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Collision Detection Using Received Signal Strength in FANETs

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Abstract—**Autonomous vehicles are important to execute missions without the need to put at risk people's life. To achieve this goal, it is essential that these vehicles are endowed of a collision avoidance system. In this study we discuss the use of received signal strength (RSS) of beacons from a vehicular ad hoc network (VANET) as a way to detect dangerous approaches among autonomous vehicles. We extend this study to flying ad hoc networks (FANETs) as a way to provide obstacle avoidance in UAVs. Nowadays autonomous vehicles has the need to be connected, and consequently has wireless network devices forming vehicular networks like VANETs and flying ad hoc network as FANETs. It favors the use of signal strength of beacons as a way to detect dangerous approaches among autonomous vehicles. Initially we presented a study of signal strength variation in relation to the distance and further we investigated how speed influences the received signal strength. Finally we evaluate the results of applying the propagation path loss formula in obtained RSS values to estimate the distance.**

I. INTRODUCTION

The use of autonomous vehicles have increased in civil and military applications like observation, search and rescue, surveillance, and reconnaissance, etc. The main reason is the desire to reduce human risk and increase mission efficiency when executing missions [1]. Autonomous vehicles can be terrestrial (Unmanned Ground Vehicles - UGV), aerial (Unmanned Aerial Vehicles - UAV) and others which are generally controlled, managed and monitored in real time by embedded systems, that have severe restrictions about faults once it might cause human deaths and/or losing high value components. Then, these systems are known as critical embedded systems.

Another characteristic of this kind of vehicle is that they are able to function during a long period without the interference of humans operators, and then they can make the navigation basing on a grid or in a way-points sequence [2]. During the operation, this vehicles are subject to threats that might be fixed obstacles (eg. walls, constructions, vegetation), or mobile (eg. other vehicles, birds), and then they have to be able to detect them and realize evasive maneuvers. Yang et al [3] states that the major problem of obstacle avoidance can be divided in "sense" or "detection", that is the perception of the obstacle and; "avoidance" that means realize an evasive maneuver in order to avoid the obstacle and reestablish the programed route before the maneuver. The authors also highlights that this is one of the most challenging problems in autonomous navigation field.

Autonomous Vehicles might also form networks and collaborate among them through the exchange of messages. The communication of these vehicles occurs through vehicular or fly networks. Currently three vehicular network architectures are known: ad hoc pure (VANETs - Vehicular Ad hoc Network), generally used in V2V (Vehicle-to-vehicle) communications; the infrastructure way, used in the communication of the vehicle with a network infrastructure (V2I - Vehicle-to-infrastructure); and the hybrid approach, where the mixture of the architectures ad hoc and infrastructured are used.

Vehicular Ad hoc Network has a special subtype known as FANET (Flying ad hoc network) that is an ad hoc network composed by aerial vehicles. The FANETs has special characteristics from when compared with another networks. In FANETs the nodes have greater degree of mobility and hence the network topology changes frequently. Another characteristic is that the distance between the nodes is often higher than in VANETs [4].

In the case of infrastructured networks (V2I), static nodes behaves as access points for IEEE 802.11 networks and have the advantages of increasing connectivity and creating the possibility of communicating with other networks, such as, the Internet. However, in infrastructured approach there is the disadvantage of high cost in deployment of network equipment to cover the entire route of the road. In some cases it is possible to reduce costs by deploying a third type of architecture known as hybrid. This last one uses ad hoc communication type associated with a minimal infrastructure to increase network connectivity in service provision.

The choice of these model's architecture has to take into account several factors such as the density of vehicles on the road, obstacles in the path and the applications for which the VANET is proposed. There are three main applications of vehicular networks: traffic safety, entertainment and driver assistance. The increase of traffic safety is a major motivation

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for the use of vehicular networks, because it generally aims to reduce accidents by exchanging information among vehicles and gathering information about the conditions of the road by sensors.

In collision detection context UGVs use sensors like cameras, laser sensors, etc. as it has to detect all objects present in the environment. In UAVs this kind of detection is even more challenging due to hight speed of the nodes. Commercial aircrafts might be equipped with TCAS (Traffic Collision Avoidance System), that allows identify dangerous approaches among two vehicles and indicate evasive maneuvers. However, the use of this equipment is not possible in some small UAVs. A few problems can be cited such as: location of the radar antenna, limited payload to embed the radar, and problems with the battery capacity to feed the system [5], [6].

In a scenario considering vehicles that have increased need for communication, a way to avoid collision among UAVs considering the restriction of payload and battery is to obtain the coarse location of them using received signal strength (RSS). Luo et al [7] proposes the use of base stations with known fixed position (V2I) to triangulate the signal intensity and calculate the estimated position of the UAV and its trajectory and then, detect possible collisions. The same work also used Kalman predictive filter to reduce the present noise in the signal and increase the accuracy of the estimation.

In the present study we aim to investigate the possibility to detect collisions using RSS obtained from a V2V connection and the behavior of the signal in different velocities to verify the viability of the use in small UAVs. Terrestrial tests were performed to verify the viability of the idea and in the future it will be extend to aerial experiments. After the tests we evaluate the results applying the propagation path loss formula in obtained RSS values to estimate the distance and calculate Pearson Correlation Coefficient among real and estimated distances. Then a collision alert trigger was simulated.

This paper is organized as follows. The next section presents some important concepts about collision detection and the relation between the signal strength and distance estimation. Section III presents the methods used to realize the experiment. Section IV present the results obtained and Section V concludes the paper and discusses about further research directions in UAVs.

II. COLLISION DETECTION AND RECEIVED SIGNAL STRENGTH

In this section some important concepts about collision detection is presented. Also the use of received signal strength to calculate a distance estimation that could be applied to collision detection is shown.

As previously described collision detection is a subpart of a major problem: “obstacle avoidance”. There are many works attempting to perform obstacle avoidance in UGVs. Nevertheless, the small UAV needs to avoid a collision differs mainly in relation to the limited payload and high speed. Then, new technologies are being developed in order to solve this problem.

Existent works about UAV generally focus on rotary wing vehicles, that do not travels in high speed. Most of this methods are vision based. Among this studies we can cite the work developed by Saunders *et al* [8]. In this work the obstacles are divided in two categories: a priori known obstacles and pop-up obstacles. They present a solution to MAVs (Miniature Air Vehicle) wherein traditional sensors are too heavy to be on board. They propose to use a single point laser ranger (approximately 2 Watts) which is able to detect straight line obstacles in a range of 400 meters.

The architecture is composed by a virtual cockpit that can be connected to either a physical MAV or a simulator by a common interface. The physical MAV is a fixed wing miniature and uses Kestrel autopilot. To realize obstacle avoidance where used two classes of algorithms: one to a priori known obstacles and other to pop-ups obstacles.

Another item that has to be considered in obstacle avoidance is the maneuvering capacity of the airplane. Moon and Prasad [1] proposes an integrated framework for obstacle avoidance and envelope protection. In this way it is possible to use restrictions to maintain the flight envelope during an evasive maneuver. To achieve it, the obstacle approximation was classified in three distinct states: warning state, safe avoidance state and unsafe avoidance state. When the airplane detects a near obstacle it enters in unsafe state. In this state decelerates until reach a safe state to execute the maneuver. On the other hand, when a obstacle is detected too soon the airplane enters in a warning state and it is able to keep the previous route during a certain time until reach a safe avoidance state.

Cruz and Encarnação [9] emphasize that the problem of obstacle avoidance in fixed wing aircrafts is quite different from another type of aircrafts concerning platform and maneuverability. One of the problems pointed out by the authors is that the aircraft have to stay above the stall speed. The authors also proposed to use fluid mechanics to describe the motion of a fluid in the presence of obstacles. The idea was tested in simulation. However, even the authors assumed that it cannot be formally proven that the aircraft will not collide with any obstacle.

Concerning autonomous vehicles there is the need of the communication among two vehicles (V2V), and among the vehicles and the base station (V2I). In this way, the autonomous vehicles possess wireless communication interfaces that might be used as a source of location and hence of the collision detection. Another possible approach to realize obstacle avoidance is using RSS from vehicular network nodes to detect possible dangerous approximation.

In this context, there are several algorithms to estimate the location through the received signal strength (RSS). Great number of researches use fixed wireless access point in the environment and calculate the position of mobile devices through the intensity of the received signal from these access points with previously know location. Then, the signal can be triangulate by the base stations to calculate vehicle positions and avoid that they get too close [7].

In order to calculate distance from base stations, generally these location systems consist in two phases: (i) environment and access points mapping; (ii) estimated position calculation, basing in the map previously created [10]

The accuracy of the estimation of the location is influenced by many factors, such as the interference of other wireless signals, number of fixed access point used as location base, *etc.* There are many researches aiming to increase the estimate accuracy using other information than the value of RSS. A solution presented by Davies et al [11] uses the signal time of flight (TOF) as an element to refine the position measurement.

Another possible approach described Zaruba et al [10], is the use of a reduced wireless network infrastructure, being possible to realize the tracking of the mobile device with only one fixed station. In order to achieve this goal, the wireless signal is treated with particle propagation algorithms, mapping the reflexions and refractions that the signal is submitted in the environment.

There are also specific algorithms to improve the estimation of the distance among a wireless node and a base station, as proposed by Mehra e Singh [12], where adaptive filters are used to reduce the oscillation in the signal levels that occurs even if the mobile station have not altered position.

Ishii [13] states that the key points for to use RSS as a distance measure are the RSS Calibration and the RSS difference detection (RDD). They propose a way to use RSS Calibration and RDD without pre-measurement. Their results show that GPS-free host approaching in MANET (Mobile Ad hoc Networks) performs effectively.

Mehra and Singh [14] propose the use of a recursive least square (RLS) algorithm to reduce error in distance estimation. They used equation 1 as a base of distance measurement and an adaptive filter to remove noise.

$$d = 10^{\left[\frac{(RSSI_{dBm} - A)}{10\eta}\right]} \tag{1}$$

In equation 1, *RSSI* is the signal strength indicator in dBm, *A* is the measured value from reference node from one-meter distance and η is the path loss exponent (PLE).

Chen [15] states that the PLE is another key point in the distance estimation algorithms. The propagation environment influences the rate at which the RSS decreases with distance and this rate is measured by the path loss exponent that is applied in path loss equations.

$$\eta = \frac{RSSI_{dBm} - A}{10log(d)} \tag{2}$$

The path loss exponent can be empirically computed from real measures through equation 2, where RSSI is the received signal strength indicator, *A* is the measured value from reference node from one-meter distance and *d* is the distance. Table I shows some pre-calculated PLEs [14].

There are few studies for UAV collision detection using RSS. The research presented by Luo et al [7] propose the utilization of several base stations with previously known location (used in the communication of the vehicles with network infrastructure - V2I) providing data to calculate the estimated position and the trajectory of the UAVs. Basing in the positioning calculation and the trajectory, is possible to predict possible collisions. This is done through the triangulation of the signal intensity that reaches the UAVs from the base stations (Figure 1).

Table I
VALUES OF PATH LOSS FOR DIFFERENT TYPES OF ENVIRONMENTS[14]

Environment	**Path Loss Exponent (η)**
Free Space	2.0
Urban area cellular radio	2.7~3.5
In-building LOS	1.6~1.8
Obstructed in-building	4~6
Shadowed urban area cellular radio	3~5

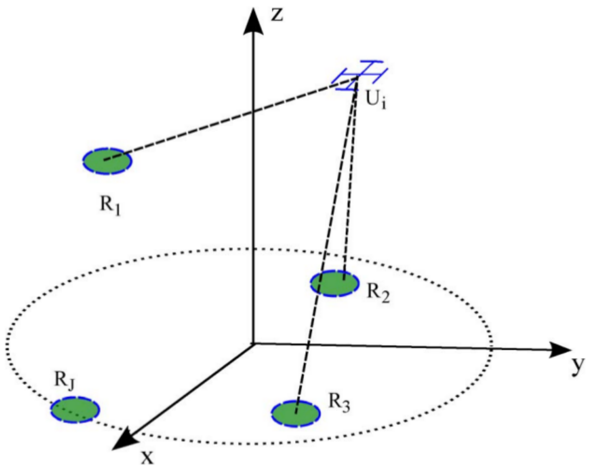

Figure 1. Model of UAV position estimation [7].

Once all wireless transmission is subject to interferences from external factors, the authors proposed to modeling the noise and use the Kalman predictive filter in order to improve the accuracy of the calculations to obtain a more reliable system. They also propose the use of a security radius to avoid dangerous approach between two aircrafts. The radius of safety zone in perfect conditions is given by maximum relative speed and reaction time. The inaccuracy caused by RSS measures was also considered in their algorithm. Figure 2 illustrates safety zone determined by a $S_{i,k}$ radius (safety radius).

III. METHODS

An experiment was run to evaluate the behavior of signal intensity in high velocities in order to verify the possibility of using the RSS provided by beacons of a VANET, or possibly a FANET, to detect collisions.

This experiment took place on a road about 5 km away from urban area in order to reduce interferences from other wireless networks. The testing site is a path of 500 meters in a rural road of Vera Cruz, SP, Brazil (450km far from the

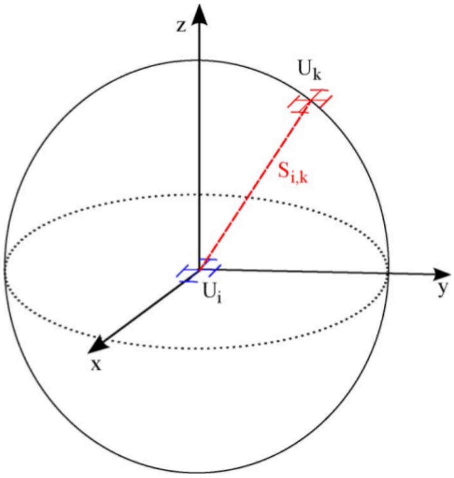

Figure 2. Three-dimensional Safety zone[7]

capital, São Paulo). Figure 3 show in details the location of test site.

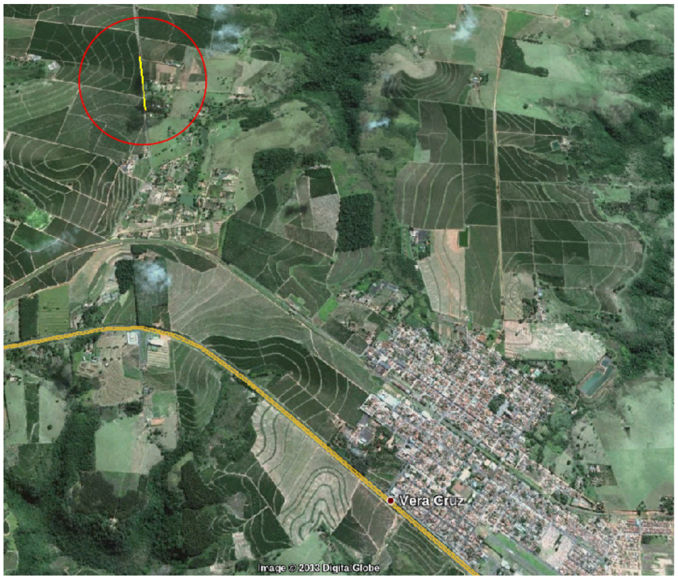

Figure 3. Map of the test site (circle highlights the path test)

The test site is composed by a rural road surrounded by coffee crops and some ranches with none or few large trees that could reflect or interfere in signal.

To the experiment were applied a router with Linux Operating System (OpenWRT), Ralink wireless chipset model RT3050F configured in ad hoc mode with beacon-interval of 10 milliseconds, transmission power of 20dBm and antenna gain of 5 dBi fixed in the end of the test path; and a cubieboard2 board with ARM processor running Linux Operating System (cubian), with wireless chipset Ralink RT 5370 configured in monitor mode with transmission power of 20 dBm and antenna gain of 2 dBi installed in an automobile. The test setup is shown in Figure 4.

In each test the automobile entered the test path with constant speed. Two different velocities were tested, 40 and 80 km/h, in order to evaluate the behavior of the signal intensity in different velocities. The automobile went trough the path 10 times with each velocity. There were 20 tests in total.

With the results, it was possible to compute empirically the path loss formula for propagation and apply the formula to predict the estimated distance between the car and the router. To validate the formula, Pearson Correlation Coefficient among real and estimated distance was performed. Then, a safety radius of 50 meters was defined and the formula was applied to the signal to verify the real distance in which a collision alert would be triggered.

Further the analyzed results motivated a discussion about using RSS in collision detection.

IV. RESULTS

To evaluate if the signal behavior varies accordingly to the distance, the path was divided into 10 classes of 50 meters each, the mean and standard deviation of signal intensity are described in Table II. Considering the tests performed at 40 km/h the classes that showed the higher standard deviation was 0-50 presenting 3.5 of standard deviation, while in the tests performed at 80 km/h the higher standard deviation was observed in the class 350-400 and was 1.6 (values highlighted in table).

Table II
MEAN AND STANDARD DEVIATION OF RSS IN THE TWO SPEED

Distance classes	RSS Mean		RSS Std. Dev.	
	40 km/h	80 km/h	40 km/h	80 km/h
450-500	-93,5	-92,9	0,4	0,5
400-450	-92,2	-90,3	0,6	1,1
350-400	-91,1	**-89,4**	0,5	**1,6**
300-350	-88,9	-86,9	0,5	1,3
250-300	-87,9	-86,2	0,6	0,7
200-250	-85,5	-86,2	0,9	1,3
150-200	-82,0	-81,2	1,5	0,9
100-150	-77,2	-75,3	1,2	1,5
50-100	-68,7	-67,2	1,8	0,9
0-50	**-54,5**	-53,8	**3,5**	1,0

In each time when the car went through the 500 meter path with 40 km/h, 3000 to 4000 beacons were captured. It means that we recorded at 6.5 beacon/meter rate in average. The intensity of the signal corresponded to the distance among the automobile and the router. Figure 5 shows how signal strength behaviors when the vehicle is moving at 40km/h. The standard deviation (vertical lines) is smaller in larger distances. In distances smaller than 50 meters the signal is higher than -70 dBm.

Concerning the test at 80km/h, about 1800-2000 beacons were received each time the automobile went through the path recording an average of 3.8 beacons/meter. The behavior of the signal intensity at velocity of 80km/h is shown in figure 6. At this velocity the behavior of signal intensity was similar to the one observed at 40km/h. In the second case the signals intensity was higher than -70 dBm in distances smaller than 50 meters. The standard deviation (vertical lines) of the signal

Figure 4. Environment used in test

intensity in velocity of 80 km/h was greater than what was observed at the velocity of 40 km/h.

Based on the observed data it was possible to calculate the path loss propagation formula using Statistica software. The formula is presented in equation 3 where RSS is the measured signal strength in dBm and dist is distance in meters.

$$rss = -10 - 30log_{10}(dist) \tag{3}$$

Inverting equation 3 (assuming that the distance cannot be 0) is possible to calculate the estimated distance based on RSS. The formula is presented in equation 4.

$$dist = 10^{\left[\frac{(rss+10)}{-30}\right]} \tag{4}$$

After these tests was possible to apply equation 4 in order to obtain a estimated distance from a given received signal strength indication. The real distance presented high positive correlation with the estimated distance, Pearson Correlation Coefficient observed was $r = 0.93$, indicating 93% of similarity among real and estimated distances. The correlation coefficient is higher in small distances with r=0.96 in distances less than 200 meters.

Once estimated distance presented hight correlation coefficient with the real distance, we aim to analyze in which real distance a collision alert wold be triggered, considering a safety radius of 50 meters. In the results, shown in Figure 8, it was observed that the test at the most distant alert was 66.4 meters and 50.4 in the closest case.

It is important to highlight that in neither of the tests the trigger got inside the safety radius.

V. DISCUSSION

The higher standard deviation found in class 0-50 meters at 40 km/h could be due to high sensitivity when signal gets strong or some signal reflections on vehicle surface. At 80 km/h the class that showed the higher standard deviation was 350-400 and that might had occurred by random noise at the site once this deviation is not so highlighted when compared to the deviations of the other classes.

Due to the speed of the vehicle, the amount of time it remained in path was different regarding the slower test which presents a broader capture of packages. Hence, in lower speeds it is possible to gain a better precision of estimates. However, even in the 80km/h tests the number of captured beacons was enough to generate a consistent distance estimate (Figure 8), where every alerts were generated inside a safe zone.

As expected, the signal strength corresponded to the distance among the automobile and the router having almost the same values in both speed tested and the logarithm curve was also similar. The standard deviation (vertical lines) is greater than 80km/h because the number of the captured beacons was lower. Statistically, as large the sample the smaller is the standard deviation.

Another reason could also be an effect caused by speed, but in the performed tests there is no strong evidence to ensure it. To prove the speed effect in the behavior of the received signal strength more tests are required at higher speeds.

Based on RSS data collected, it was possible to empirically compute an propagation formula (equation 4) using Statistica software. Compared to equation 1, it is possible to affirm that the path loss exponent obtained in this test is three (3), that is equivalent to a plain environment [15].

The high positive correlation observed among the real and estimated distance indicates that the equation 4 fits this scenario very well. Based on distance estimates, it is possible -in future work- to calculate the approach speed of

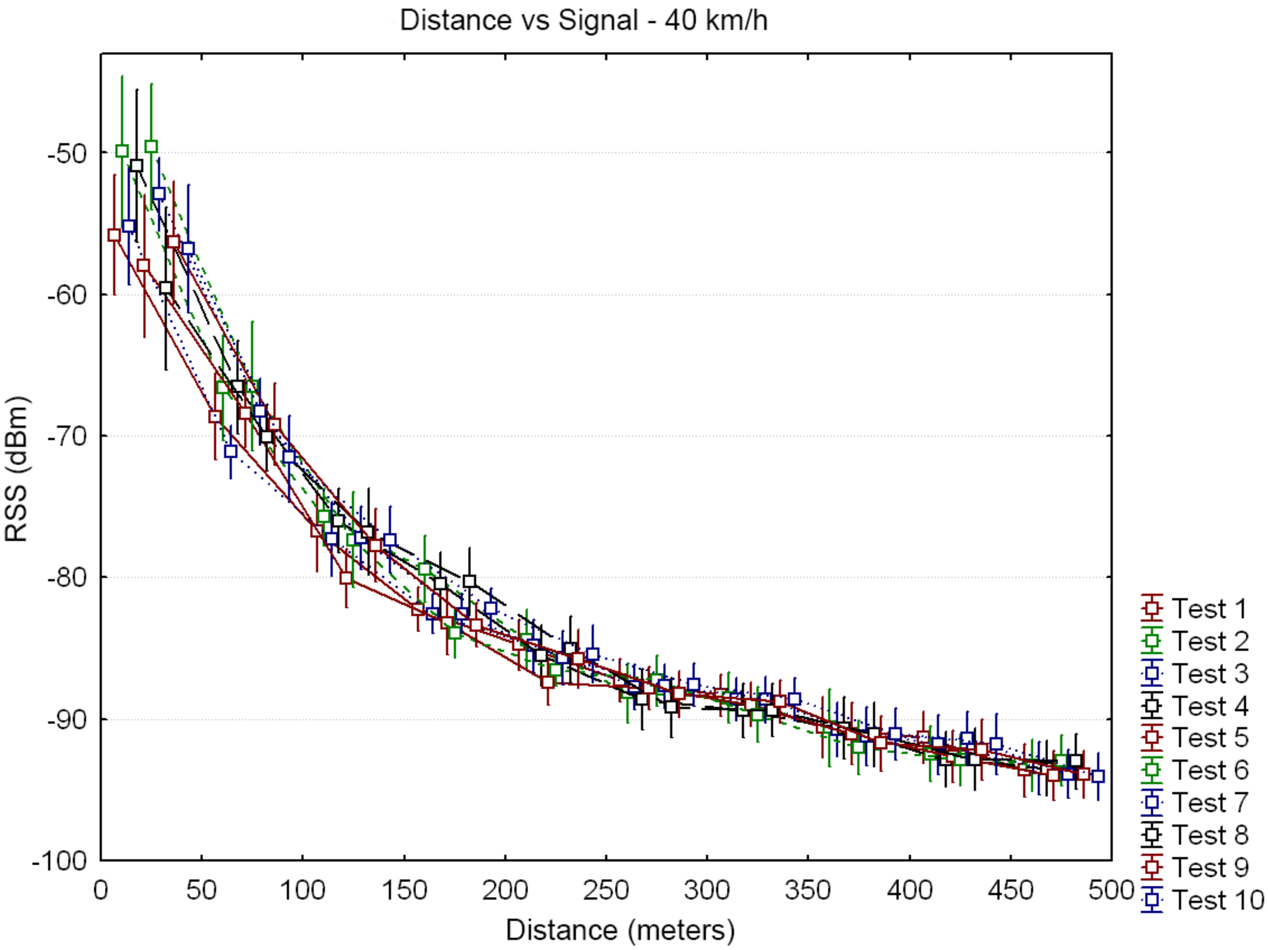

Figure 5. Signal x Distance on 40 kilometers per hour

the vehicle and improve and improve the quality of collision detection considering the reaction time rather than the safe zone (instead of using a fixed distance, 50 meters, using a reaction time).

According to what was mentioned before, in order to avoid collisions, a safety radius of 50 meters was defined. If the estimated approximation reaches a distance less then 50 meters an alert must be sent to the system to realize an evasive maneuver.

The 50 meters distance was chosen, because it is the distance in which it is possible to realize maneuvers in some aircrafts. The definition of an ideal distance is not the aim of this paper. In the same way it is important to highlight that evasive maneuver also is not the aim of this study.

This work focus to study the behavior of RSS and how it could be used to collision detection. In order to validate the idea, firstly we performed tests with terrestrial vehicles, that allow us to determine 2D approaching. In the aerial vehicles context, is important considerate position and trajectory in 3D.

Previously works try to elucidate this problems, such as the study presented by Lou *et al* [7]. In their study they solved this problem by triangulating the signal from base stations in known locations. However, it is not aways possible to contact enough base stations to triangulate the signal.

Our study in 2D will further be expanded to 3D considering triangulation from several UAVs without the need of fixed stations with known locations.

The UAVs that will be used in the scenario are Tiriba (Figure 9) and TLUAV (Tailsitter LSEC UAV) (Figure 10). Tiriba is the name of a family of small, electric-powered, low cost unmanned aircraft developed for monitoring applications mainly in agriculture and security. This UAV was developed by the LSEC (Critical Embedded System Laboratory) in partnership with INCT-SEC (National Institute of Science and Technology - Safety-Critical Embedded Systems - Brazil) and AGX Tecnologia.

Despite its apparently simplicity, as can be seen in Table III, the avionics of Tiriba is a complex safety-critical embedded system [16].

The autonomous control system is divided into control and navigation units that have different tasks and can be executed at different frequencies [18], [19], [20], [21], allowing the distribution of the autopilot system tasks over multiple

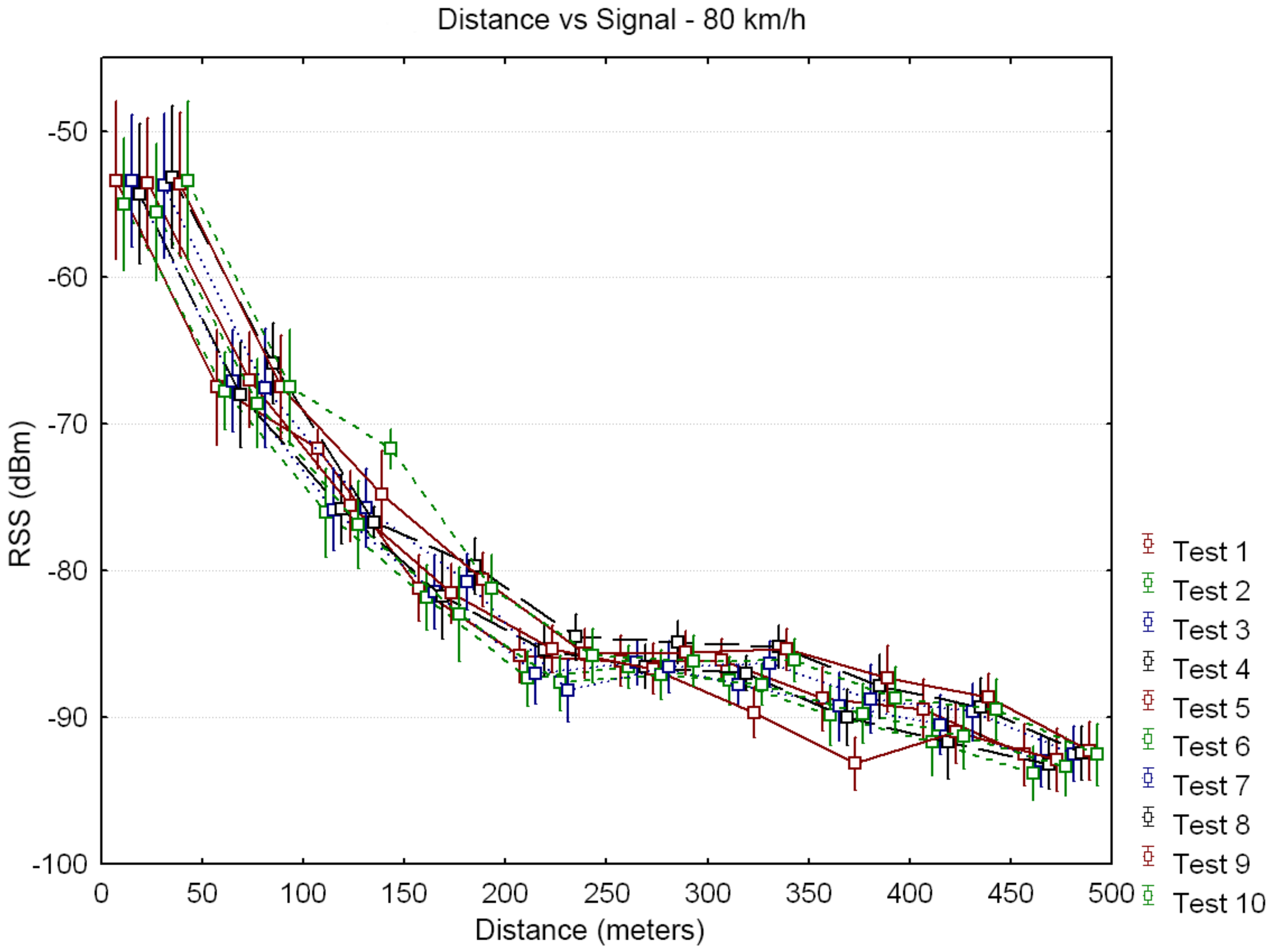

Figure 6. Signal x Distance on 80 kilometers per hour

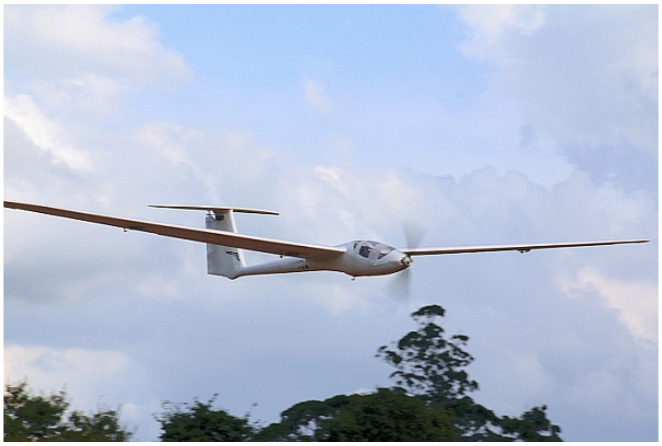

Figure 9. The Tiriba Aircraft[16]

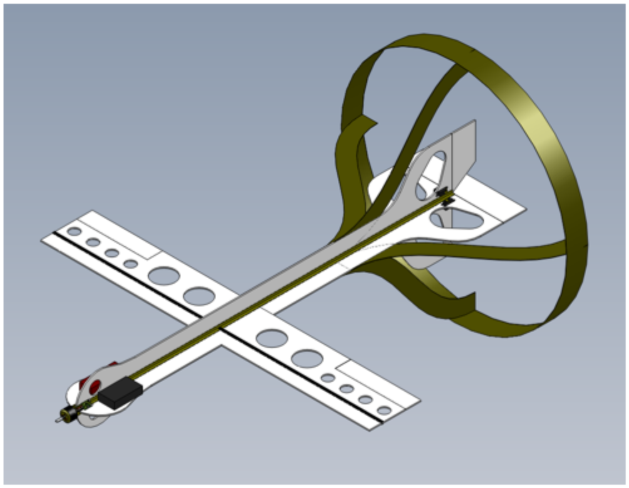

Figure 10. The TLUAV Aircraft [17]

processors. Its code is automatically generated using the Matlab/Simulink Model-Driven Development (MDD) toolbox [22]. The use of MDD allows code reuse and decreases time spent in code maintenance and development, then reducing the final cost of the aircraft [23], [24], [25].

The design of the TLUAV is based on Convair XFY-1 [26], the TLUAV size is of 90 cm height and 1 meter of wingspan. The main design feature chosen is its simplicity, since there are no major mechanical changes in comparison with other

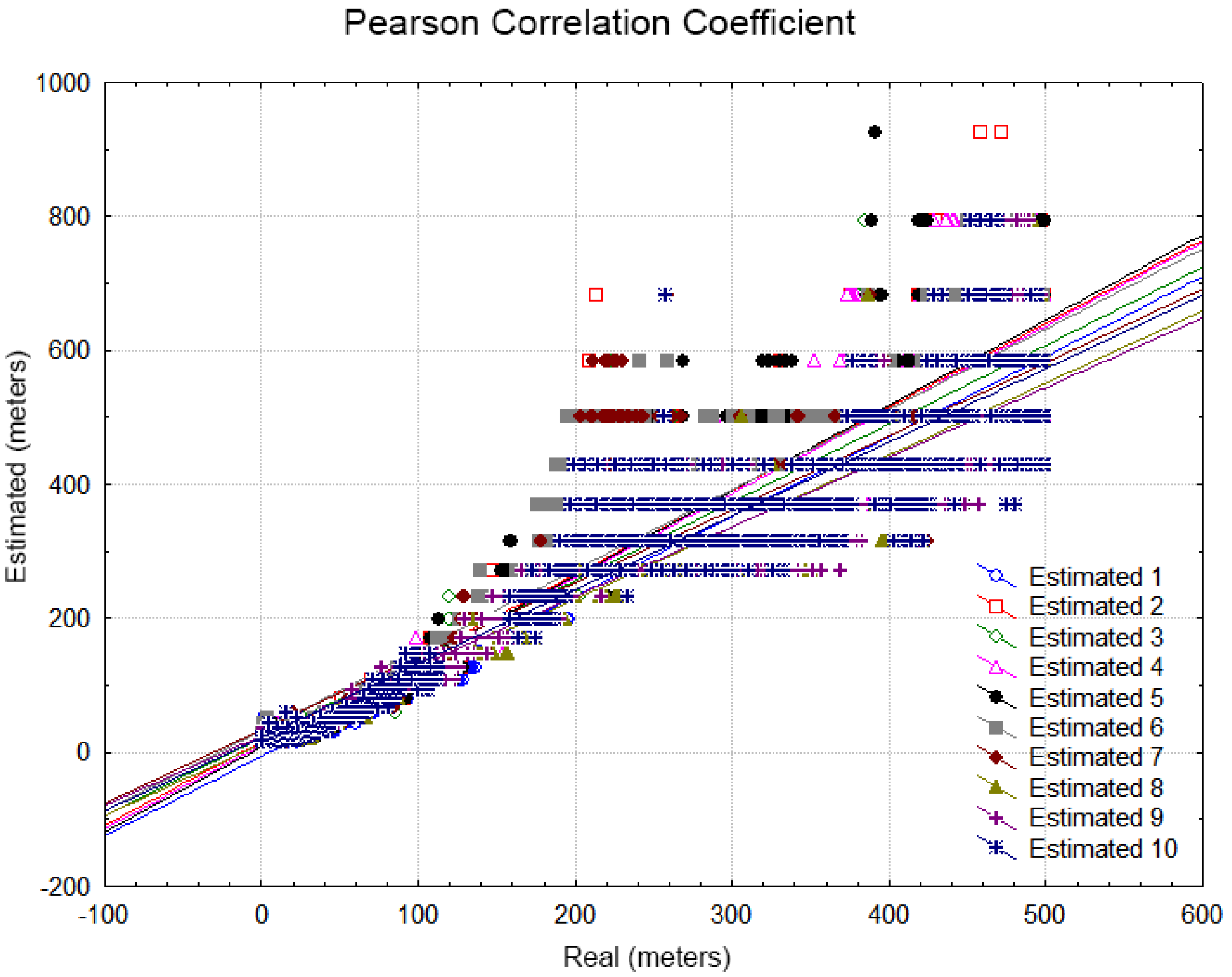

Figure 7. Real and Estimated Distance Correlation

fixed wing UAV [17].

Table III
TIRIBA – BASIC SPECIFICATIONS[16]

TIRIBA - BASIC SPECIFICATIONS

Propulsion	Electric,1.2KW
Max Takeoff weight	3 Kg
Payload	0.7 Kg
Endurance	40min/1h30min
Cruisier speed	100Km/h/60Km/h
Takeoff	Hand launch/catapult
Landing	Automatic, parachute
Missions	Autonomous
Ground Station	Smartphone based
Assembly time	10 min

In order to implement 3D systems new tests wold be required to verify the signal propagation behavior in high speeds using different altitudes. Some studies proposed propagation models focused in 3D environment[27], [28], [29] but they generally cover urban or indoor environments. Then some adaptations might be required for the operation in aerial and high speed environments.

Note that in collision avoidance context, it is not important to have the exact location of the vehicles. Instead, it is enough to know the trajectory vectors of the aircrafts. This can be achieved by sending together with beacons, the information about RSS received from the others vehicles.

For instance, considering that there are four aircrafts in a given scenario.

Aircraft 1 should send information about RSS received from the other three aircrafts (0, 2 and 3); Aircraft 2 should send information about 0, 1 and 3; and Aircraft 3 should send information about 0, 1 and 2. In some point, Aircraft 0 could then compile information about all aircrafts in the scenario, like illustrated in table IV.

Based on the data arriving from the different aircrafts it is

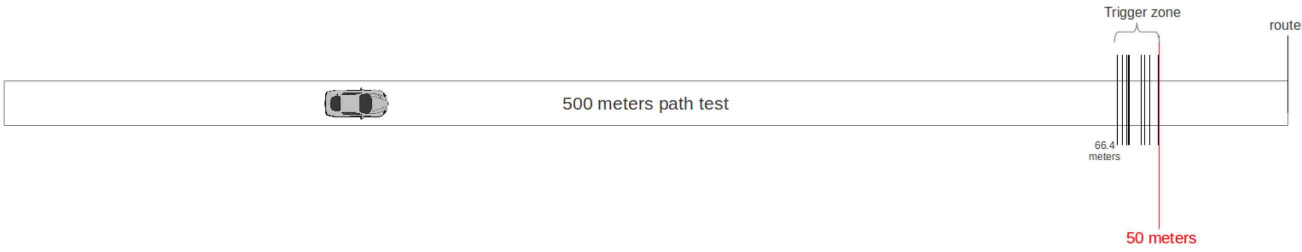

Figure 8. Alert Trigger from RSS signal

Table IV
EXAMPLE OF RSS INFORMATION RECEIVED FROM AIRCRAFT 0.

Source	Reference	Value (dBm)*
Aircraft 1	Aircraft 0	-70
Aircraft 1	Aircraft 2	-70
Aircraft 1	Aircraft 3	-65
Aircraft 2	Aircraft 0	-70
Aircraft 2	Aircraft 1	-70
Aircraft 2	Aircraft 3	-65
Aircraft 3	Aircraft 0	-95
Aircraft 3	Aircraft 1	-65
Aircraft 3	Aircraft 2	-65

* - dBm values are just example

possible to calculate the distance to each and triangulate the signal. In the next beacon, the data will change, indicating which aircrafts are getting close to each other and those that are getting away. This way it is possible to compute the trajectory vectors of each aircraft (blue arrow in Figure 11).

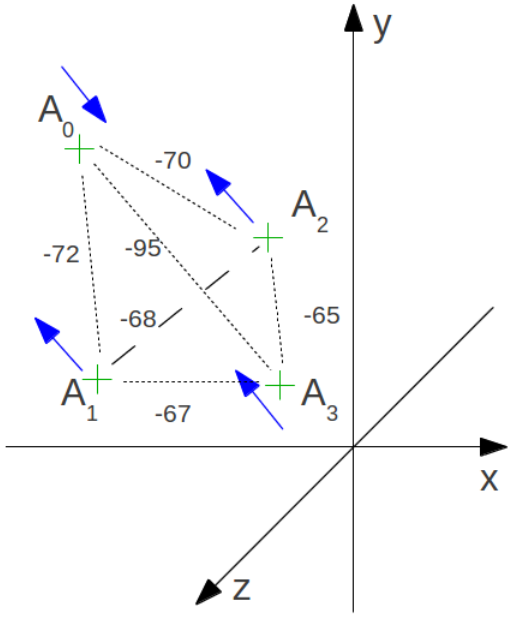

Figure 11. Example of a three-dimensional scenario

The scenario presented in Table IV is illustrated by Figure 11. Wherein the green crosses represented by A0, A1, A2 and A3 are aircrafts; the dotted lines represent the signals exchanged between the aircrafts and the RSS value is indicated near the line.

As mentioned before, a set of these values in different time can be used to calculate the trajectory vectors. When the RSS do not change significantly during time means that the trajectory vector among the two aircrafts are similar (A1, A2 and A3 in Figure 11).

Using data from a single aircraft allows to determine a safety radius, but it do not have any information about directions and an evasive maneuver can be achieved without need. The approach using multiple aircrafts will be tested in future to improve the collision avoidance system and prevent false positive warnings.

VI. CONCLUSIONS

Based on the results we can affirm that it is possible to use the signal strength as an indicator of proximity among two vehicles that compound the vehicular network. This occurs because the signal intensity varies consistently with the distance. Also, we have not found evidences that the speed influences the signal strength.

As future work, it could be interesting to evaluate higher speeds and extend our tests to aerial vehicles considering a three-dimensional environment. In a three-dimensional environment it is necessary to calculate the trajectory vectors to avoid false positives that could occur when an aircraft enters the safety zone of another. In this situation, even if the trajectories are not intersecting, a warning would be triggered resulting in an unnecessary evasive maneuver.

Another point that might be considered is to repeat the experiment in different locations where could exist some interferences of other wireless networks and use others sensors such as accelerometers, gyroscopes, etc to improve the estimated distance.

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