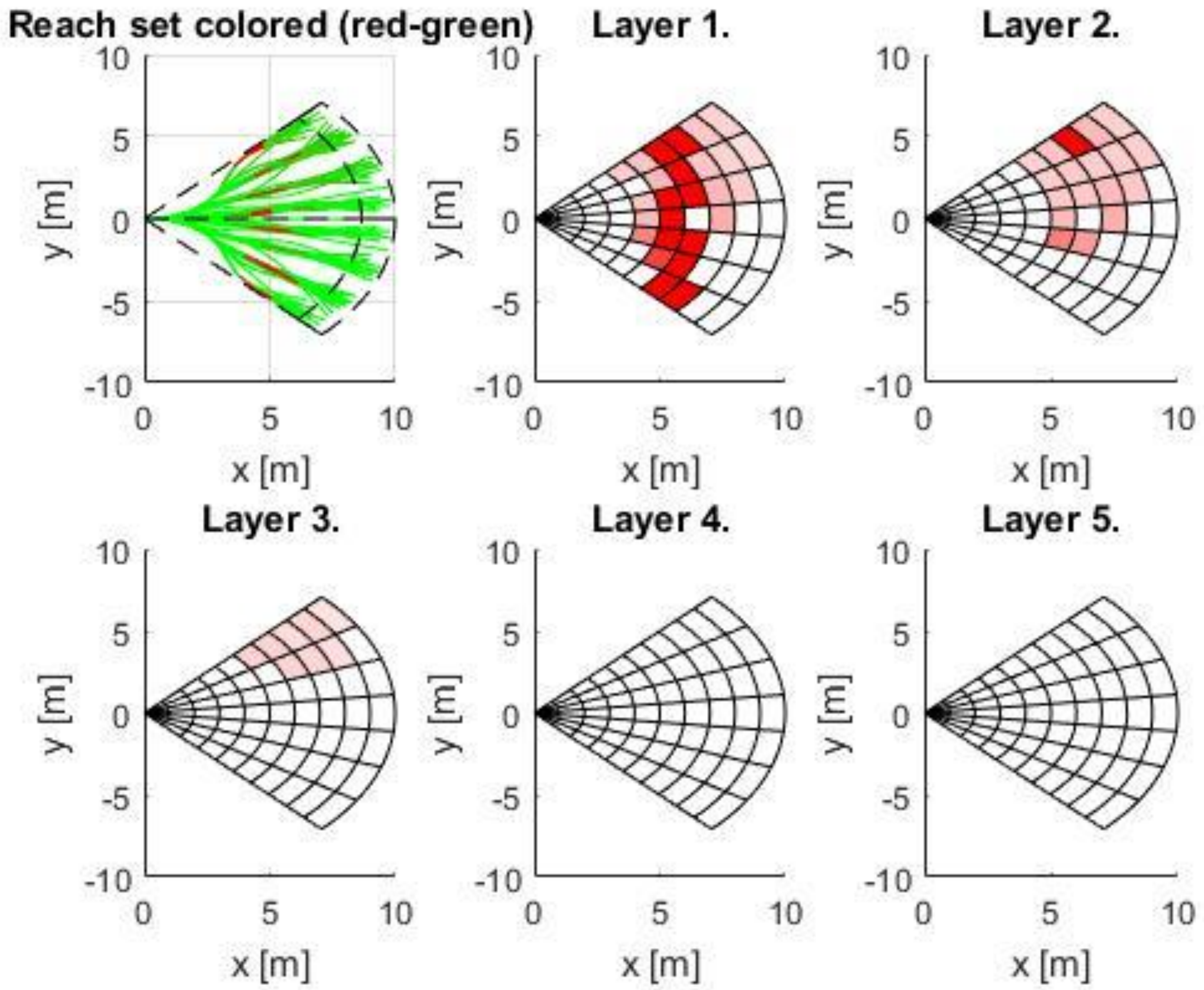
Decision Frame 13 (Obstacle Space)



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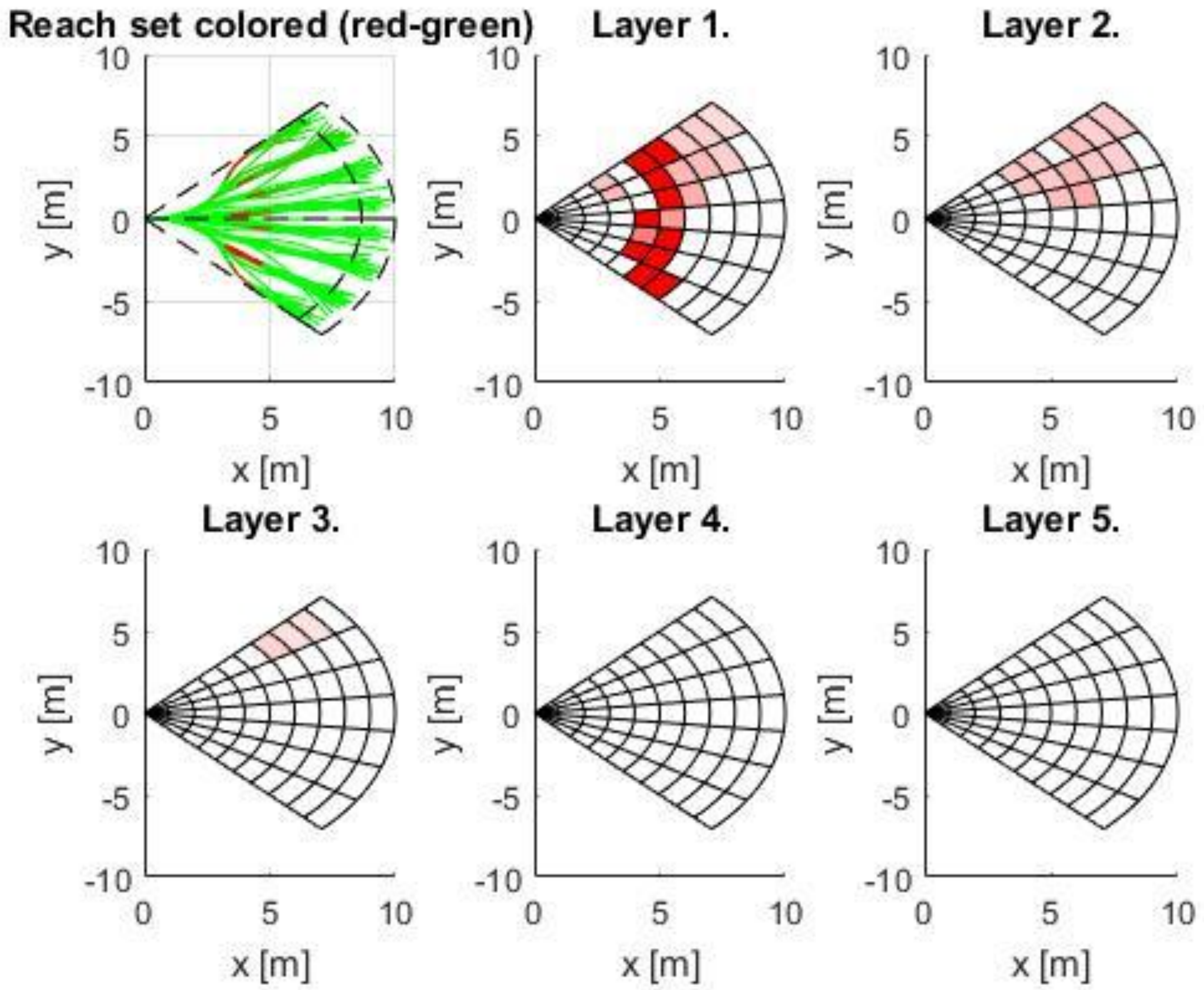
Decision Frame 14 (Obstacle Space)



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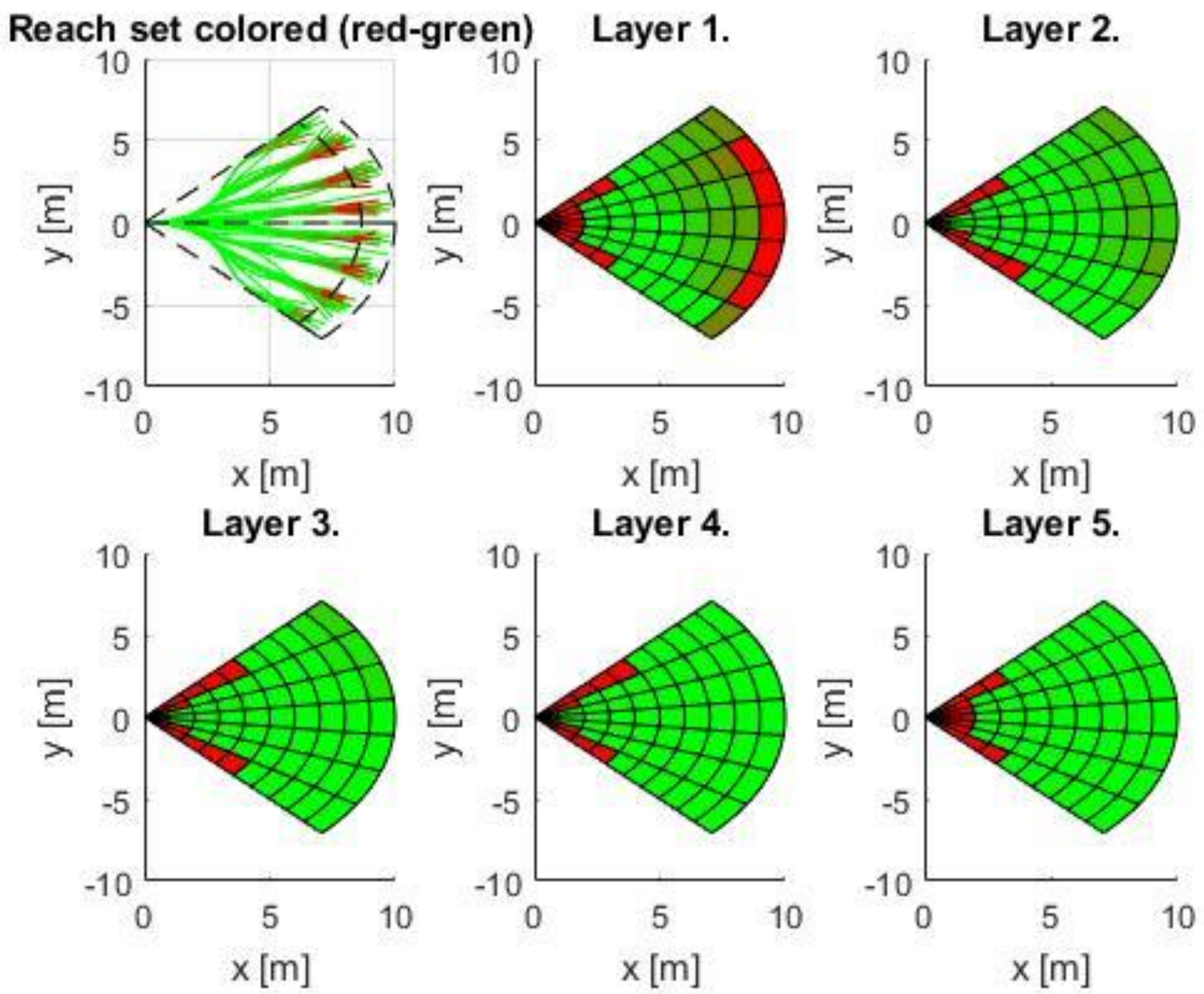
Decision Frame 7 (Reachable Space)



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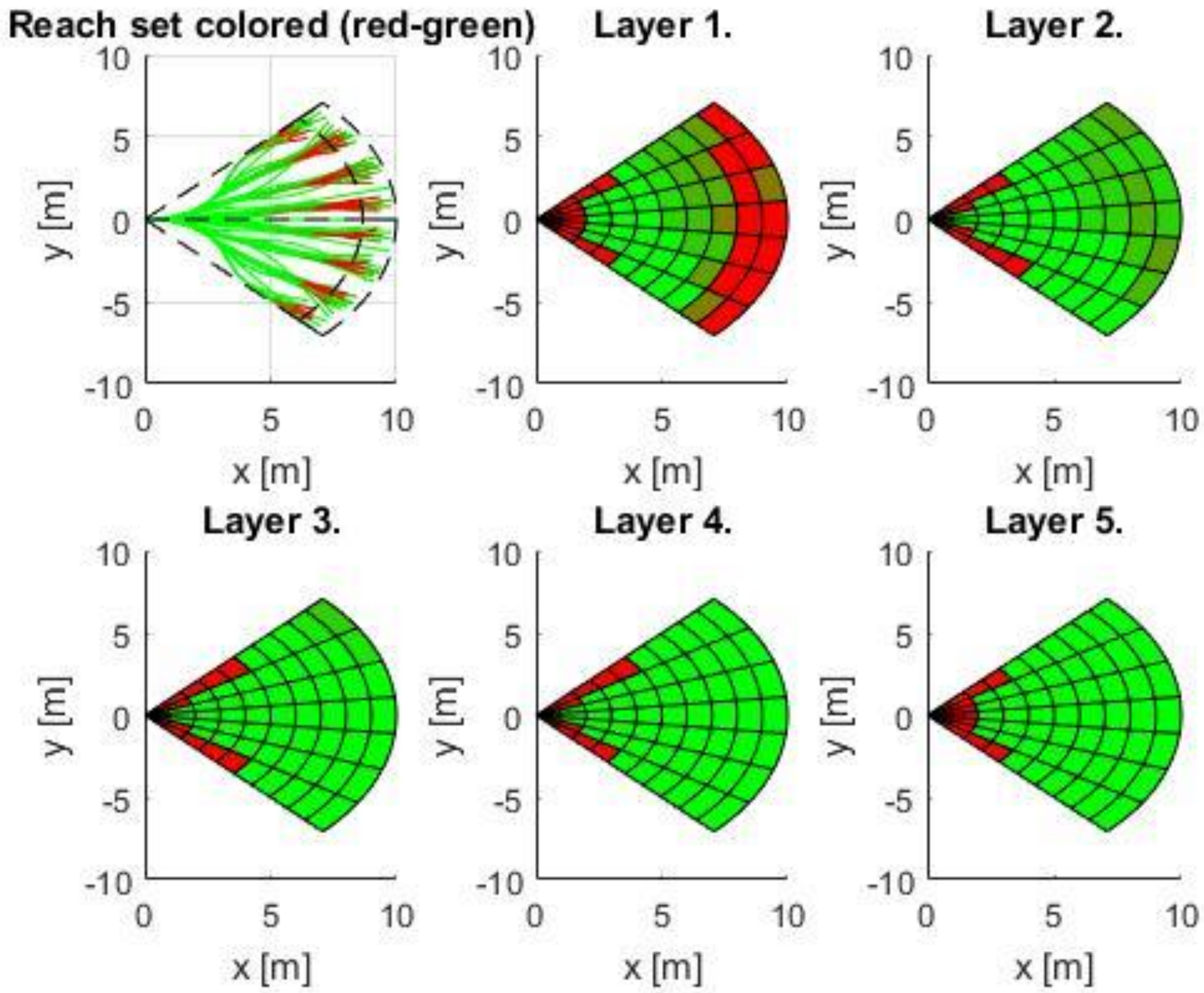
Decision Frame 8 (Reachable Space)



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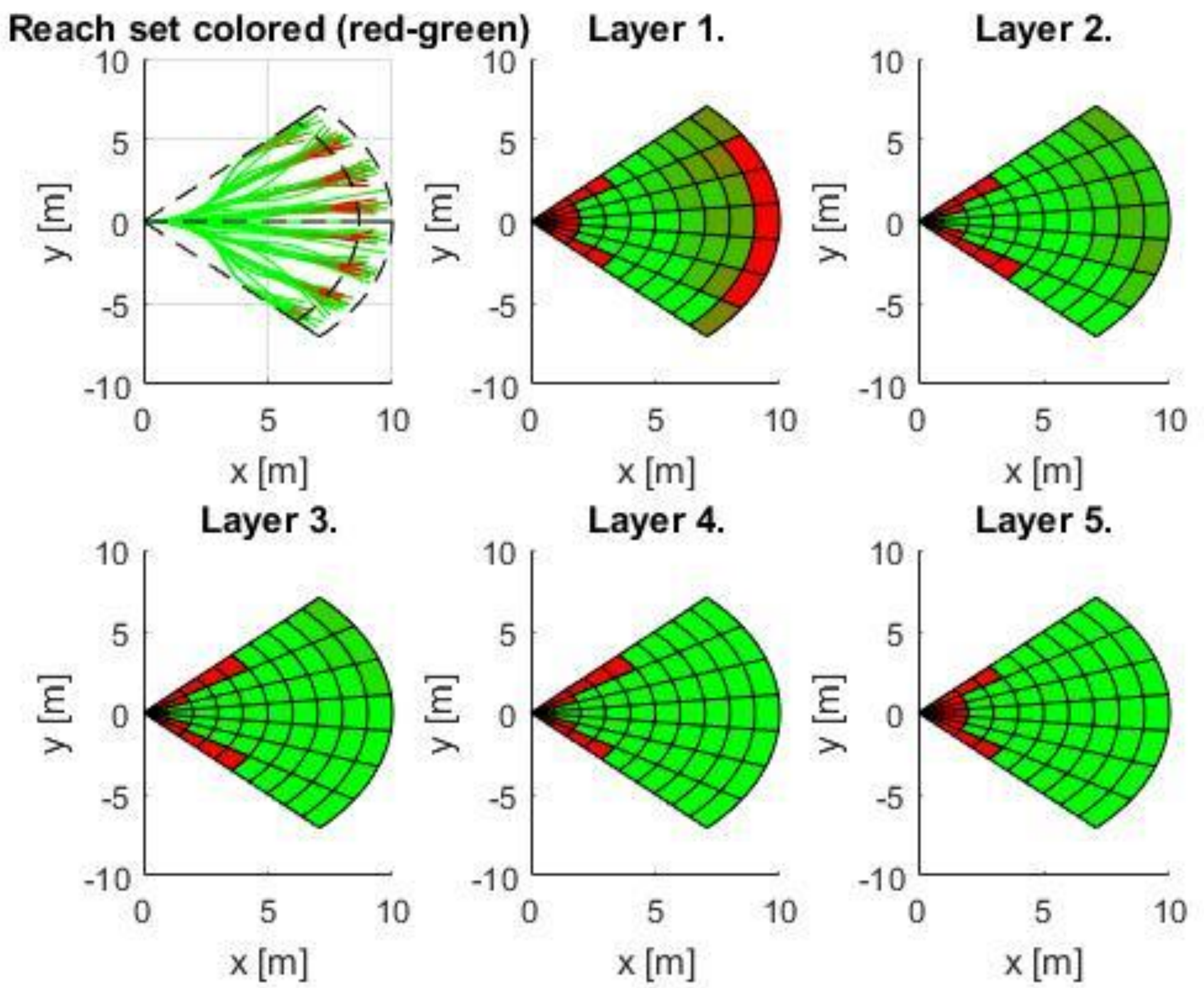
Decision Frame 9 (Reachable Space)



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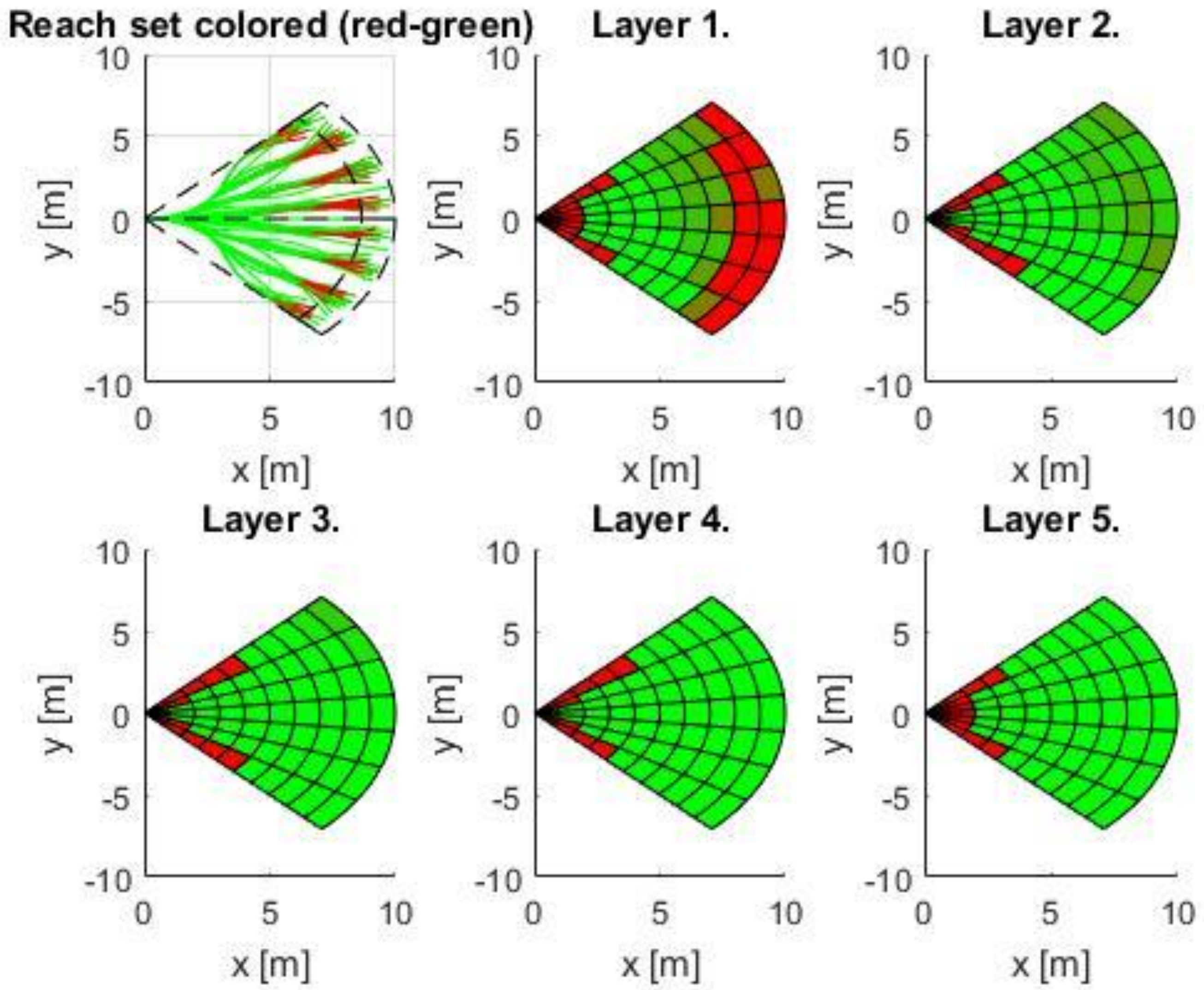
Decision Frame 10 (Reachable Space)



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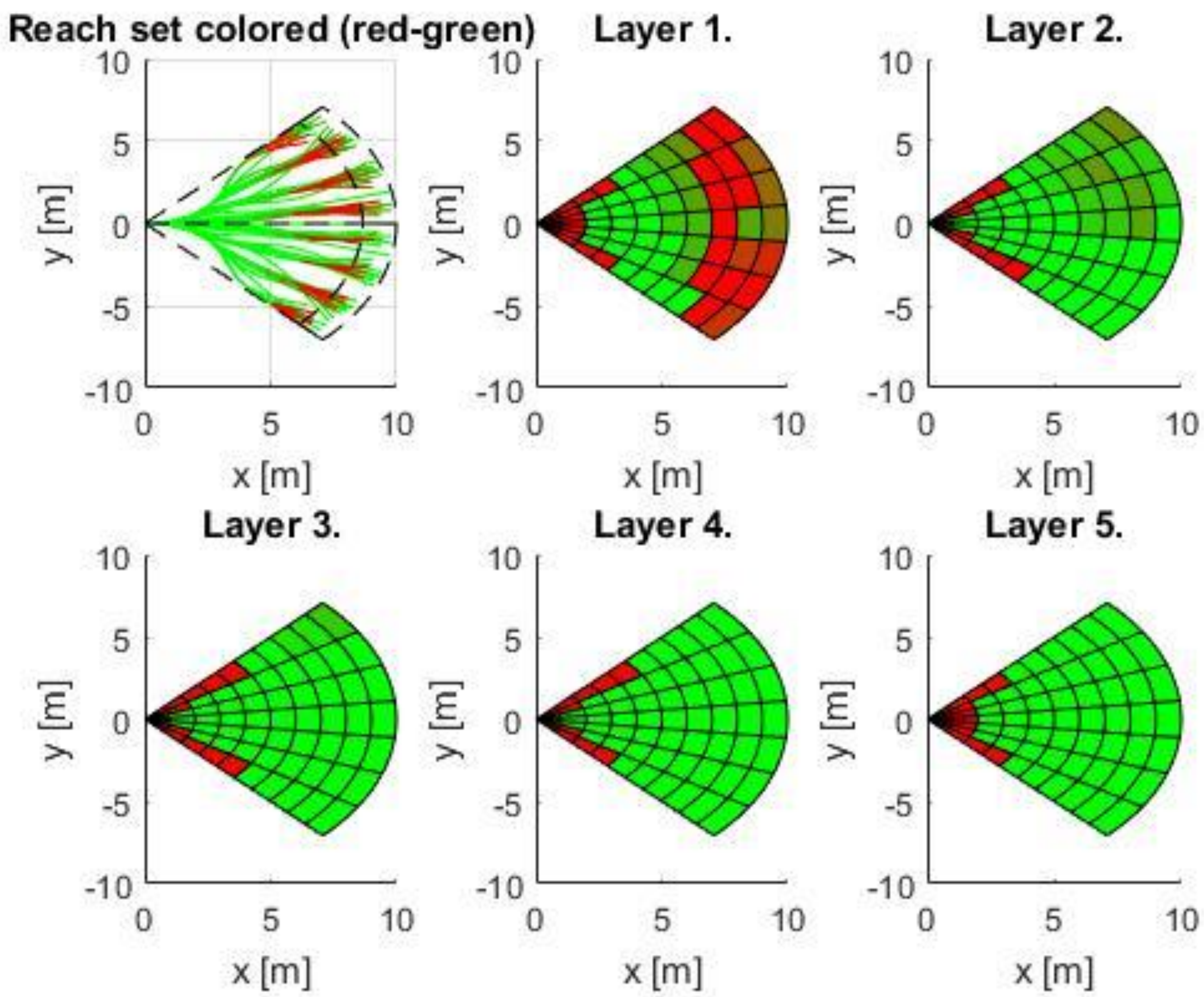
Decision Frame 11 (Reachable Space)



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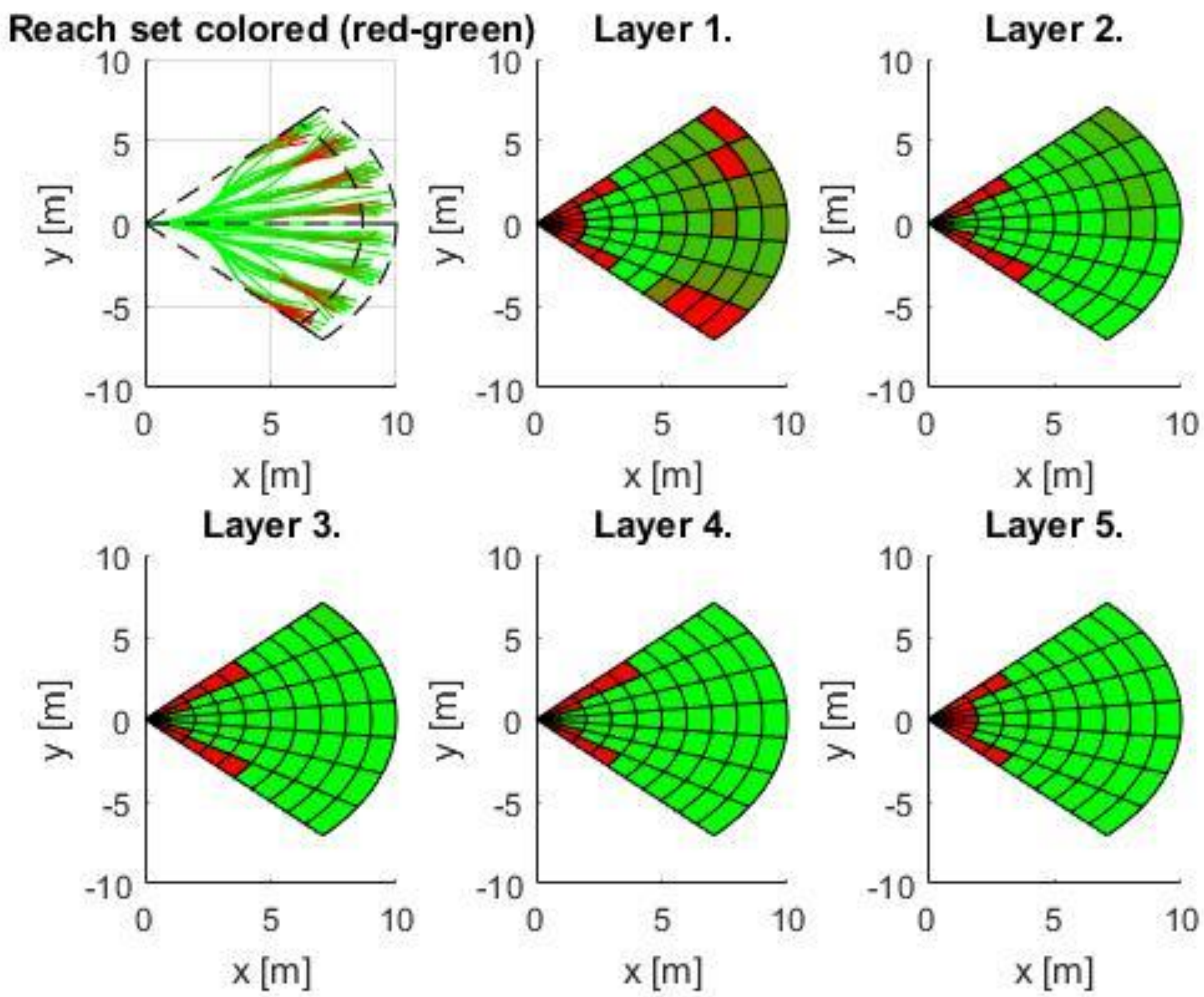
Decision Frame 12 (Reachable Space)



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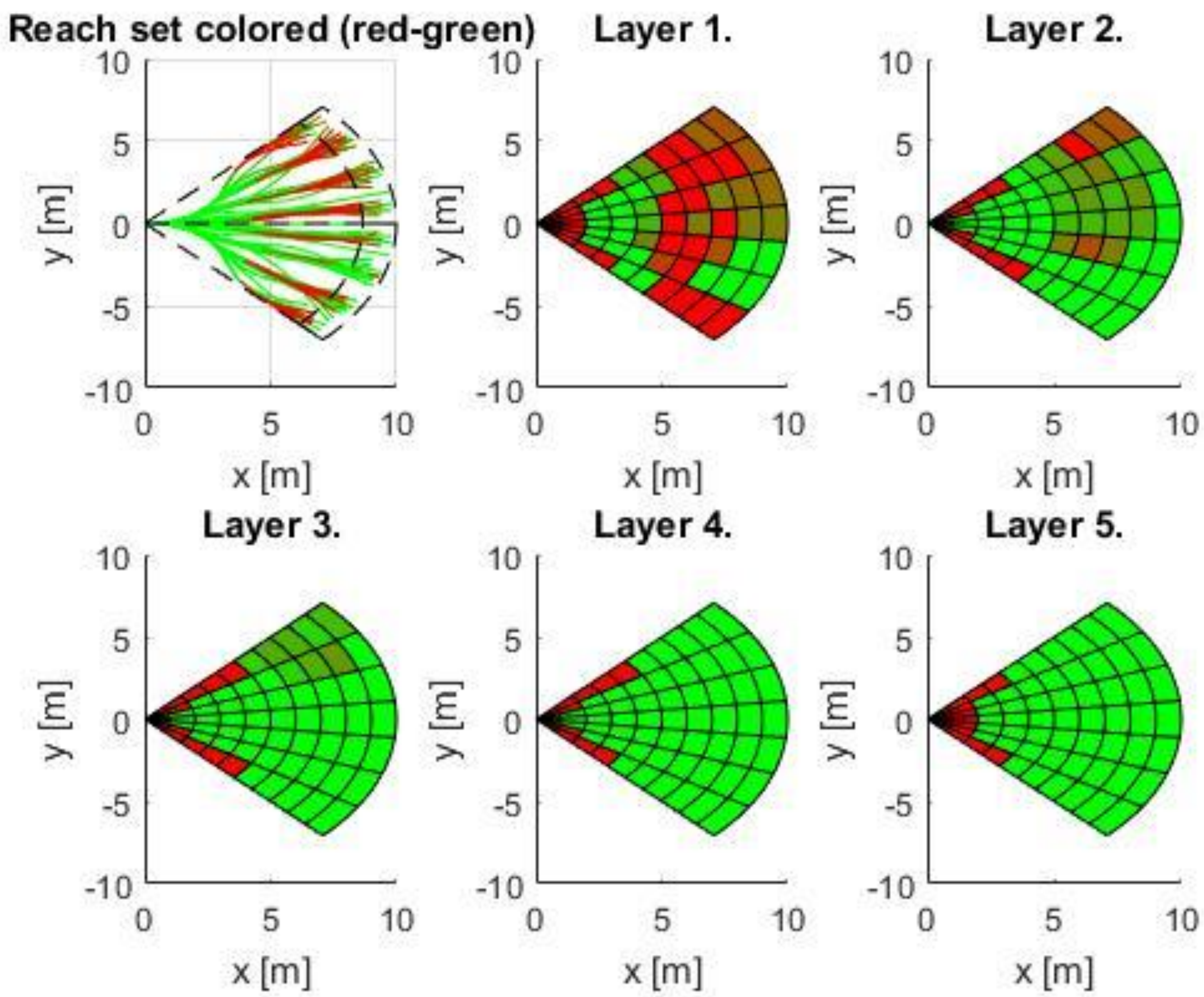
Decision Frame 13 (Reachable Space)



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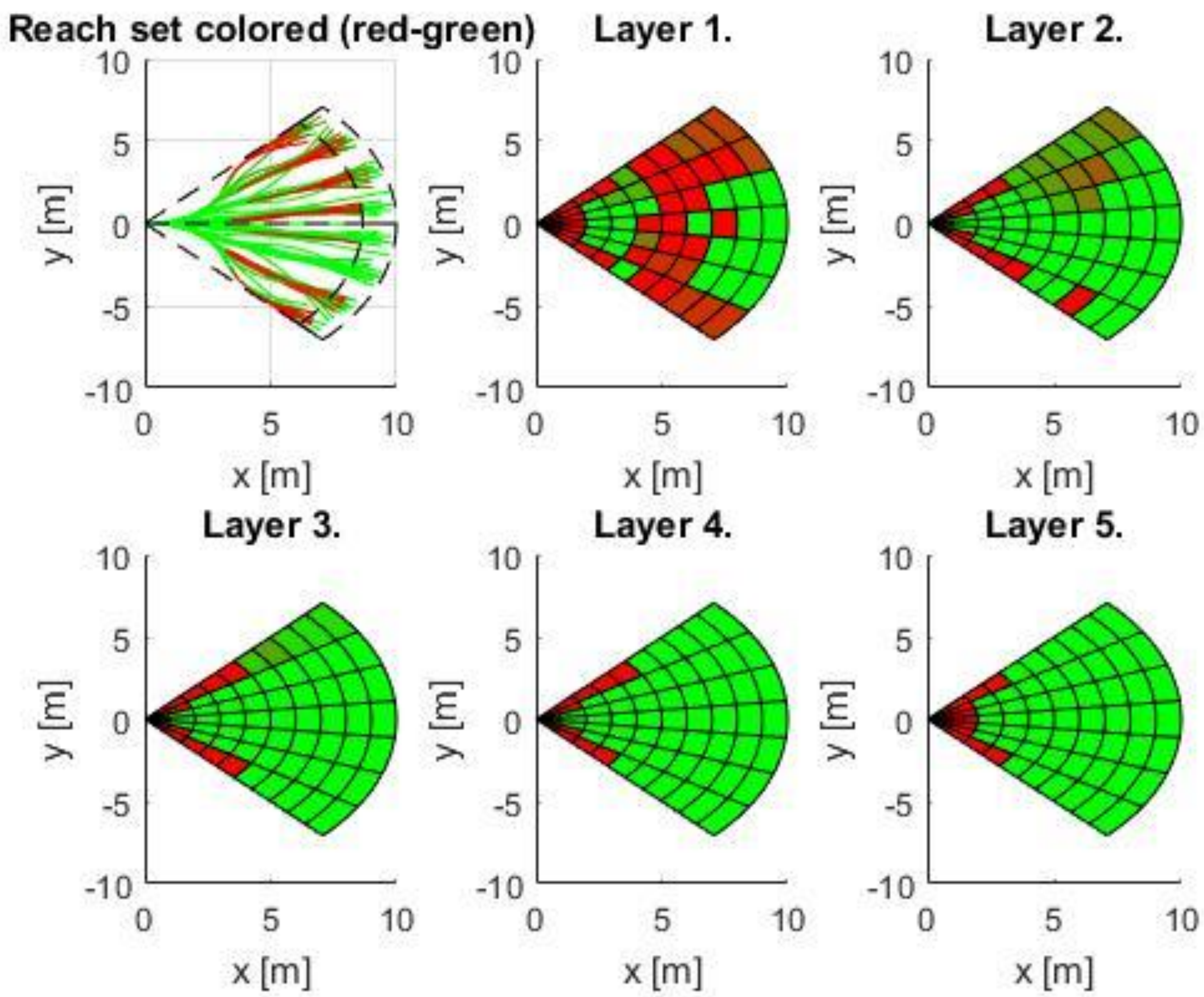
Decision Frame 14 (Reachable Space)



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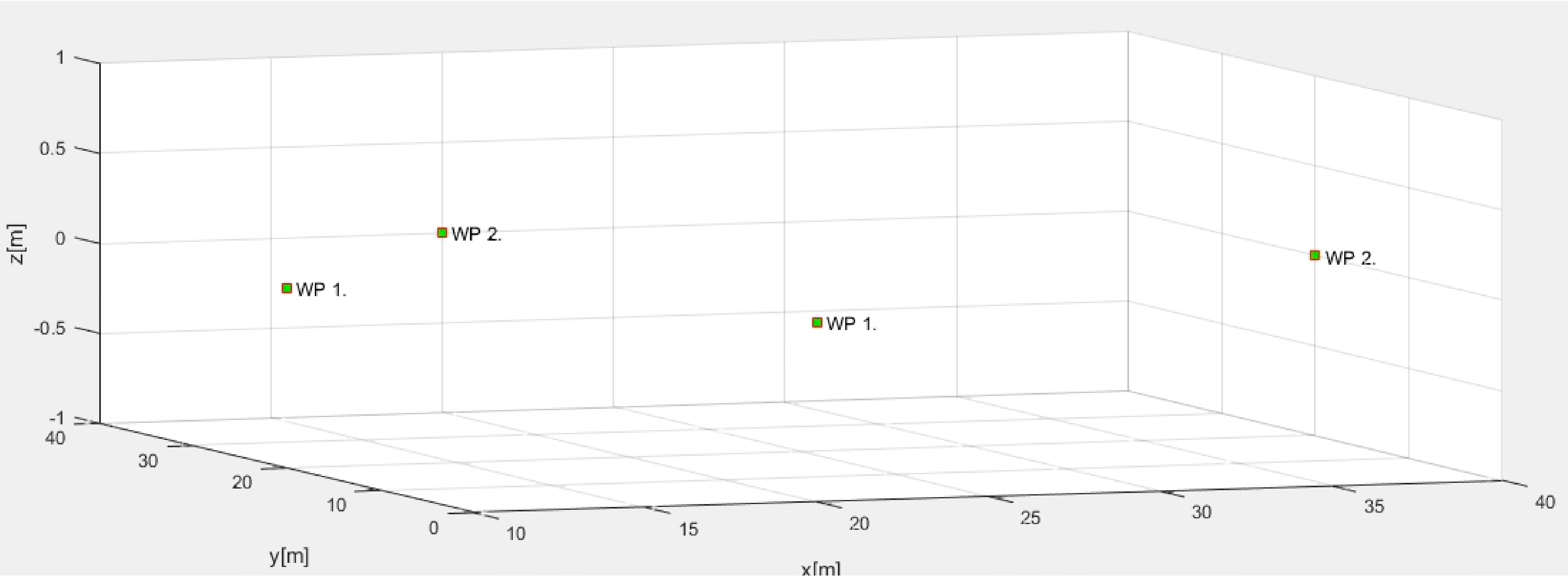
Slower speed as intruder with "Right of the way"



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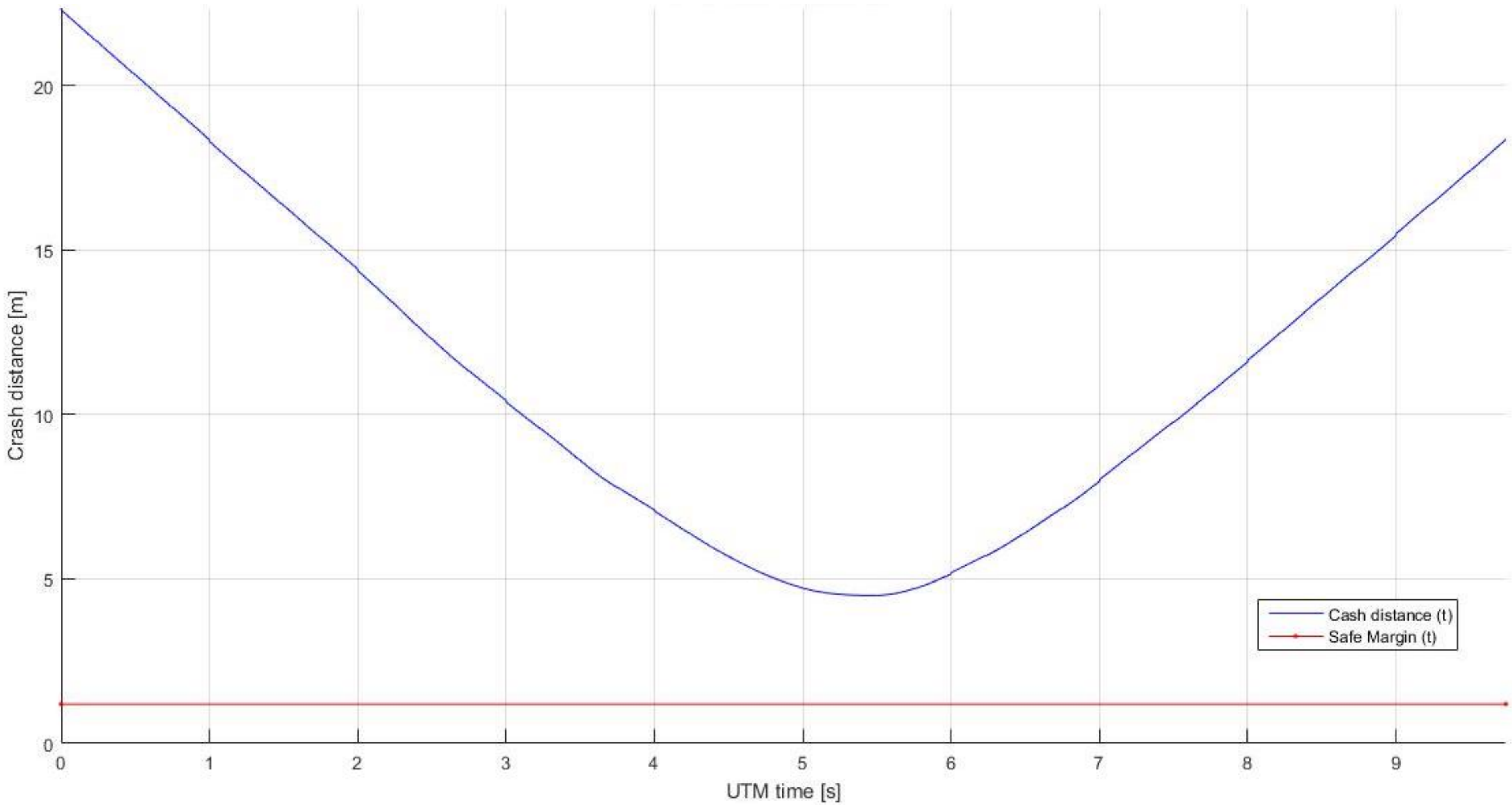
Crash distance $d_c(t)$ evolution (Normal ACAS)



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