# Design of a Modular Simulation Environment for Vehicle Mounted Logical Units

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**Abstract.** In spring 2014 the first of a new kind of running event will take place - the *Wings for Life World Run*. It is based on the so-called moving finish line concept where the finish line (represented by a car) gradually catches up with the participating athletes. As a result, the timing of these events has to evolve in order to meet the new requirements. However, developing and especially testing systems that rely on the interaction between different technologies, such as GPS, RFID and mobile communication, can be very costly. Therefore, this paper presents a novel method to simulate the technologies stated above in a parameterizable way. A modular approach to simulate the technologies and emulate their output is illustrated. Furthermore, a software-based prototype capable of simulating a human driver, a car, RFID detections, GPS accuracy and mobile network reliability is presented in this paper.

## 1 Introduction

Traditional running events are typically limited either by a fixed distance to be completed by the participants (e.g., 100-meter dash, marathon, Olympic triathlon) or by a time limit, where typically the athlete who is able to complete the highest distance wins. However, a new kind of running event is about to emerge - the *Wings for Life World Run* [1] [2]. At this kind of event neither the distance nor the time are determined in advance. Instead, persons who are not able to surpass the required distance at any point of time during the race are counted as finished and can be ranked.

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The required distance can be considered a function of the elapsed time. The person that finishes *last* and therefore has completed the highest distance wins the race.

The timing of such events is realized with a *moving finish line*, which is a car that starts a certain time after the athletes have started and catches up with them gradually during the race. This is the so-called *catcher car*. The catcher car has to stick to a predefined speed profile as closely as possible in order to generate comparable results. The slowest athletes will be overtaken first, which eventually leaves the winner, who is the last unranked person.

Sports events are typically timed using RFID (Radio Frequency IDentification) technologies with timing stations on pre-determined points of the track. However, this kind of timing, while perfect for traditional, fixed-distance events, is not suitable for sports events where the time *and* the distance are dynamic. The solution is to mount the timing equipment (including the timing station and its antenna(s)) onto the catcher car.

Another requirement is the ability to organize multiple events of this kind all over the world, at the same time and in a synchronized way. This should result in comparable real-time results from all sub-events across the world. Furthermore, it means that the catcher cars have to be synchronized in terms of their distance traveled at any point of time during the event.

This paper shows how it is possible to simulate the problems that can arise during an event in order to achieve a more cost- and time-efficient testing process of the OBU (On Board Unit) that has to be developed for the catcher car. The problems that should be simulated include unforeseen problems on the track (like collapsed athletes), the driver driving too fast or too slow, unreliable data connections and imprecise positioning. A system overview of the OBU can be seen in Figure 1.

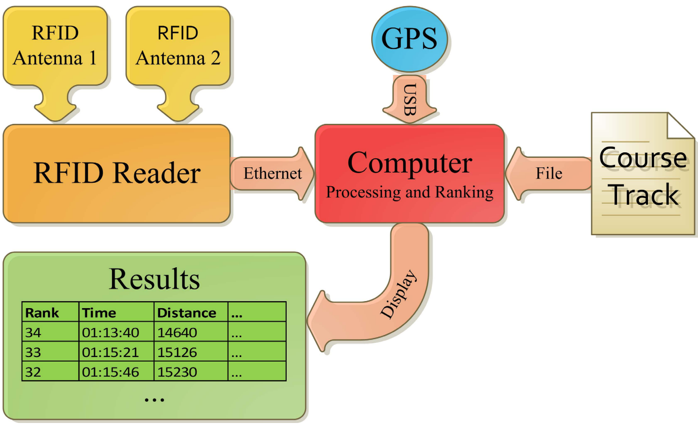


**Fig. 1** System overview of the OBU in the catcher car

## 2 Factors to Be Simulated

In order to understand the developments presented in this paper, it is important to gain an understanding of the factors that are to be simulated. Therefore, this section identifies these parameters and determines their influence for the OBU.

### 2.1 GPS Accuracy

Generally, GPS (Global Positioning System) is based on the concept of trilateration, which means that it determines the location of the receiving device by measuring its distance to multiple given reference points. In the case of GPS, these reference points are satellites situated in MEO (Medium Earth Orbit) about 20,200 km above sea level. [3]

A robust encoding is used for the signals sent by the GPS satellites in order to compensate the errors that can occur on the distance between the MEO and the receiving device. Therefore, a coded pulse pattern that is comparatively fail-safe is utilized in GPS. This pattern is called PRN (Pseudo Random Noise) because it looks similar to real noise. However, it has information encoded in it. [4, p. 50]

The calculation of the actual position is done by the receiving device. For this, it needs the data sent by the satellites, which includes the exact location and additional information of all available satellites, called the *almanac*. The distance to the satellites is determined by measuring the run-time of the pulsed signals issued by the satellites. The communication is done on the L-band, which utilizes a frequency between one and two GHz, corresponding to a wavelength between 15 and 30 cm. [3]

#### 2.1.1 Identification of Errors

Errors in GPS positioning are induced by constantly changing surroundings. There are no principles to determine the exact impact of the changes. Hence they are random variables within a probability calculation. Most likely random errors come from the electromagnetic wave propagation, electromagnetic noise and uncertainty in the measurement. [3, p. 87]

Thus the resulting run length between the satellite and the receiver can be summarized as shown in Equation 1.

$$\rho_{code} = r + \delta_{eph} + \delta_{iono} + \delta_{trop} - c_{adj}T + \delta_{mp} + v_{rcvr} \tag{1}$$

The range $r$ is the distance between the satellite and the GPS receiver that should actually be calculated from the run length of the signal. The ephemeris error is represented by $\delta_{eph}$ and states the difference between the actual satellite position and the satellite position predicted by the ephemeris. The ionospheric and tropospheric effects are indicated by the $\delta_{iono}$ and $\delta_{trop}$ respectively. A physical effect that is represented by $c_{adj}T$ is that the waves radiated by the satellite cannot travel at the speed of light in the ionospheric and tropospheric layers of the atmosphere. Therefore, an adjusted $c$ is used. $T$ represents the error caused by the clock of the receiver. Furthermore, the multipath propagation error $\delta_{mp}$ and the device dependent receiver measurement noise $v_{rcvr}$ are shown in the equation. Typical magnitudes for these deviations are 3 m for $\delta_{eph}$, 5 m for $\delta_{iono}$, and 2 m for $\delta_{trop}$. $c_{adj}T$ can be reduced to as low as 1 m. DGPS (Differential Global Positioning System) is capable of eliminating local errors such as $\delta_{eph}$, $\delta_{iono}$ and $\delta_{trop}$. [5]

According to [6], the height value is the part of the GPS data set that is most severely affected by the weather. Furthermore, the overall accuracy is not very much affected by weather fronts if the GPS receiver is moving. This coincides with the findings of [5] who amount the deviation induced by weather to only 2 m. In [6] it is also stated that "even with surface meteorological data, it is hard, if not impossible, to properly model or predict the wet delay". In this context wet delay describes the delay "caused by water vapor in the troposphere's lower layers". For this reason, the $\delta_{trop}$ will not be simulated in the course of this paper, and the value recommended by [5] will be adopted. However, $\delta_{eph}$, $T$, $\delta_{mp}$ and $v_{rcvr}$ will be taken into account in order to be able to modify the simulation for different scenarios (e.g. best-case, standard and worst-case).

## 2.2 RFID in Sports Events

In many current sports events UHF (Ultra High Frequency) RFID (Radio Frequency IDentification) systems are used to determine the finish and split times of the athletes in a cost-efficient and reliable way. [7]

When comparing RFID to other identification methods such as barcodes, biometry or smart cards some obvious advantages of RFID can be seen. Some of them are the high amount of storable data, good machine readability, no influence of optical covering and comparatively small operating costs. A detailed comparison has been conducted by Finkenzeller in [8, p. 8].

Passive UHF RFID systems such as the one used in this paper utilize modulated backscattering. This is a technology where the reader transmits a modulated signal. The signal is received by the antenna of the chip and thereby transformed into electrical energy, which is used to power a chip inside the transponder (or tag). According to its internal logic the chip changes its own impedance. By doing so, it controls the amount of energy that is reflected by the antenna. The reader then evaluates the reflected signal and is able to determine the code sent by the tag. The small integrated circuits that are used here and the easy production of the integrated antennas makes this technology very cost-effective. [9]

### 2.2.1 Identification of Errors

In the following section, only the errors induced by the measurement itself are taken into account, but not those that occur during the processing of the measured data.

The most important factor for the result of the read operation is the gap between the reader and the transponder. The transponder has to be supplied with enough power to activate the chip that is responsible for modulating information onto the backscattered signal. In addition the signal must be strong enough to reach the reader and still be processable there. Important influencing factors here are the design of the reader- and transponder-sided antennas and the maximum allowed output power of the reader, which is regulated by various administrations. [8, p. 145]

Another factor is the amount of noise on the used frequency range. Concerning passive UHF RFID systems, the following is stated in [8, pp. 145-146]:

> In backscatter readers the permanently switched on transmitter, which is required for the activation of the transponder, induces a significant amount of additional noise, thereby drastically reducing the sensitivity of the receiver in the reader.

As the timed sports events have more than one participant, there is the possibility that collisions occur when multiple transponders are active at the same time. Multiple-access and anti-collision procedures are used to reduce and recognize collisions. Some examples of multiple-access procedures in RFID are Space Division Multiple Access, Frequency Domain Multiple Access, Time Domain Multiple Access and Code Division Multiple Access. The anti-collision procedures include (Slotted) ALOHA and the Binary search algorithm. [8, pp. 200-219]

## *2.3 Reliability of Wireless Networks*

A permanent data connection between the OBU and a centralized server is necessary during the event in order to ensure a global comparability of the results in real-time. However, an outage may happen at any time during the race. Therefore, multiple wireless communication modules to choose from inside the vehicle are planned. It is the OBU's job to switch between these modules in a transparent way. So it is necessary that the simulation algorithms described in this paper generate outages and other problems just as they could happen in reality.

Arguably the most important factor for the reliability of wireless networks is the mobile signal variation, which happens due to three reasons:

**Physical path loss:** Occurs during the free space propagation. The signal strength decreases exponentially with the distance.

**Large scale or slow fading:** Describes the attenuation due to objects that are blocking the direct path between the sender and the receiver. Due to the diffraction of radio waves, not all the area behind the object is affected. Depending on the wavelength of the signal and the shape of the object, the signal can be received again in some distance behind the object even without a direct line of sight.

**Multipath or fast fading:** Influences the signal by convoluting or erasing parts of the signal due to the multipath propagation.

Further quality influences include the properties and conditions of the surroundings, electromagnetic noise and the manufacturing quality of the wireless modules.

### *2.4 Computer-Directed Human Behavior*

It is not common that humans are instructed by computers how they should drive a vehicle in terms of the exact velocity. In a usual environment the opposite is the case. However, this is exactly what the situation at hand is about. Because of the uncommonness of this combination, there are no reliable sources in terms of how humans respond to the instructions provided by the DAU (Driver Assistance Unit). Therefore, it was necessary to make one important assumption according to one's own experiences and interviews with other persons.

The assumption is that the driver checks the DAU more often if the current speed differs greatly from the speed instructed by the DAU. This is because a driver tries to decrease the difference as fast as possible. One can compare this behavior with that of a driver getting driving directions from a navigation system. When following a highway for a long time, the navigation system is only consulted sporadically. However, when navigating to a destination within a city and on a route with many branchings and crossroads, the driver will often check the navigation system.

## 3 Methodology

This section provides a structural overview of the most fundamental parts of the developed system, how they work and how they interact with each other. Before the actual development process started, an evaluation of existing simulation modules has been conducted. The result of this evaluation was not satisfying, because there are no simulation solutions available, that cover such a broad spectrum, as it is intended here.

### *3.1 Overall Concept*

Before starting the development of the modular simulation unit it was crucial to specify the components and the interfaces between each other. To achieve the required modularity, the following design decisions were made in advance:

- Fragmentation of different simulation tasks
- Parameterizability through configuration file(s)
- Development of a simulation controller, providing the modules with instructions
- Flexible interfaces for the communication between the simulation modules

The next step was to define how the simulation modules, the controller and the external devices, which the simulation is made for, should interact with each other. Figure 2 shows this in a comprehensible way.

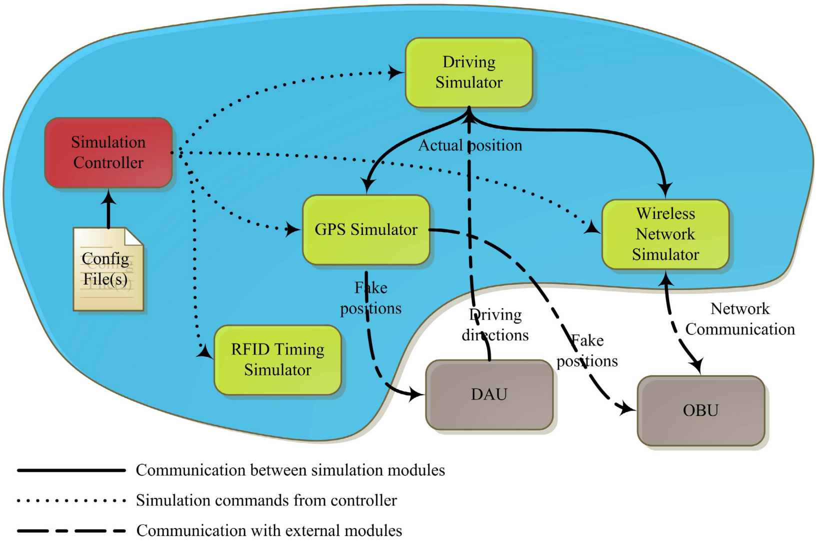


**Fig. 2** Overall concept and interfaces of the simulation unit

The most important module of the overall simulation is the simulation controller, displayed in the upper left corner of Figure 2. It provides the other simulation modules with commands that parameterize their simulation tasks. The controller depends on the information in the configuration file which is created by the user. It contains the general information about the track and the surroundings which are to be simulated, as the following list shows:

**Course definition:** A list of GPS coordinates representing the track.
**GPS accuracy:** Definition of the severity of parameters influencing the GPS accuracy.
**Driver accuracy:** Description of how accurate the driver is able to follow the instructions given by the DAU.
**RFID detections:** This parameter defines the detection frequency.
**Wireless network throughput:** A representation of the throughput in up- and download on any given position on the track.

All the simulation modules are provided with simulation commands from the controller, whose task it is to decide about special events triggered by certain actions. Also the simulation modules communicate with each other. This is necessary because they have to supply each other with information. For example, the GPS simulator and the wireless network simulator need to retrieve the current location from the driving simulator.

## *3.2 Algorithm Design*

This section describes the algorithms designed for the simulation environment. The key functionality of each algorithm is shown below.

### 3.2.1 Driving Simulator

In Figure 2 the driving simulator was shown as a single block. However, due to modularity reasons and to make the simulation more realistic, the decision was made to split this module into two separate parts. These parts are:

**The DriverThread:** This sub-module simulates the behavior of the driver, including the intervals the driver checks the DAU, the driver's use of the throttle/brake and the overall accuracy of the driver. All these values are randomized within the degree of freedom specified in the configuration files. This is especially important for the simulation of human behavior.

**The CarThread:** It simulates the more complex and low-level parts of the overall module. Some of them are the acceleration and braking pattern of the car and the calculation of the simulated distance and position on the intended track. To facilitate the simulation, linear acceleration and braking patterns have been assumed. Furthermore, possible turns on the track do not influence the speed of the car in the simulation. The calculation of the current distance $dist_{cur}$ can be achieved by adding the distance traveled since the last calculation to the previous distance $dist_{prev}$. Due to the linear acceleration pattern, the distance traveled since the last calculation can be computed as shown in Equation 2. The calculation of the current GPS coordinates is especially important, because they have to be forwarded to the GPS simulator and the wireless network simulator. Equation 3 shows an exemplary calculation of the current latitude $lat_{cur}$. $dist_{cur}$ represents the distance currently traveled, as calculated in Equation 2. The latitudes/distances of the current and next position in the track definition are represented by $lat_1$, $lat_2$, $dist_1$ and $dist_2$. The result is the latitude of a given point with known distance between two points with known latitudes and distances, whereas a straight line between the known points is assumed. The calculation of the current longitude builds upon the same principle.

$$dist_{cur} = dist_{prev} + \left(\frac{v_{prev} + v_{cur}}{2}\right) * t \tag{2}$$

$$lat_{cur} = lat_1 + (lat_2 - lat_1)\frac{dist_{cur} - dist_1}{dist_2 - dist_1} \tag{3}$$

### 3.2.2 GPS Simulator

As could be seen in Section 2.1, the accuracy classification is a very complex task. Even with exact data concerning the surroundings, weather and the satellites, it would be nearly impossible to simulate the results of the positioning process. Furthermore, the influences of the receiver's quality would be very hard to numeralize. The parameterization by the user would also require a thorough understanding of weather influences, multipath propagation and the technologies used in the GPS receiver from the user.

Therefore, the decision was made to let the user specify the maximum error according to the desired situation to be simulated. This maximum error is then weighted with a normally distributed random value (with a mean of zero and a standard deviation of one) and appropriately applied to the latitude and longitude values.

### 3.2.3 Wireless Network Simulator

When the catcher car drives on a track, the communication unit will experience rising and falling reception levels and a transition between different mobile communication technologies with different properties. This also includes complete outages if they are specified in the network coverage file provided via the simulation controller. For this simulation the attenuation is modeled with a cubic function, which is similar to the real behavior.

The network coverage file specifies zones that are covered by a certain base station and its properties. These properties are start distance, end distance, maximum upload/download speed and upload/download speed at the margin of the cell. If the current distance is not covered by any cell, the upload/download speed is zero.

According to the distance, a cubic attenuation factor $f$ can be calculated, which is between 0 (no attenuation) and 1 (full attenuation). If the maximum bandwidth $B_{max}$ and the marginal bandwidth $B_{mar}$ are known from the network coverage file, the current bandwidth $B_{cur}$ can be calculated as shown in Equation 4.

$$B = B_{max} - f \times (B_{max} - B_{mar}) \tag{4}$$

### 3.2.4 RFID Timing Simulator

The RFID Timing Simulator simulates the athletes passing an RFID timing station. However, one problem for the simulation of the passings is that in a real sports event they can be distributed in a broad variety of ways. Furthermore, the simulation is required to be parameterizable, which means that the user should at least be able to configure when the main wave of athletes should pass. For this reason, a wide range of distributions and functions was evaluated and it was researched how these can be used in the simulation, but still be parameterizable. However, most of these distributions pose the problem that they cannot guarantee that all athletes have passed the timing point at any given point of time. Most notable for this is the Chi-squared distribution and the hyperbolic tangent function.

In the end the decision was made to use linear ascends and descends, which are staggered into parts. Each of these parts represents a discrete amount of time, whereas the magnitude of the part represents the relative number of athletes passing the timing point. The position and magnitude of the part where most of the passings occur (also known as the main wave) can be configured by the user. Furthermore, a randomization factor has been inserted in order to model a real sports event.

## 4 Results

After the algorithm design, a prototype of the software was implemented in Java. This software provides the necessary functionalities to let the user specify all the important parameters of the event to be simulated and execute the simulation in real-time. Some important parameters are a list of transponders, a specification of the track and its mobile coverage, the behavior of the driver and the car, the overall accuracy of the GPS receiver and the maximum upload and download speed of the wireless communication module. Every detected athlete can be seen by the user.

Figure 3 displays the behavior of four important output parameters over the driven distance. The first graph shows the progression of the car's speed during the event. A target speed of 8 km/h (2.22 m/s), which is marked by the dashed reference line has been set for this simulation. Furthermore, a deliberately low accuracy of the driver has been chosen, which explains the high fluctuations of the speed. The cumulative number of finished athletes is shown in the second graph. According to the parameterization, the main wave of athletes is passed at around 70 percent of the track. In the last graph, the progression of the up- and download speeds can be seen. The simplified model that is applied here, shows that both speeds get lower and the fluctuations gets higher with a higher distance from the center of the cell.

Another important type of data to be simulated are the GPS coordinates extracted from GPS modules. Figure 4 shows a histogram of the deviations between the "real" GPS coordinates according to the track specification and the simulated coordinates calculated by the GPS simulator. For this simulation, a maximum deviation of five

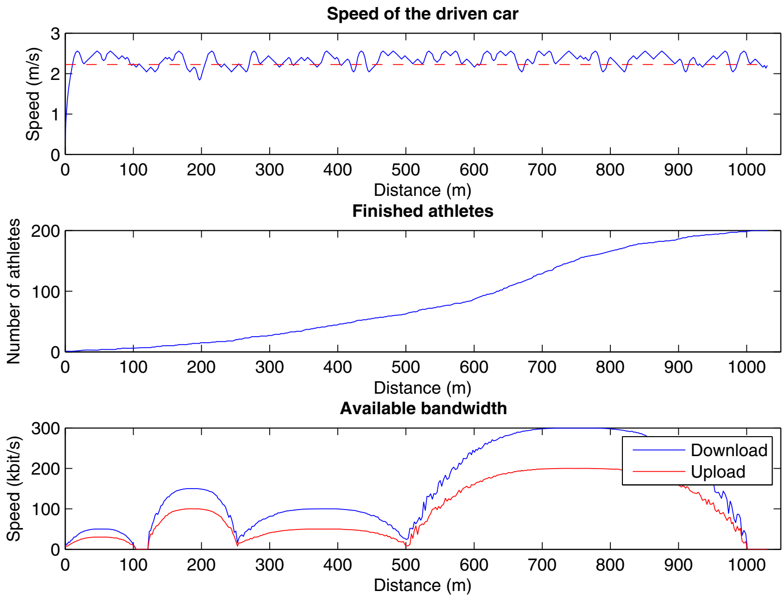


**Fig. 3** Graphically formatted results of a simulation

meters has been specified (see 3.2.2), which matches exactly with the simulation results seen in the figure.

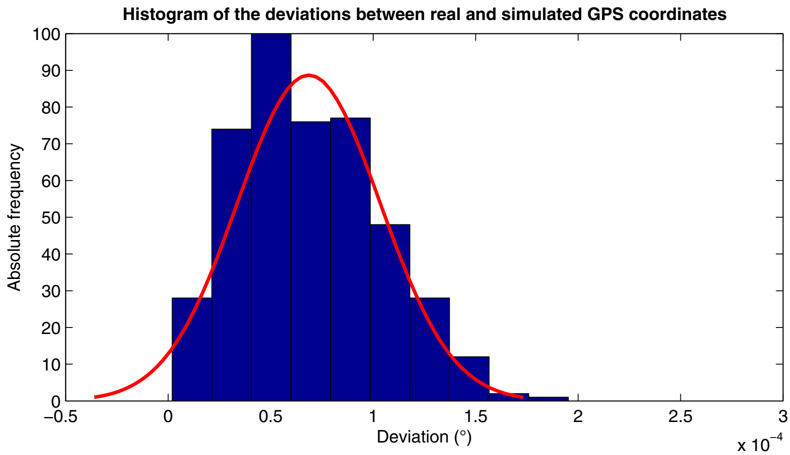


**Fig. 4** Deviation of the GPS coordinates

In the current version some features are still missing. This includes the ability to simulate unexpected events such as collapsed athletes in front of the car or mobile communication outages caused by the mobile communication unit. Furthermore, the ability to employ statistical distributions for the detection rates of the athletes has not been implemented yet. However, this would make the simulation more realistic.

Altogether, the system provides a good foundation for further development in the area of simulation environments for vehicle mounted logical units.

## 5 Conclusion

After conducting all the necessary research and implementations, it can be said that, when testing vehicle mounted logical units, a simulated approach holds significant advantages over conventional testing. The main reasons for this are of organizational and financial nature, but also the parameterizability of the simulation plays an important role. Already slight modifications of the developed prototype result in a working test unit for the OBU as soon as its first version has been developed.

The most significant scientific conclusion of this paper is the general model of a modular and parameterizable simulation unit shown in Section 3.1. Due to the possibility to adapt this model for other simulation tasks and to re-use the existing simulation modules including their algorithms and implementations, a rapid creation of simulations for other vehicle mounted logical units is possible.

It is suggested that the next steps for the further development of this simulation environment are to specify the hardware and the interfaces in order to enable the simulation to communicate with the OBU and the DAU as soon as they are developed. Furthermore, a mathematical thesis could deal with the evaluation and implementation of adequate distributions for the detection sequences of the transponders. Also a thesis in the area of network modeling or radio frequency communication could create and implement a more realistic model for the properties of the data channel between the OBU and the central server.

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