TaaS Phase 2 Report (RPT0381A)

for OnPoint Systems

Spirent Professional Services

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3 Executive Summary

Spirent Professional Services conducted a series of field tests to evaluate the performance of GPS enabled dog collars manufactured by SpotOn and Halo. The test programme was split into two phases, the first using simulated GNSS signals and the second using live GNSS signals and real motion to stimulate on-board inertial sensors. Six tests took place in San Jose, California. The first four took place in the premises of Spirent Communications offices, the fifth at Ulistac Natural Area and the sixth used a test vehicle driving through a dense urban environment, with heavy sky obscuration and multipath. The conducted tests are summarized in the table below.

	Conducted live-sky tests	Description
Test 1	Open sky environment	Open sky conditions test in the car park outside Spirent Communications office.
Test 2	Side obscuration environment	Conifer tree cover to one side, limiting satellites coverage.
Test 3	Obscuration above	Conifer tree cover above, with open sky to sides, limiting satellite coverage further.
Test 4	Open sky environment repeat	Open sky conditions test in the car park outside Spirent Communications office.
Test 5	Full overhead obscuration	Footpath under dense vegetation with almost no direct sky cover.
Test 6	Urban test	Dense urban route (in vehicle) with heavy obscuration and multipath conditions.

Table 1: Summary of conducted tests.

The goal of the tests was to compare both devices in different environments (see Table 1).

It was not possible to log or retrieve position data from the devices, only a marker on a satellite image with a slow update rate. Tests 1-5 were designed to utilize the warning alarms on each device as a method of determining accuracy. This was achieved by setting the fence-lines and distance thresholds the same on both devices. The collars were then moved perpendicular towards the fence-line, noting when each of the warning tones were activated relative to the fence-line.

Test 6 was a dynamic test utilizing screen recording of two mobile phones, connected to each device, and showing their position via markers on a satellite image.

Each device has three independent warnings. The SpotOn alarms at 3m, 1.5m and on the fence-line. The Halo alarms at a configurable distance (set to 2.6m), an unknown unconfigurable distance, and the fence-line. As Warning 2 could not be configured, it was only possible to compare performance directly for the first warning and on the fence-line.

For Test 1, the SpotOn device performed well, with warning before the fence-line and correction signal very close, whereas the Halo device was more inconsistent with warnings and correction signal, which occurred up to 8 m past the fence.

For Test 2, the SpotOn device performed consistently with Test 1, but the Halo was more inconsistent. It sometimes provided all the warnings and correction signal at the same time up to 10m past the configured fence line.

In Test 3, the SpotOn provided warnings before the fence-line and correction between 0-2 m past the fence line. The Halo did not provide any warnings before the fence line and went up to 5 m past the fence-line before providing the correction signal.

In Test 4, the Halo performed much better that the previous open-sky test. It sometimes performed better than the SpotOn, but on average the SpotOn still performs better across all tests.

Test 5 was a very harsh environment with full sky obscuration. Neither device was expected to perform that well. Both devices gave warnings later than they should, but the SpotOn broadcast the correction warning 0.5 m before the Halo.

As for the urban test, the SpotOn's initial position showed a 0.38 m 2D error, while the Halo's position showed 4.33 m of 2D error. During the run in the urban canyon, the SpotOn was able to maintain a GNSS lock throughout the run, while the Halo kept losing track of its position.

Based on these test results, SpotOn's boundary warnings and corrections were 6 times more consistent than Halo's.

In terms of boundary warnings and alerts, Halo's device only worked consistently 16% of the time during the tests that were run. 30% of the time of the tests we ran, the Halo device issued only a static correction with no warning.

In total, the SpotOn performed seven times better, in terms of correction accuracy.

4 Success Criteria

The following criteria have been taken from the SOW:

Criteria name	Criteria description
C1	Successful completion of tests and delivery report for R1 *(Spirent to test the capabilities/performance of OnPoint's full system)*

Table 2: Success criteria

5 Results

5.1 Test Methodology

For Tests 1-5, the following methodology was used:

- For each collar (SpotOn & Halo) two identical virtual fences were created by making use of each device's mobile app.
- For each of the tests, the accuracy of the two products was tested and more specifically the distance from the fence, at which each warning was provided.
- The fence was set to a size such that the dog collars could be moved from within the area to an outside edge.
- To measure the distance, away from the fence, and the time it took for each device to broadcast the correction, measuring tapes and flags were used, respectively. SpotOn was assigned the red flags and Halo the blue flags.

For Test 6, the following methodology was used:

- Both devices were placed under the windscreen of a vehicle and were allowed enough time for their GNSS receivers to get a valid position fix, before entering the urban environment.
- A reference GNSS receiver, with a multi-band GNSS antenna, was used to provide the truth PVT information against which the two devices' GNSS solution was compared.

5.2 Test 1: Open sky environment

For this first test, a virtual fence was constructed in the car park, on Spirent's premises in San Jose, California. The goal was to start the tests with a baseline test and as many visible satellites as possible in order to test both devices under "ideal" conditions.

The parking bay markings and dividing verges were used for visualizing the fence borders.

Figure 1: Location of Test 1.

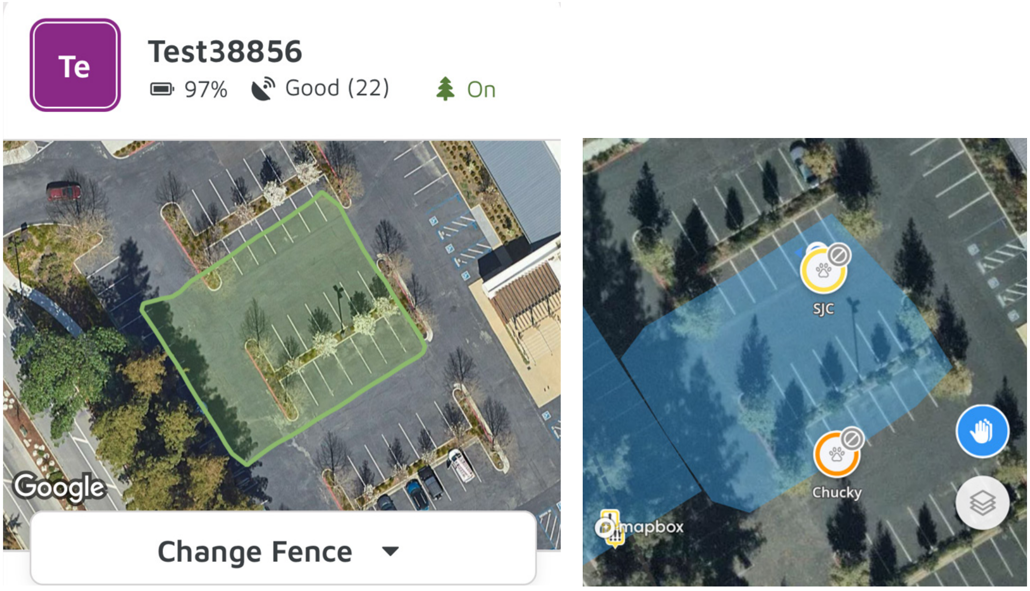


Figure 2: Virtual fences (left SpotOn – right Halo).

Figure 3: Measuring the fence line.

The test was repeated 10 times, and the results are shown in the Figure below. The vertical axis shows the distance from the fence-line that the dog collar warnings occurred. The "0 cm" point represents the fence, with negative distances being before the fence and positive distances after the fence.

The distances either side of the fence were measured using a measuring tape and three flags for each device were used to measure the distance away from the fence that each warning/correction was broadcast (Figure 3).

The Figure below (Figure 4) shows the average distances across all ten tests (in cm).

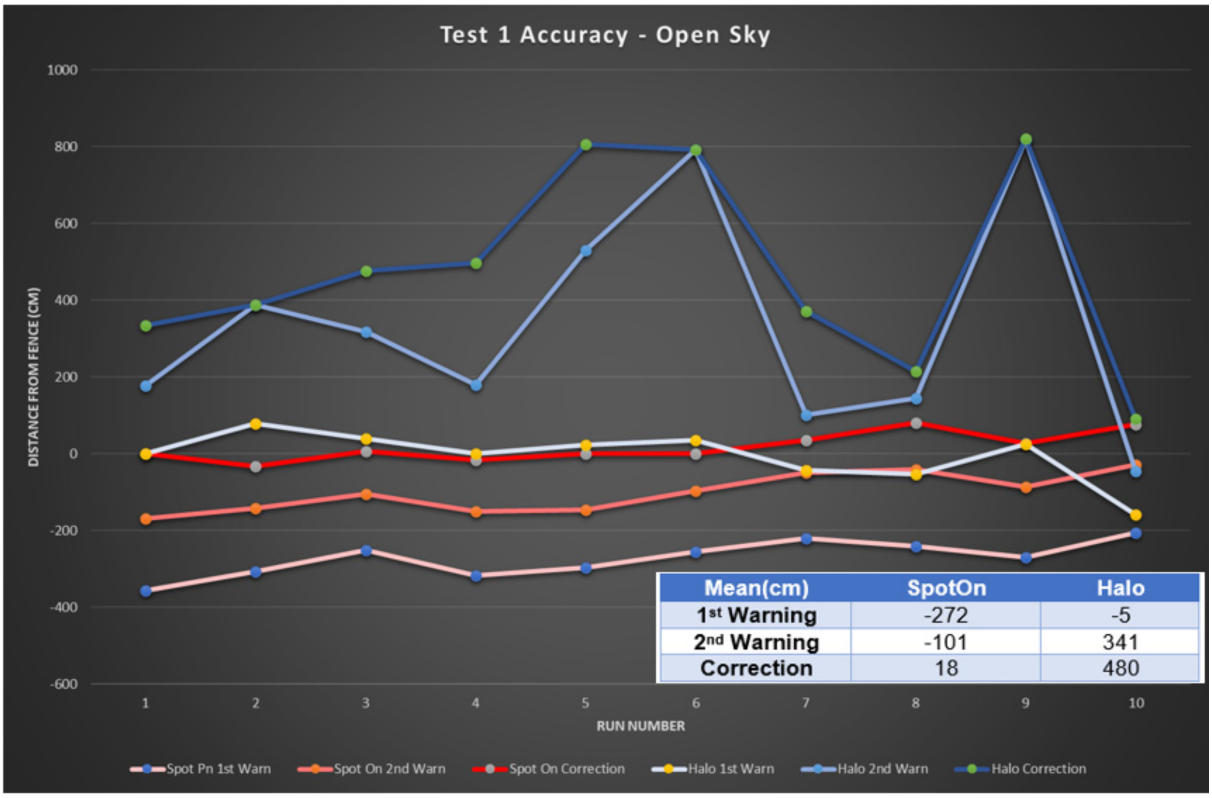


Figure 4: Warning alert distance from the fence across all runs.

SpotOn's first warning is set, by default, to -3 m, second warning to -1.5 m and the correction is broadcast right on the fence-line.

Figure 4 shows that SpotOn performed better than Halo, with its first warning varying from -355.6 cm to -205.74 cm, with a mean value of -272 cm that was very close to the -3 m threshold. On the other hand, Halo's first warnings varied from -157.48 cm to 78.74 cm, far outside the -2.6 m boundary, with a mean value of -5 cm.

The second warnings of SpotOn varied from -167.64 cm to -45.72 cm, with a mean value of -101 cm. Halo's second warnings showed a very high variation, way past the fence-line. The values varied from -46 cm to +820 cm. Spirent has no information regarding the second warning threshold, so no direct comparison between the two devices can be made. Nevertheless, Halo's mean value of +341 cm indicates that it broadcast the second warning way past the fence-line which means that it did not perform as expected.

SpotOn's correction reported values showed a very good consistency, with a mean value of 18 cm and ranging from -33 cm to +81 cm. Halo, on the other hand, showed again large variations with values up to +820 cm away from the fence-line and a mean value of +480 cm which is very large compared to the +18 cm of SpotOn.

5.3 Test 2: Side obscuration environment

This test used the opposite side of the virtual fenced area (Figure 6), which had heavy conifer tree coverage (red rectangle) blocking the western hemisphere.

The fence (Figure 6) ran along the ends of the parking space lines to easily visualize the fence borders.

Figure 5: Location of Test 2.

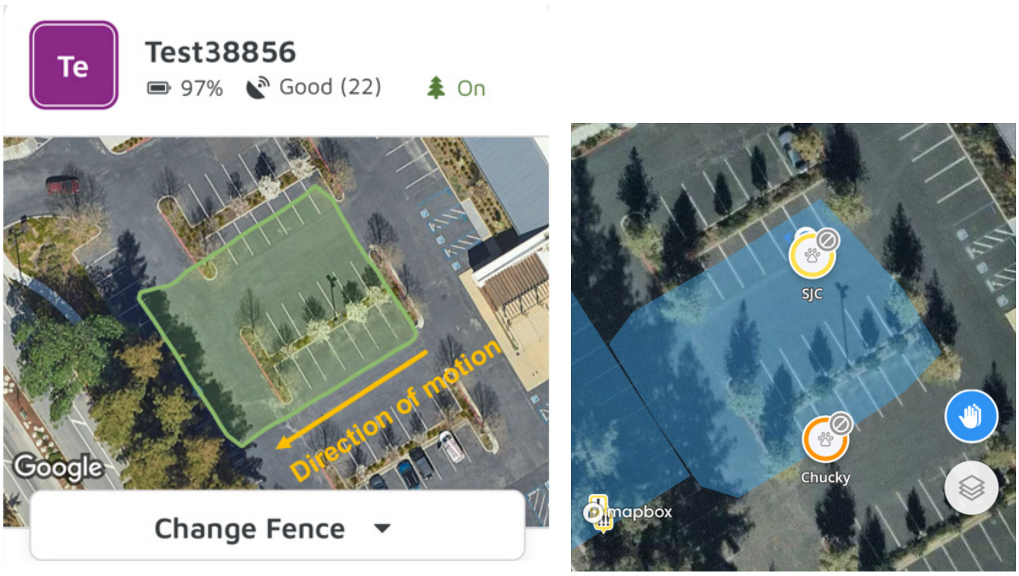


Figure 6: Virtual fences (left SpotOn - right Halo).

As one can see in Figure 7, the distances either side of the fence were measured using a measuring tape and three flags for each device were used to measure the distance away from the fence that each warning/correction was broadcast.

Figure 7: Measuring distances using tape measure either side of the fence.

This test was also repeated ten times. The vertical axis shows the distance from the fence line to the dog collar warnings occurred. The "0 cm" point represents the fence, with negative distances being before the fence and positive distances after the fence.

The figure, below (Figure 8), shows the average distances across all tests (in cm) as well as the different broadcast distances per run, for both devices. SpotOn's first warning varied from -325 cm to -135 cm with a mean value of -247 cm, close to the -3 m threshold value. The Halo device, on the other hand, did not provide any first warnings for the first four runs. For runs 5-10, its value varied from -155 cm to -79 cm, giving a mean value of -83 cm which is away from the -2.6 m threshold.

SpotOn's second warnings varied from -175 to +30 cm, with a mean value of -98 cm, i.e. 52 cm away from the -1.5 m threshold. Halo, on the other hand, provided only one second warning, that was -122 cm away from the fence line.

SpotOn's correction varied between +36 cm and +140 cm, with a mean value of +76 cm away from the fence boundary. The Halo showed a larger variation, with value varying from -79 cm to +960 cm and a mean value of +273 cm. Again, the SpotOn device performed better than the Halo.

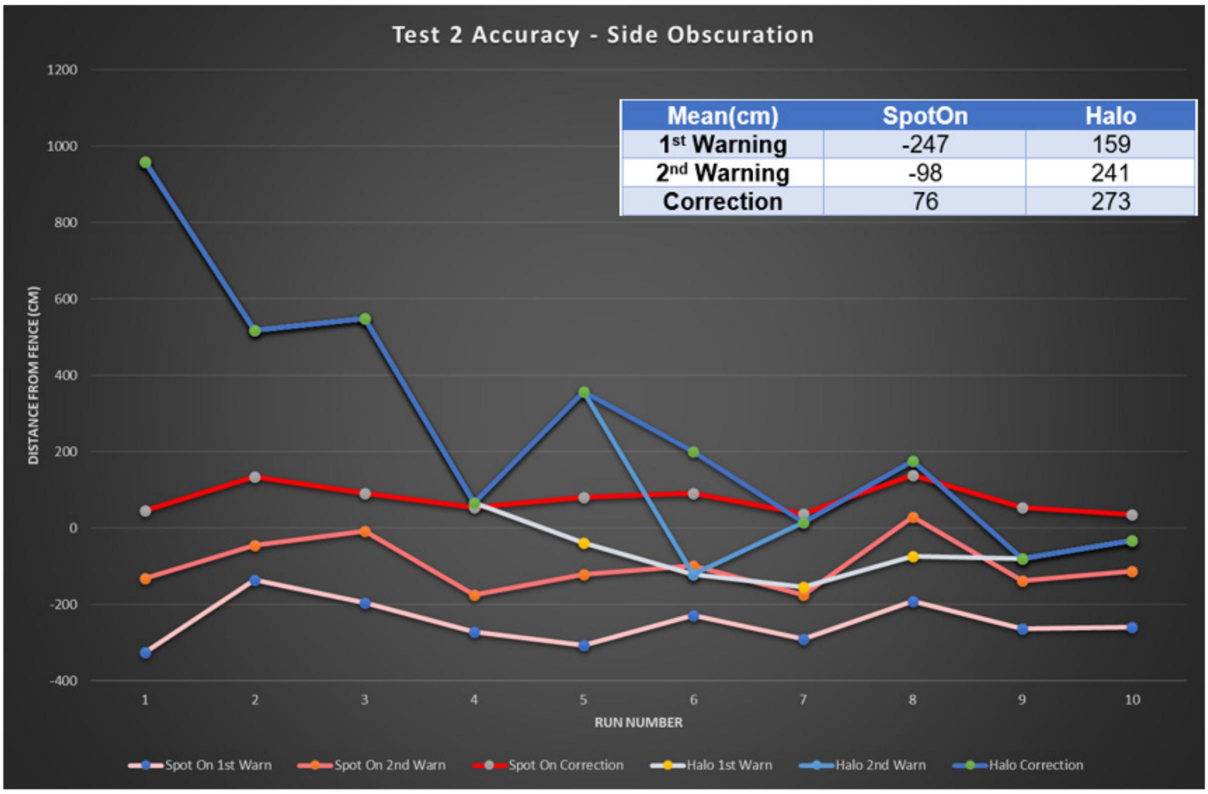


Figure 8: Warning alert distance from fence across all runs

5.4 Test 3: Obscuration above

For this test, virtual fences were constructed directly under the trees (Figure 10). Each fence was created to span either side of the sidewalk, with one edge passing through the trees running across the sidewalk. The dog collars were carried from clear open sky towards the fence, under the trees.

Figure 9: Location of Test 3

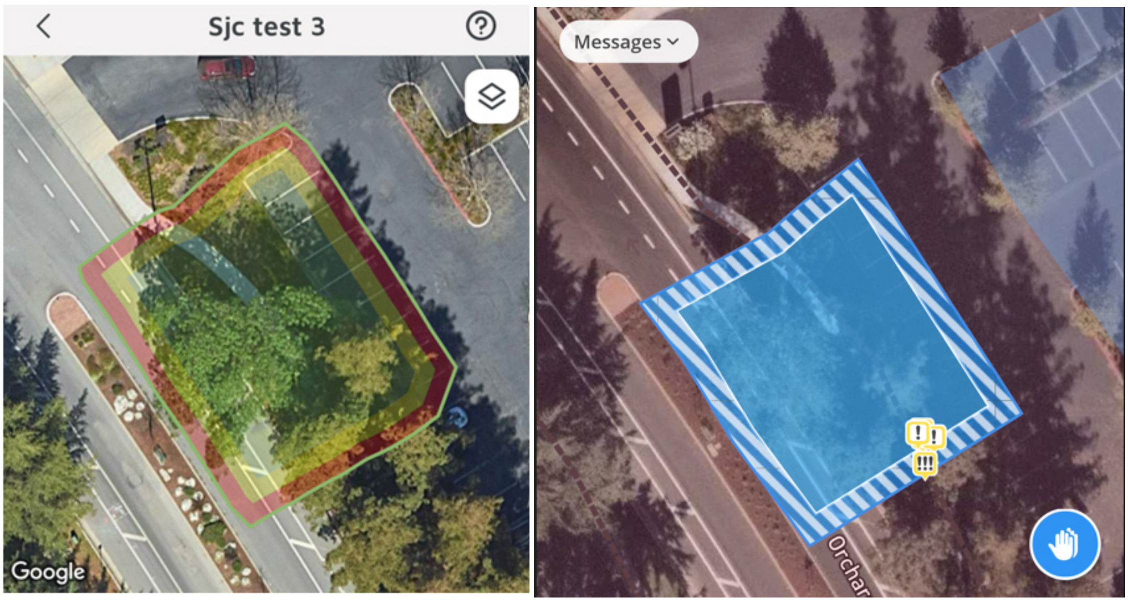


Figure 10: Virtual fences (left SpotOn - right Halo)

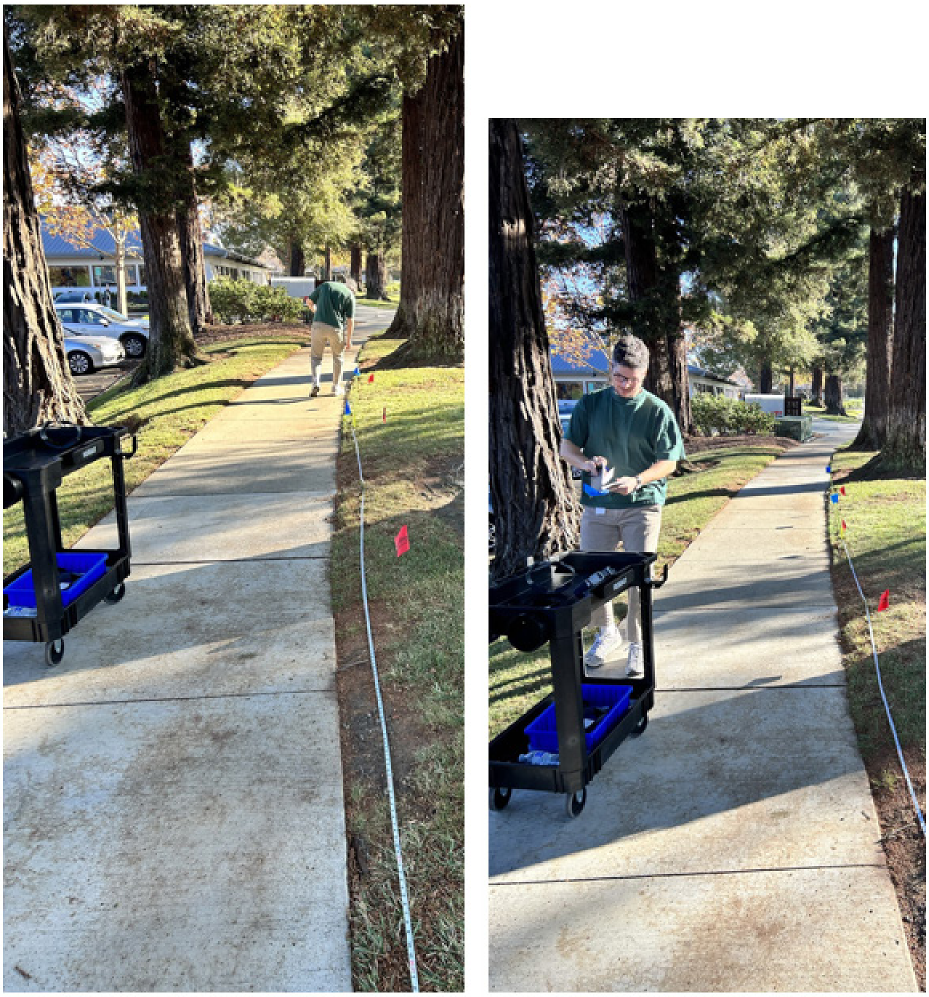


Figure 11: Measuring distances from fence.

Again, as can be seen in Figure 11, measuring tape and flags were used for the tests. SpotOn's first warnings varied from -295 cm to -437 cm, giving a mean of -369 cm, which is 69 cm more than the threshold value of -3 m. The Halo device varied between 0 and +226 cm, way beyond than the -2.6 m threshold for the first warning. Its mean value was +120 cm. Basically, all the first warnings broadcast from the Halo device were beyond the fence-line, and not before as one would expect.

The second warning values for SpotOn varied from -229 cm to -48 cm, with a mean of -132 cm, which is 18 cm away from the threshold value of -1.5 m. Halo, on the other hand, did not broadcast any second warnings.

The SpotOn's corrections seem to have been affected by the dense conifer coverage, as they were broadcast, on average, 115 cm past the fence-line. Nevertheless, during the last two runs, the corrections were broadcast right on the fence-line, as one would expect. The Halo collar showed a higher variation of values, varying from almost 5 meters to 1 m. Its average value was 270 cm past the fence boundary. The results suggest that the Halo device was affected more that the SpotOn by the trees.

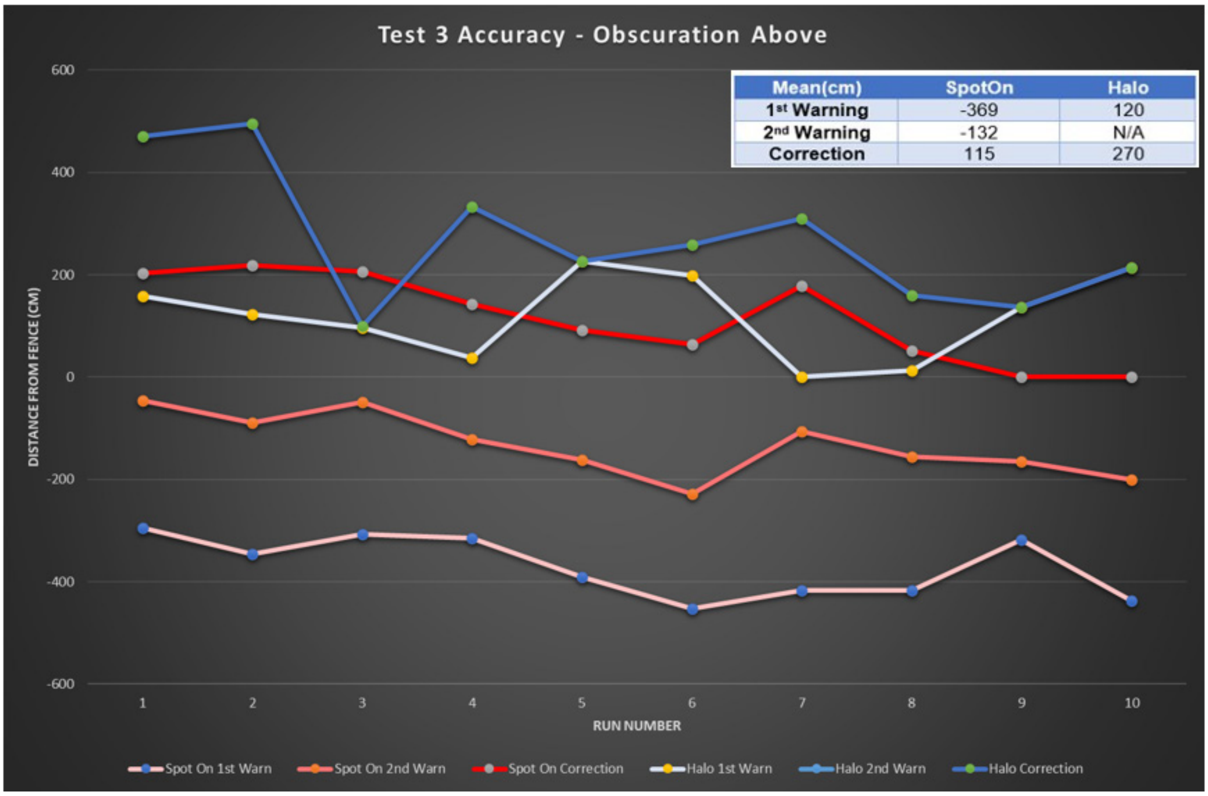


Figure 12: Warning alert distance from fence across all runs

5.5 Test 4: Open sky environment repeat

This test is practically a repetition of Test 1, with new virtual fences constructed using the same boundaries. The parking bay markings, dividing verges, were used for visualizing the fence borders. The fences were set to a size such that the dog collars could be moved from within the area to an outside edge.

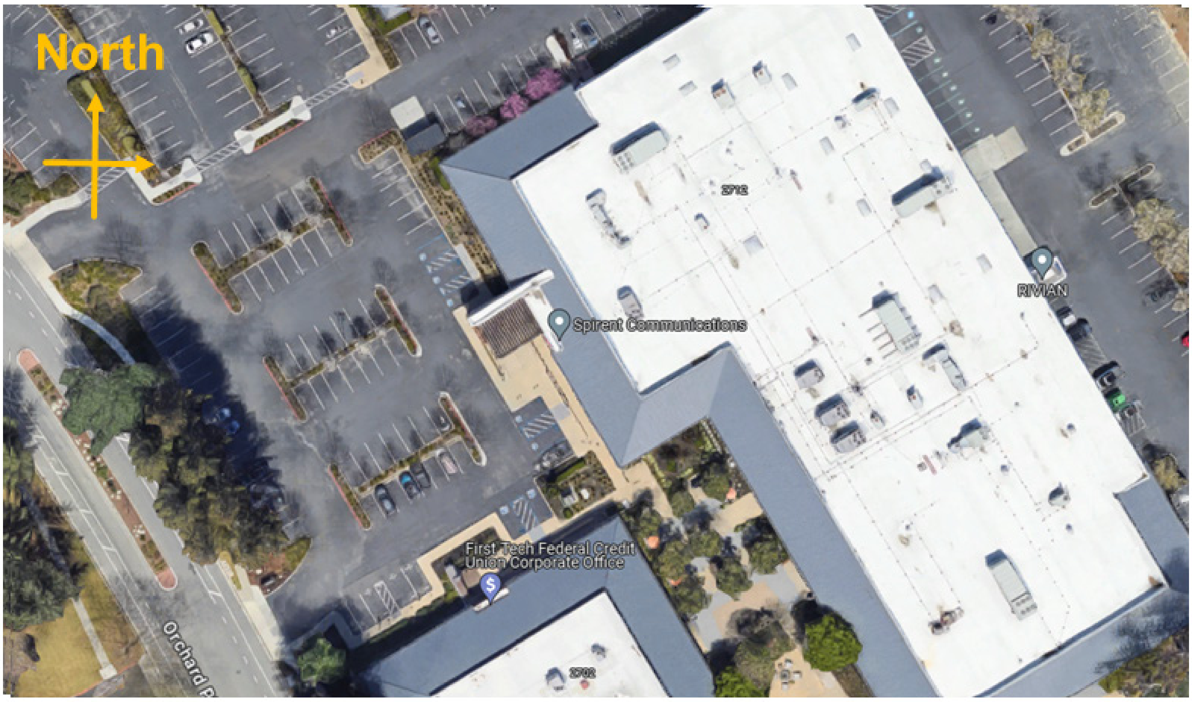


Figure 13: Location of Test 4

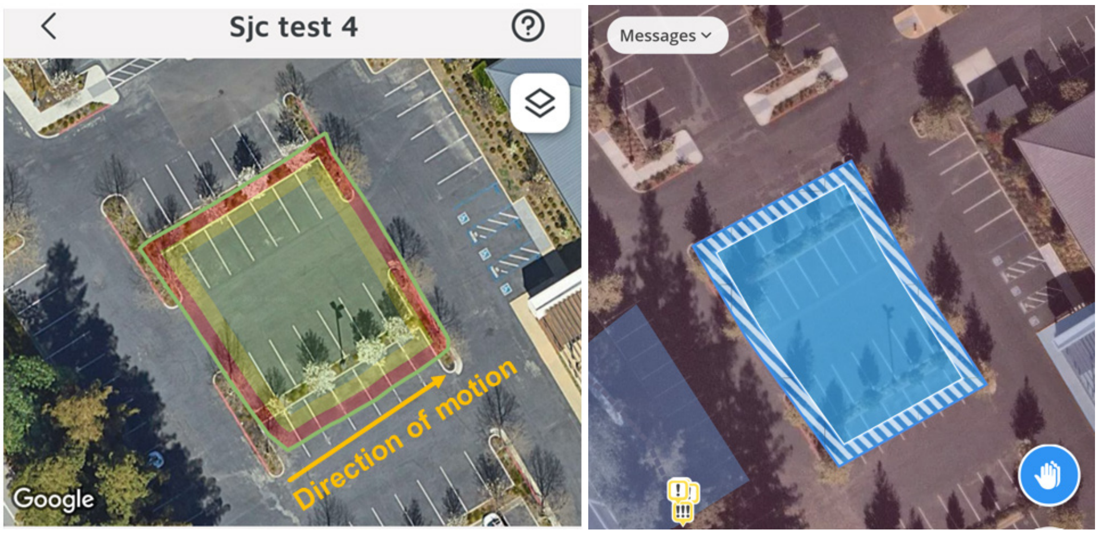


Figure 14: Virtual fences (left SpotOn - right Halo)

The tests were, again, repeated ten times. The vertical axis shows the distance from the fence line that the dog collar warnings occurred.

SpotOn's first warnings varied from -340 cm to -170 cm, with a mean value of -258 cm, close enough to the -3 m threshold. Halo's warnings showed a higher variation with an average -72 cm indicating that they were quite far from the -2.6 m threshold value. Their value varied from -272 cm to +8cm.

The second warnings for the SpotOn collar showed a mean value of -89 cm, 61 cm far from the -1.5 m threshold. Their values varied from 0 cm to -160 cm. Halo broadcast only three warning, during runs six, seven and ten. Their average value was -48 cm.

The SpotOn corrections showed a good consistency, with most of the values close to 0cm, while during three runs there was a divergence with values ranging from +131cm to +152 cm and an average value of 64 cm away from the fence-line. The Halo device showed higher variations with values ranging from -97 cm to +211 cm and a mean of 70 cm, very close to the SpotOn's.

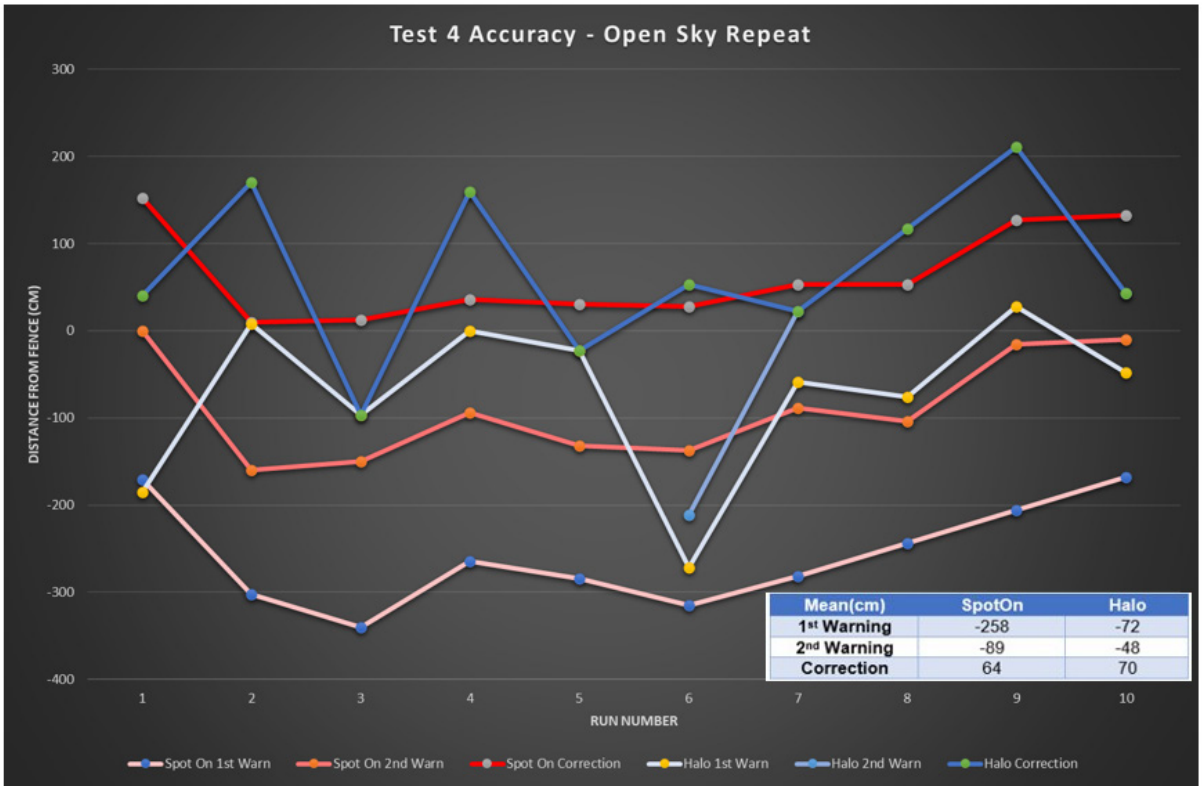


Figure 15: Warning alert distance from fence across all runs

5.6 Test 5: Full overhead obscuration

The purpose of this test was to evaluate the performance of both devices in situations where the fence-line is inside a forest-like environment. Ulistac Natural Area was chosen as a suitable example (Figure 16). The dense vegetation offered a challenging environment.

Figure 16: Ulistac Natural Area.

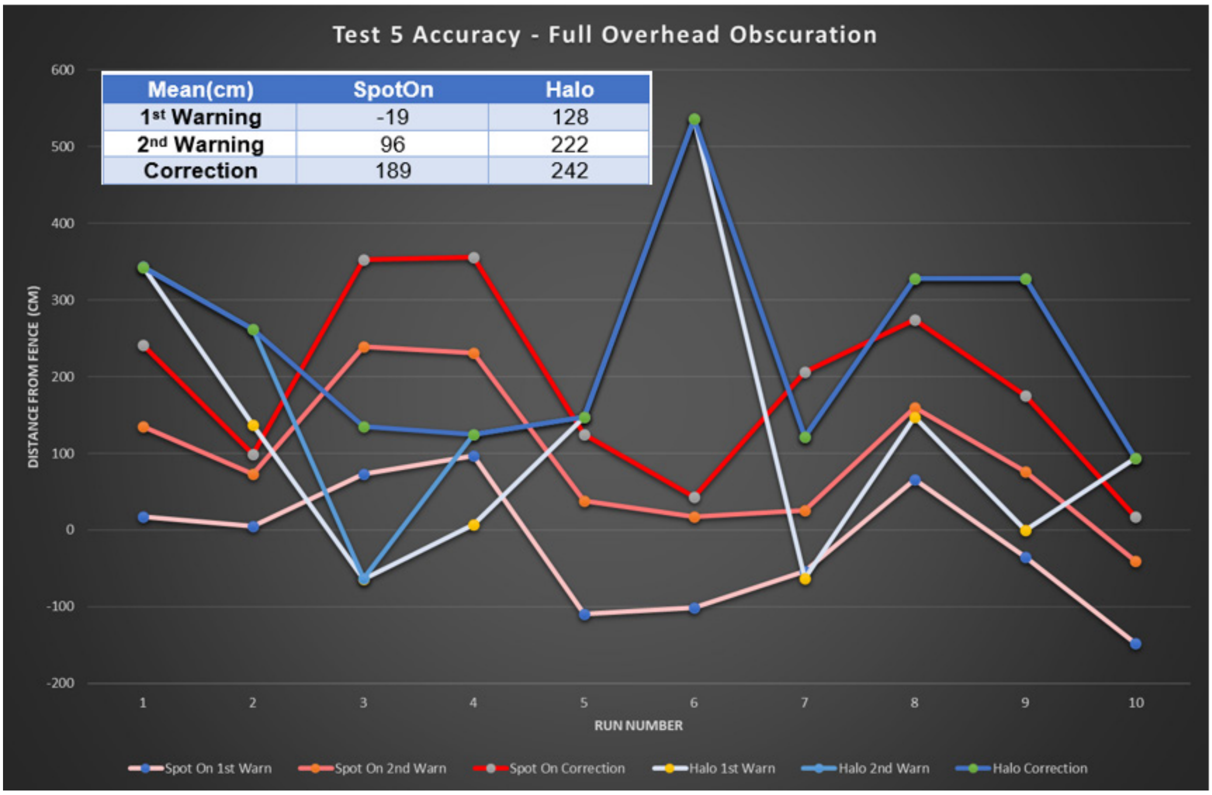
Figure 17: Virtual fences (left SpotOn - right Halo)

The challenges this environment added to the tests are depicted in the Figure below. Both devices struggled to perform according to specs.

SpotOn's first warnings varied from -147 cm to +97 cm, with an average value of -19 cm and a standard deviation of 84 cm. The Halo device showed larger deviations from the -2.6 m threshold, with values varying from -64 cm to +536 cm and a mean value of 128 cm. Its standard deviation was 188 cm.

The same was observed for the second warnings. SpotOn values varied from -41 cm to +239 cm, with a mean value of 96 cm and a standard deviation of 93 cm. Halo, however, showed even higher variations which ranged from -64 cm to +536 cm and an average value of 222 cm, while its standard deviation was 170 cm.

The same holds true for the corrections. SpotOn's reported values were all beyond the fence-line, with the values in runs six and ten close to the fence line (+43 cm and +18 cm respectively). In total, the values ranged from +18 cm to +356 cm, with a mean of 189 cm and a standard deviation of 188 cm. The Halo device showed values varying from +94 cm to +536 cm, a mean of 242 cm and a standard variation of 142 cm.



Mean(cm)	SpotOn	Halo
1st Warning	-19	128
2nd Warning	96	222
Correction	189	242

Figure 18: Warning alert distance from fence across all runs

5.7 Test 6: Urban test

This test replicated an urban environment surrounded by tall buildings obscuring the view of satellites and causing multipath signals. The two collars were placed under the windscreen of a vehicle, whilst connected to their respective phone apps tracking their location in real-time.

The route that was followed is seen in Figure 19. The test was limited by a slow position update (6 sec) from the dog collars but highlights the variability of position error and loss of lock when compared to the true path.

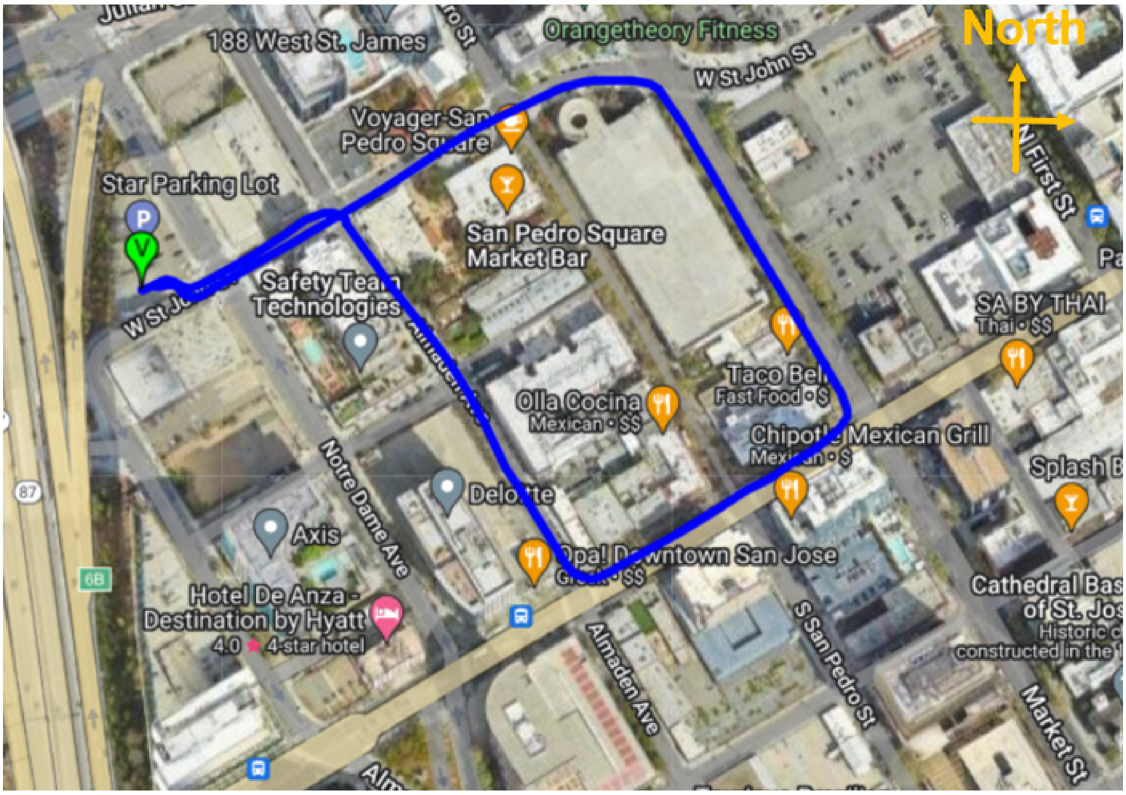


Figure 19: Urban route, in San Jose

Both devices were given enough time to acquire satellite signals before the start of the test, while, during the run in the urban canyon, both devices were compared against a GNSS reference receiver.

The start location is seen in Figure 20. The SpotOn collar reported a better position, compared to the Halo device, with a 2D error of only 0.38 m with regards to the true location, while the Halo showed a 2D error of 4.33 m. During the run, the SpotOn was able to maintain a valid GNSS lock throughout the route, while Halo kept losing track of its position. A video, showing how both devices performed, has already been shared with OnPoint. Due to its size, it was decided to not include it in this report.

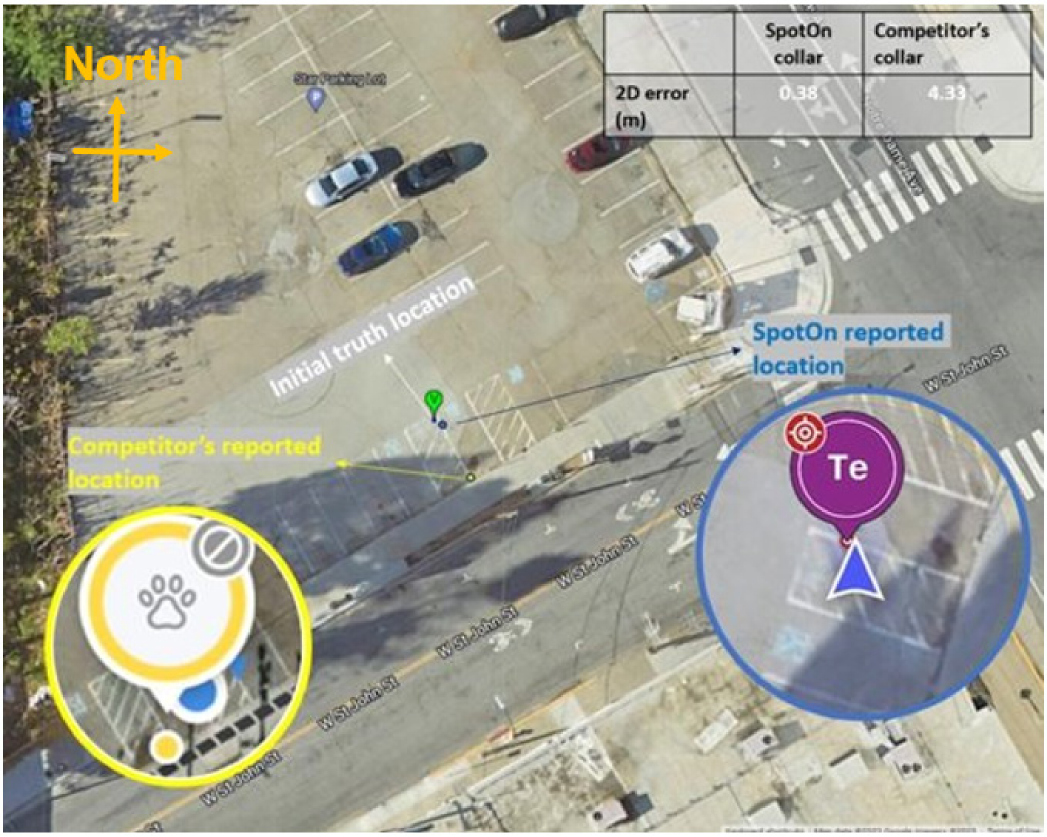


Figure 20: Start location.

5.8 Summary of results from Phases 1 and 2

Phase 1 report has already been shared with the customer separately. In this Section, the most important observations, from both reports, are discussed.

All devices were tested in a lab environment, during Phase 1. The SpotOn receiver, under open-sky conditions, reported the lowest horizontal (2D) error and standard deviation (i.e. 1.3 m and 0.63 m) and it was able to re-acquire, briefly interrupted, signals faster than the Halo OriginGPS and Telit receivers.

The SpotOn receiver also performed better than the other two receivers in both the urban and forest simulated environments. SpotOn showed 3.8 times lower 2D error in the Urban environment, compared to the OriginGPS device and 3.5 times lower 3D error. The SpotOn receiver seems to be more resilient than the Halo in challenging urban environments.

SpotOn, however, was found to be more sensitive to in-band RFI than the Halo receiver, as it lost its PVT at around -61 dBm, while Halo was able to report a valid PVT solution until an RFI power of - 30dBm. Receiver sensitivity, RFI performance and multipath performance are a compromise made by a receiver manufacturer. The SpotOn is more sensitive, it doesn't perform so well against RFI but performs better under multipath conditions, while the Halo is less sensitive, it performs better against RFI but struggles in multipath environments.

Moreover, the SpotOn receiver passed the RAIM test, while the other two devices failed. The SpotOn receiver successfully excluded the affected GPS and GLONASS satellites but not the Galileo and Beidou satellites. Nevertheless, the reduction in affected satellites in the position solution improved performance.

During **Phase 2**, two devices were tested under the same environmental conditions. The tests options were limited due to the lack of output data from both devices, e.g. NMEA data. Thus, a measuring tape and flags were used to indicate the distance of each device from their respective fence-lines.

		SpotOn	Halo
		Standard deviation (cm)	
Test 1	1st Warning	46.7	66.3
	2nd Warning	49.9	292.4
	Correction	37.4	254.5
Test 2	1st Warning	59	379
	2nd Warning	69	349
	Correction	38	326
Test 3	1st Warning	60	82
	2nd Warning	61	N/A
	Correction	85	134
Test 4	1st Warning	60	93
	2nd Warning	60	141
	Correction	53	95
Test 5	1st Warning	84	188
	2nd Warning	93	170
	Correction	119	142

Table 3: Standard deviations

Spirent cannot compare the two devices against the second warning, because there was no information about the threshold distance values set in the Halo device. However, for each test, the standard deviations of warnings 1 & 2 were calculated and are presented in Table 3, above. From that Table, it is evident that SpotOn collar showed better consistency. That said, the reported warnings were close to the mean for the SpotOn collar, compared to those for the Halo collar.

Both devices faced difficulties to perform according to specs during the fifth test, in the Ulistac Natural Area, in the presence of dense vegetation. This was an extreme test case and performance was expected to be worse. However, the SpotOn still performed better than the Halo collar.

In general, it was observed that the Halo device was more inconsistent with warnings and correction signals that deviated from its specs.

The field test results suggest that the SpotOn collar is more resilient to obscuration and multipath, present in urban canyons, compared to the Halo collar that was unable to maintain a lock during the urban route and had an initial 2D error of 4.33 m, i.e. 11 times worse than that shown by the SpotOn receiver.

Test		SpotOn			Halo			Factor
		Measured (cm)	Expected (cm)	Error (cm)	Measured (cm)	Expected (cm)	Error (cm)	
1	1st Warn	-272	-300	-28	-5	-260	-255	9.11
	Correction	18	0	-18	480	0	-480	26.67
2	1st Warn	-247	-300	-53	159	-260	-419	7.91
	Correction	76	0	-76	273	0	-273	3.59
3	1st Warn	-369	-300	69	120	-260	-380	5.51
	Correction	115	0	-115	270	0	-270	2.35
4	1st Warn	-258	-300	-42	-72	-260	-188	4.48
	Correction	64	0	-64	70	0	-70	1.09
5	1st Warn	-19	-300	-281	128	-260	-388	1.38
	Correction	189	0	-189	242	0	-242	1.28
							Average	7.00

Table 4: Average delta of correction errors

By averaging the deltas of the correction errors (i.e. expected minus measured), in Table 4, one can conclude that SpotOn performed **seven** times better than Halo, in terms of correction accuracy.

6 Referenced Documents

Reference	Document No.	Title	Issue
a)		RPT0345A Issue 1-00 OnPoint TaaS Phase 1 Report	1-00

Table 5: Referenced documents