Modelling Communication Channel Availability for Networked Radars

Adapt_MFR V3.2.9 software release notes

Prepared by:

B. Yue
C-CORE, 400 March Road, Suite 210, Ottawa, ON, K2K 3H4

Project Manager: Dr. Peter Moo 613-998-2879
Contract Number: W7714-125424
Contract Scientific Authority: Dr. Peter Moo 613-998-2879

The scientific or technical validity of this Contract Report is entirely the responsibility of the Contractor and the contents do not necessarily have the approval or endorsement of the Department of National Defence of Canada.

DRDC-RDDC-2015-C030

Contract Report
June 2014

© Her Majesty the Queen in Right of Canada as represented by the Minister of National Defence, 2014
© Sa Majesté la Reine (en droit du Canada), telle que représentée par le ministre de la Défense nationale, 2014

# Abstract

DRDC Ottawa has contracted C-CORE for software support services relating to target tracking using a stand-alone Interactive Multiple Model Nearest Neighbour Joint Probabilistic Data Association (IMM-NNJPDA) tracker and coordinated radar resource management (RRM) using an Adaptive Multi-Function Radar simulator (Adapt_MFR). When the radars in a network work in one of the RRM types, the resource manager receives the tracking and detection data from each radar through a communication channel and then sends over the resource scheduling commands through the communication channel. If the channel between radars is not available, the radars cannot be scheduled adaptively.

The purpose of this task is to evaluate the detection and tracking performance of radars under variable communication channel availability. To do so, the communication channel availability control capability was first implemented in the simulator. The target track estimation results using Scenario B with variable communication channel availability were then analyzed and compared with the results generated with the communication channel available all the time.

The experiments show that the communication channel availability status didn't affect the track completeness metrics to a noteworthy degree. The track completeness of all the coordinated management types regardless of the communication channel status was high for all experiments run. However, the track occupancy and frame time varied as the communication channel availability changed in the simulation. When the communication channel was not available, track occupancy and frame time declined to become analogous to the independent radar; when the communication channel recovered, the radars in the network resumed resource coordination and their performances increased correspondingly.

This page intentionally left blank.

Table of contents

This page intentionally left blank.

1 Introduction

DRDC Ottawa has contracted C-CORE for software support services relating target tracking using a stand-alone Interactive Multiple Model Nearest Neighbour Joint Probabilistic Data Association (IMM-NNJPDA) tracker and coordinated radar resource management (RRM) using an Adaptive Multi-Function Radar simulator (Adapt_MFR). When the radars in the network work in one of the RRM types, the resource manager receives the tracking and detection data from each radar through the communication channel and then sends over the resource scheduling commands through the communication channel. If the communication between radars is not available, the radars cannot be scheduled adaptively.

The purpose of this task is to evaluate the detection and tracking performance of radars under variable communication channel availability. To do so, the communication channel availability control capability was first implemented in the simulator. The target track estimation results using Scenario B with variable communication channel availability were then analyzed and compared with the results generated with the communication channel available all the time.

This report summarizes the work done under Task 4 Phase 2 which includes the implementation of the communication channel availability control and the new functionality testing. The track estimation results with variable communication channel status were generated using Scenario B.

2 New functionality

2.1 Central tracker structure

In this task, the simulation scenario with variable communication channel availability is: the radars in the network are setup to work coordinately either with RRM Type 1 or Type 2, but the communication channel is not always available during the simulation time. When the communication channel is not available, each radar should conduct detection and tracking independently using its own tracker. When the communication channel is available, a central tracker should take over the work, it will process the detection data from all the radars and then conduct tracking using these data.

Based on the simulation scenario, the independent trackers and central tracker in the simulation should exist simultaneously but do the tracking work alternatively. The previous version (V3_2_8) of the IMM tracker did not support this functionality. To generate and keep both independent and central tracker structures available through the simulation time, the tracker structure of the IMM tracker was modified first. To accommodate this modification, several modifications to the IMM tracker code and the simulator code were also conducted, these modifications includes:

...\IMMTracker\IMMTracker.m

- line 112: added a new column for the central tracker structure to avoid overwrite the tracker structure for Radar 1.
- line 843: added one condition to check the *assn _radar_perm_flag* parameter of the tracker to make sure the assigned radar can be changed only in the case when assn *_radar_perm_flag* is 0.

...\Main\adaptmfr_run.m

- line 668: added one more tracker structure to be initialized for central tracker if coordinated RRM types are used.
- line 2921: added one more loop for central tracker if coordinated RRM types are used.

...\Gui\cbAnalysis.m

- line 133: added one more figure to plot the prediction and estimation results from central tracker if coordinated RRM types are used.
- line 269: added one more loop to save the analysis data for central tracker if coordinated RRM types are used.

...\Main\whats_next_adaptive.m

- line 349-350: changed *time_bal(tmp)* to *time_bal(n)*. This should be a bug that was not corrected from previous modification.

- line 1146-1155: added *try-catch* block in case the tracker hasn't been initialized yet.
- line 760: changed the conditions which have to be satisfied to schedule a confirmation beam. After modification, a confirmation beam cannot be scheduled if the detection beam has the biggest time balance value.

2.2 Communication channel availability control functionality

As mentioned, two coordinated RRM types, Type 1 and 2 were tested in the simulation when the communication channel status was variable. In the simulation, the simulation time was divided into several time intervals, the communication channel may be either available or not available in each interval. The simulator behaviors are described in detail in Table 1 at the communication channel availability switching moment.

Table 1: *Simulator behaviors with variable communication channel availability*

RRM Type 1 behavior:	
Available -> not available	For each tracked target, the assigned radar continues to track that target. For example, if a target is being tracked by Radar 1, then Radar 1 continues to track the target. If Radar 2 detects the target, then Radar 2 will attempt to initiate and confirm a track on that target.
Not available -> available	If the radars have separate tracks of the same target, then the tracks are fused into one track and assigned back to central tracker to the radar that was assigned to the track initially.
RRM Type 2 behavior:	
Available -> not available	For each tracked target, the radar that last updated the track continues to track that target. For example, if the last update of a target was done by Radar 1, then Radar 1 continues to track the target. If Radar 2 detects that target, then Radar 2 will attempt to initiate and confirm a track on that target.
Not available -> available	If the radars have separate tracks of the same target, then the tracks are fused into one track and assigned back to central tracker. For each subsequent track update, the update is assigned to the radar based on the current calculated range and priority results.

Several global variables are added in adaptmfr_run.m to build up the communication channel availability control vectors.

- *communication_channel_always_on*
  1: communication channel is available during the simulation time;
  0: communication channel is not always available during the simulation time.
- *communication_channel_on_and_off_switch_interval*
  Unit time which defines the smallest interval time during which the communication channel

status is stable, e.g. if the value is 10, it means that the communication channel can be available or not available for 10 seconds, or multiples of 10 seconds.

- *communication_channel_on_time_percentage*
  Given the simulation time, this parameter defines the percentage of the simulation time during which the communication channel is available.

Two new functions are added to the .\Main folder of the simulator:

...\Main\communication_availability.m
...\Main\communication_channel_control.m

The communication channel availability control vectors are generated by *communication_availability.m* function with the global parameters described above as inputs. The outputs of this function are:

- *commu_channel_interval_start_time*
  A line vector, the value in each cell defines the start time of each interval.
- *commu_channel_interval_end_time*
  A line vector, the value in each cell defines the end time of each interval.
- *commu_interval_availability*
  A line vector with values 0 or 1. 0 means the communication channel is not available during the interval, 1 means the communication channel is available during the interval.

The communication channel availability control was implemented in *communication_channel_control.m* function and it is only called by *adaptmfr_run.m* when *communication_channel_always_on* is 0. When the radars in the network work in one of the coordinated RRM types, this function decides the RRM type the radars should use based on the communication channel availability. When the communication channel is not available, the radars are setup to work independently; when the communication channel recovers, the radars are assigned to work for the central tracker in their initial coordinated RRM type. The data and information transfered between the independent and central trackers are also implemented in this function.

3 Testing with Scenario B

3.1 Simulation setups

The top view of the scenario (Scenario B) simulated in this task is shown in Figure 1. In this scenario, a two-radar network system with 30 targets were modeled. Radar 1 was positioned at [0,0] and Radar 2 at [0,-10km]. The initial position of each target is indicated by a red triangle.

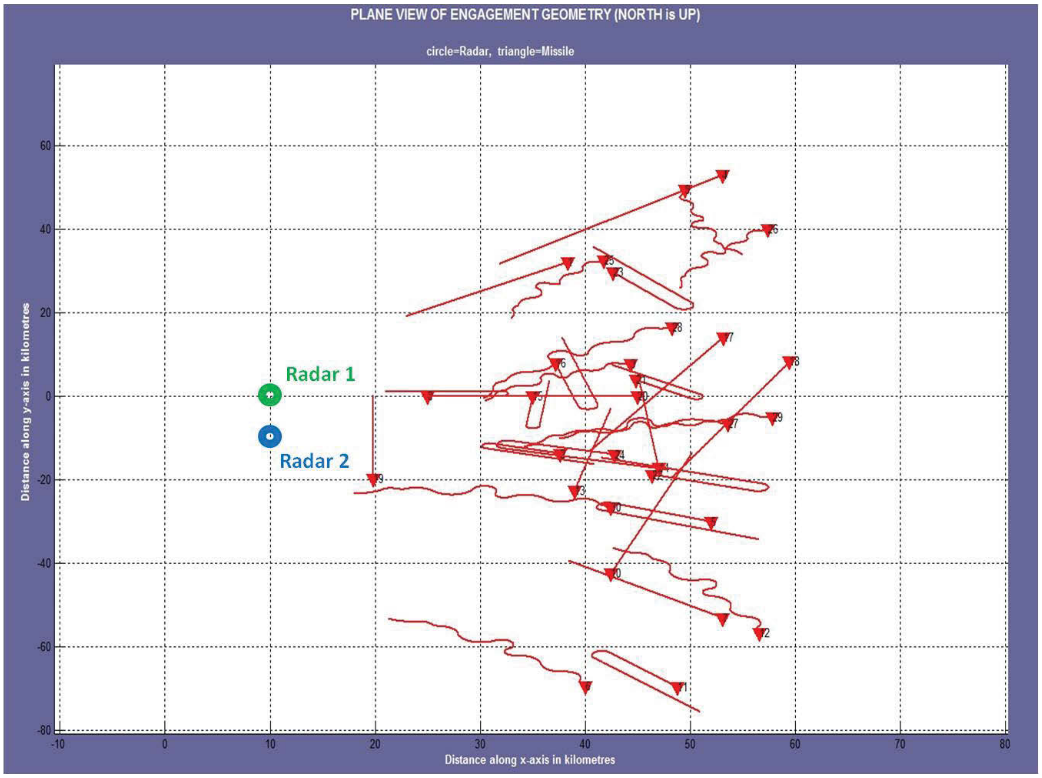


Figure 1: *Radar positioning and target trajectories for Scenario B*

Three target trajectory types were simulated in the scenario: straight line, U-turn, and weave trajectories. The parameters used to define the three trajectory types are listed in Table 2. The targets were created using the Adapt_MFR GUI Missile Editor, their initial parameters are given in Table 3. Constant speed and altitude for each target were used.

Table 2: *Target trajectory types*

Trajectory type	*Leg #*	*Duration* (s)	*Head** (deg)
1	1	200	0
2	1	70	0
	2	20	180
	3	110	0
3	1	5	0
	2	5	-45
	3	20	110
	4	20	-90
	5	25	90
	6	15	-150
	7	25	180
	8	30	-120
	9	20	80
	10	5	-55
	11	5	25
	12	5	45
	13	20	-45

* Head: target heading at end of leg relative to start degree, CCW is positive direction.

Table 3: *Scenario B target parameters*

Target ID	*altitude* (m)	*Head* (deg)	*Range* (km)	*Velocity* (m/s)	*Azimuth* (deg)	*RCS* (m^2)	*Trojectory type*
1	500	0	50	100	90	50	1
2	750	0	40	100	110	50	2
3	600	3	45	100	80	75	3
4	500	0	75	150	45	75	1
5	750	5	60	150	120	50	2
6	600	0	80	150	150	50	3
7	500	2	75	100	135	75	1
8	750	-180	25	100	90	75	2
9	600	45	70	100	45	50	3
10	500	-60	60	150	135	50	1
11	750	3	85	150	145	75	2
12	600	-30	80	150	135	75	3
13	500	-70	45	100	120	50	1
14	750	-65	50	100	110	50	1
15	600	85	35	100	90	75	2
16	500	90	38	150	78	75	2
17	750	50	55	150	75	50	1
18	600	60	60	150	82	50	1
19	500	-45	28	100	135	75	1
20	750	0	45	100	90	75	1
21	600	135	45	100	85	50	2
22	500	180	50	150	112	50	2
23	750	90	52	150	55	75	2
24	600	0	45	150	108	75	2
25	500	0	53	100	52	50	3
26	750	5	55	100	66	50	3
27	600	0	54	100	97	75	3
28	500	5	51	150	71	75	3
29	750	2	58	150	95	50	3
30	600	5	50	150	122	75	3

$^{\text{Head}}$: 0 degrees is towards Radar 1, CCW is positive direction.
$^{\text{Range}}$: initial ground range on top view plane.
$^{\text{Azimuth}}$: degree from north to target, CW is positive direction

Table 4 lists the three RRM types simulated in this task. Type 1: Permanent assignment means the radar assigned to a track is not changed once initially assigned; Type 2: dynamic assignment means the assigned radar changes at each track update based on the current calculated range and priority results; Independent RRM: Radars work independently without coordinations between each other. Track assignment is based on minimum range of the target to the radars and the maximum fuzzy logic priority. If the range or priority are the same the other parameter is used to determine assignment. If both are the same the track is assigned to Radar 1.

Table 4: *RRM types*

RRM Type	*Track assignment*
Type 1	coordinated system with permanent track assignment, min range then max priority
Type 2	coordinated system with dynamic track assignment, min range then max priority
Independent RRM	independent radars, no coordination between radars

The radar system parameters used by Adapt_MFR are listed in Table 5.

Table 5: *Adapt_MFR parameters used in simulations*

Radar 1,2	Azimuth boresite*: 90 degree Elevation boresite*: 0 degree Antenna height: 30 m
Track update rates:	Target priority ≥ 0.75: update rate = 1.5 s Target priority < 0.75: update rate = 3 s
Scenario length	200 s

* 0 degree is north, CW is positive direction.

The communication channel availability vectors used in this experiment were fixed in the experiment and same for RRM Type 1 and Type 2 in order to analyze and compare their performances. Table 6 lists these vectors.

Table 6: *Communication channel on and off setup*

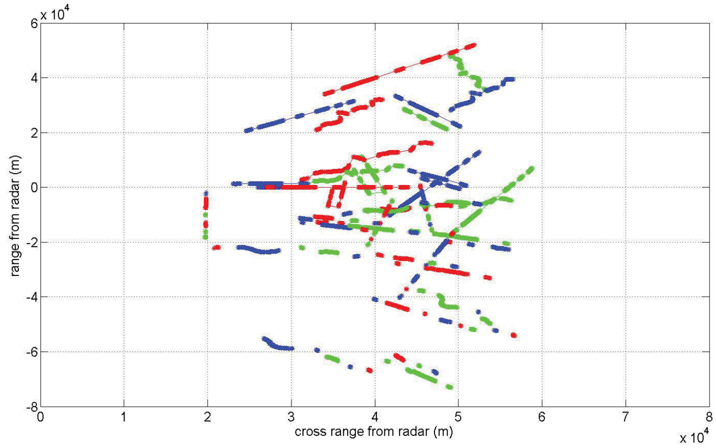
Interval start	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
Interval end	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Availability	1	0	1	0	1	0	0	1	1	0	1	1	0	0	0	0	1	0	1	1

3.2 Results

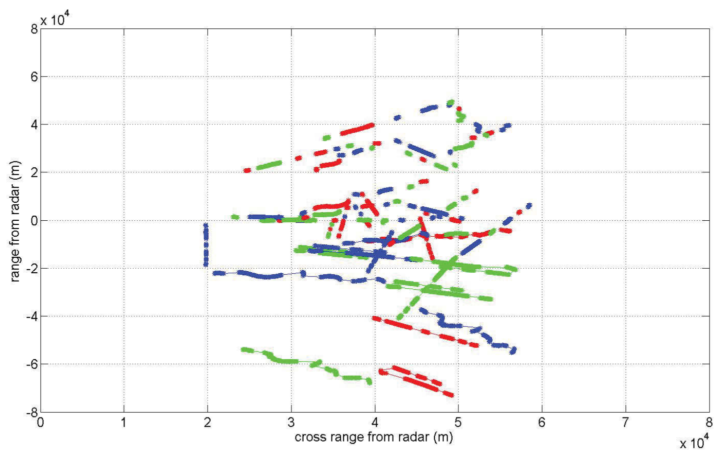
Figure 2 shows the track prediction results from the Radar 1, Radar 2 trackers and the central tracker when RRM Type 1 was used. Figure 3 shows the results of RRM Type 2 from the three trackers.

A close look at how the radars worked in different RRM types when the communication channel switched between available and not available, Figure 4 shows the track prediction result on a single target, target 19. As shown in Figure 1, the trajectory of target 19 started at a location closer to Radar 2, it flew straight up to the north direction passing Radar 2 first and then entered to the area closer to Radar 1, and finally ended at a location in that area. When using RRM Type 1, the tracking task of this target would be permanently assigned to Radar 2; however the tracking task would be assigned to Radar 2 first and then switched to Radar 1 when using RRM Type 2.

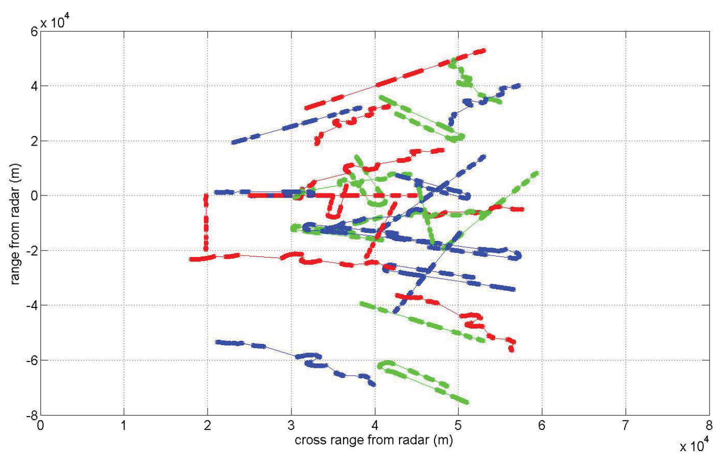
The left column of Figure 4 shows the track estimation results from the individual radar trackers and central tracker using RRM Type 1. In the first interval, the communication channel was available, so the tracking task started by the central tracker, the track ID generated by the central tracker is 30. During the whole simulation time, track 30 was always assigned to Radar 2 when the communication channel was not available, and taken over again by the central tracker when the communication channel became available. Radar 1 was also able to detect and track this target when the communication channel was not available, however a new track was always launched (they were not connected as shown in the figure). The RRM Type 2 results were shown on the right column, the track was assigned to Radar 2 at the beginning of the simulation, as the target flew closer to Radar 1, the track assignment was switched from Radar 2 to Radar 1 by the central tracker in one simulation interval; and then when the communication channel became not available, track 30 was assigned to Radar 1 as indicated by the black arrow on the top of Figure 4 (d), and Radar 2 initiated a new track when it detected this target in the same interval.



(a)

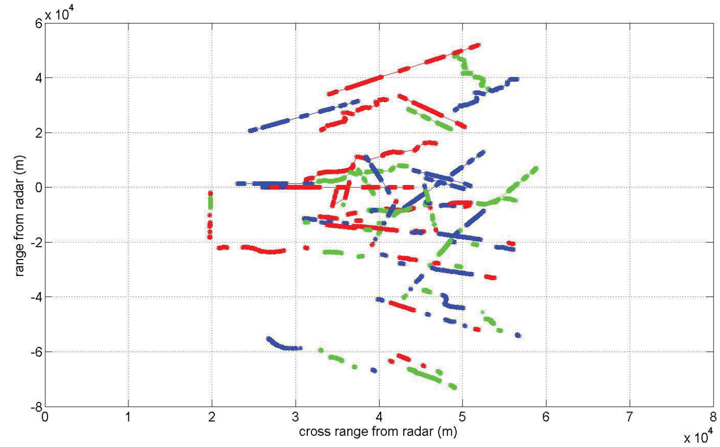


(b)

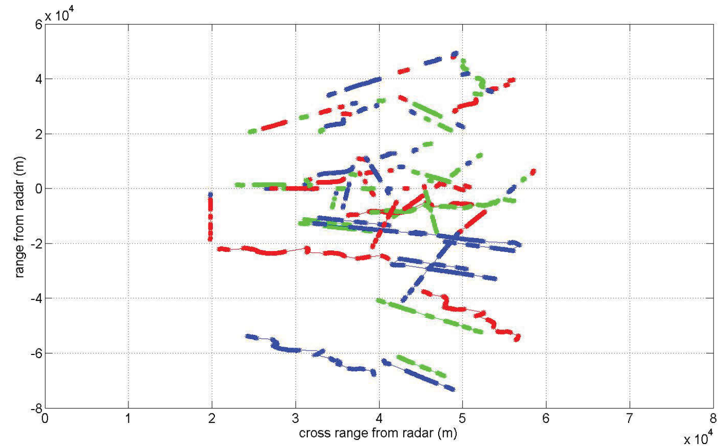


(c)

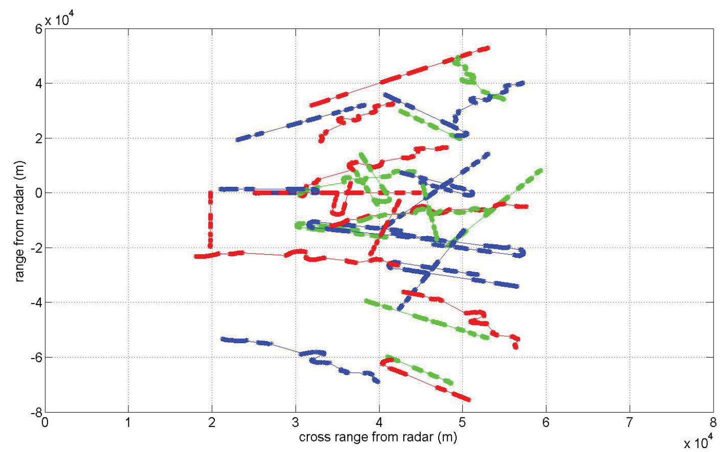
Figure 2: *Scenario B target track estimations with variable communication channel availability for RRM Type 1. (a) Radar 1 tracker. (b) Radar 2 tracker (c) Central tracker.*



(a)



(b)



(c)

Figure 3: *Scenario B target track estimations with variable communication channel availability for RRM Type 2. (a) Radar 1 tracker. (b) Radar 2 tracker (c) Central tracker.*

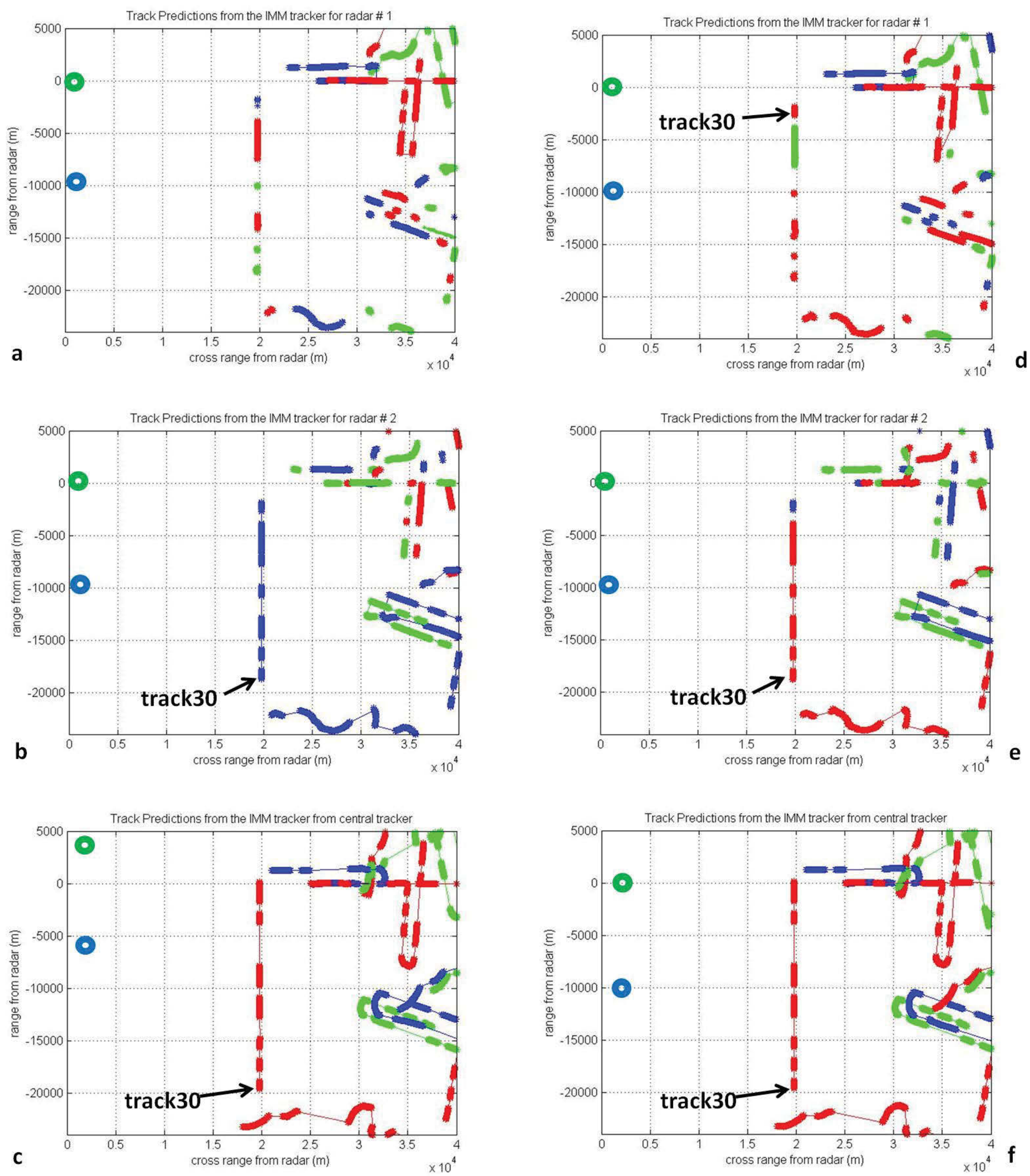


Figure 4: *Target 19 track estimation with variable communication channel availability. Left column: RRM Type 1 (a) Radar 1 tracker. (b) Radar 2 tracker. (c) Central tracker. Right column: RRM Type 2 (d) Radar 1 tracker. (e) Radar 2 tracker. (f) Central tracker.*

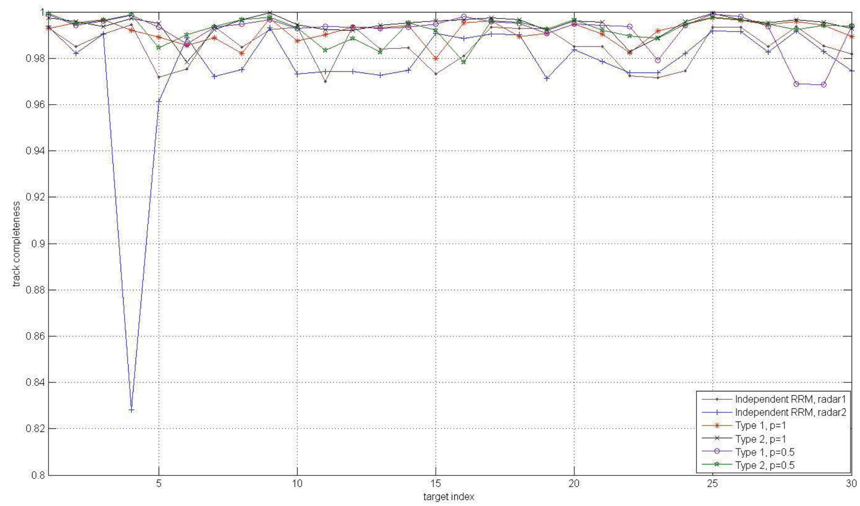
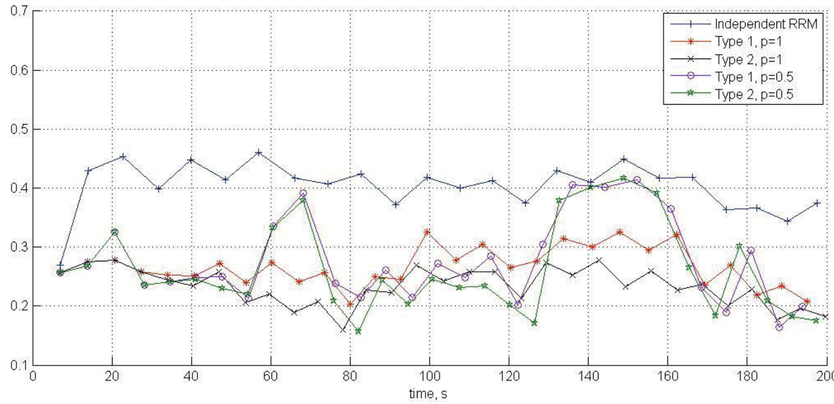


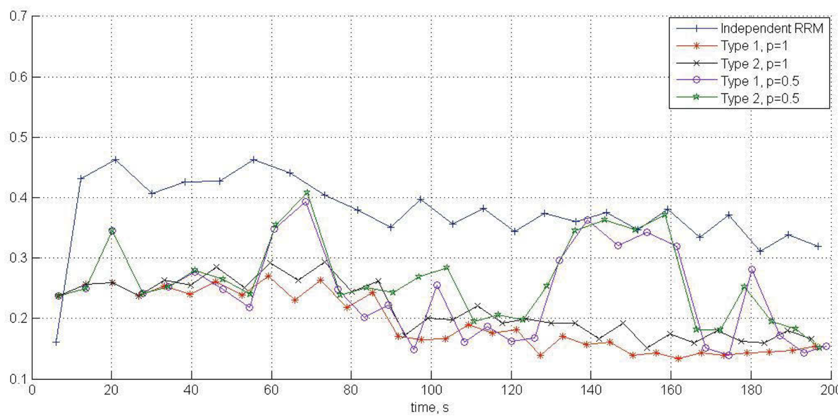
Figure 5: *Track completeness of Scenario B*

The track completeness, track occupancy and frame time of the three RRM type networks are shown in Figure 5, 6 and 7. When the communication channel was available during the whole simulation interval, the cases were represented as p=1 (availability probability=100%) in the figures; p=0.5 means the communication channel is available during 50% of the simulation time. In each figure, five cases were plotted: independent radar, RRM Type 1 with communication channel always available (Type 1, Commu 1), RRM Type 2 with communication channel always available (Type 2, Commu 1), RRM Type 1 with communication channel not always available (Type 1, Commu 0), RRM Type 2 with communication channel not always available (Type 2, Commu 0).

As shown in Figure 5 the communication channel availability status has minimal effect on the track completeness metrics. The track completeness of all the coordinated management types regardless the communication channel status was all similar and at a very high level. This implies that the network of each RRM type was not over loaded, it was always able to assign a radar resource to track each target during the simulation time. However, the performances of the networks in the aspects of track occupancy and frame time varied as the communication channel availability changed in the simulation. When the communication channel was not available, the performance of the radars in the aspects of track occupancy and frame time declined to the independent radar level; when the communication channel recovered, the radars in the network worked cooperatively again and their performances also recovered to their initial levels.

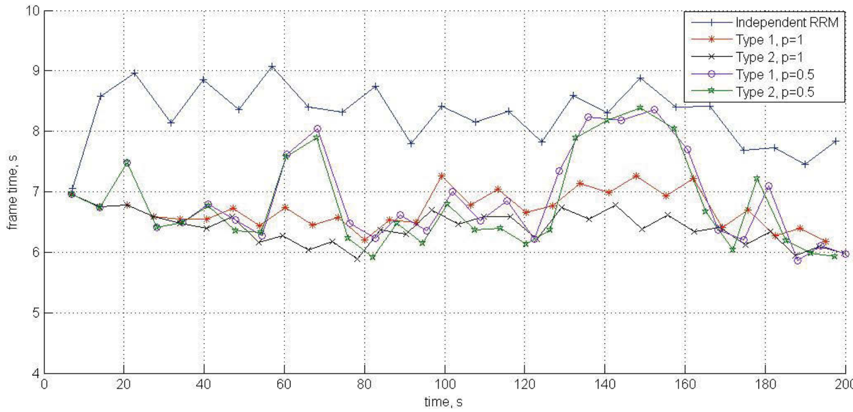


(a)

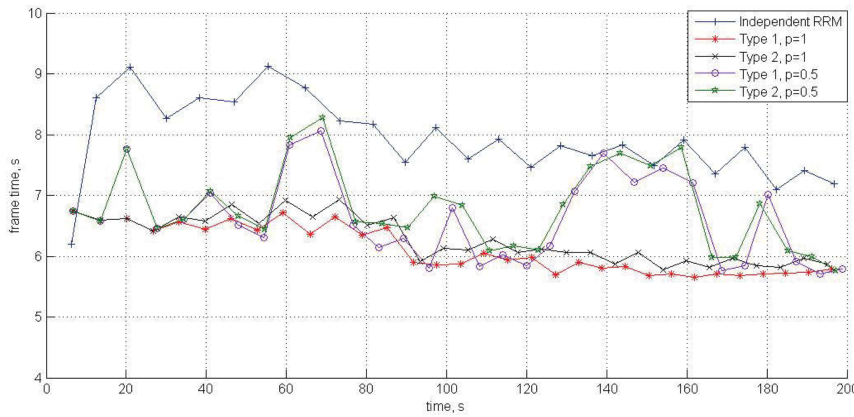


(b)

Figure 6: *Scenario B track occupancy. (a) Radar 1. (b) Radar 2.*



(a)



(b)

Figure 7: *Scenario B frame time. (a) Radar 1. (b) Radar 2.*

4 Conclusions and recommendations

In this task, the communication channel available control capability was implemented to the Adapt_MFR simulator and was tested using Scenario B. The track estimation results generated with different communication channel availability setups were analyzed and compared.

The experiment results show that the communication channel availability status didn't affect the track completeness metrics to a noteworthy degree. The track completeness of all the coordinated management types regardless the communication channel status was all about the same and at a very high level in this experiment. However, the performances of the networks in the aspects of track occupancy and frame time varied as the communication channel availability changed in the simulation. When the communication channel was not available, the performance of the radars in the aspects of track occupancy and frame time declined to the independent radar level; when the communication channel recovered, the radars in the network worked cooperatively again and their performances also recovered to their initial levels.

Some global variables, including the ones discussed in the previous software release note (V3_2_8) and the new ones added in this task, are still hard coded in the simulator functions. To improve the efficiency and accuracy of the simulation run, these variables are recommend to be input from the GUI by the users.

5 List of symbols/abbreviations/acronyms/initialisms

Adapt_MFR Adaptive Mulitfunction Radar
CW Clock Wise (angular rotation)
CCW Counter Clock Wise (angular rotation)
DRDC Defence Research & Development Canada
IMM-NNJPDA Interactive Multiple Model Nearest Neighbour Joint Probabilistic Data Association
MFR Multi-Function Radar
RRM Radar Resource Management