Simulations for enhancing of the FLARM

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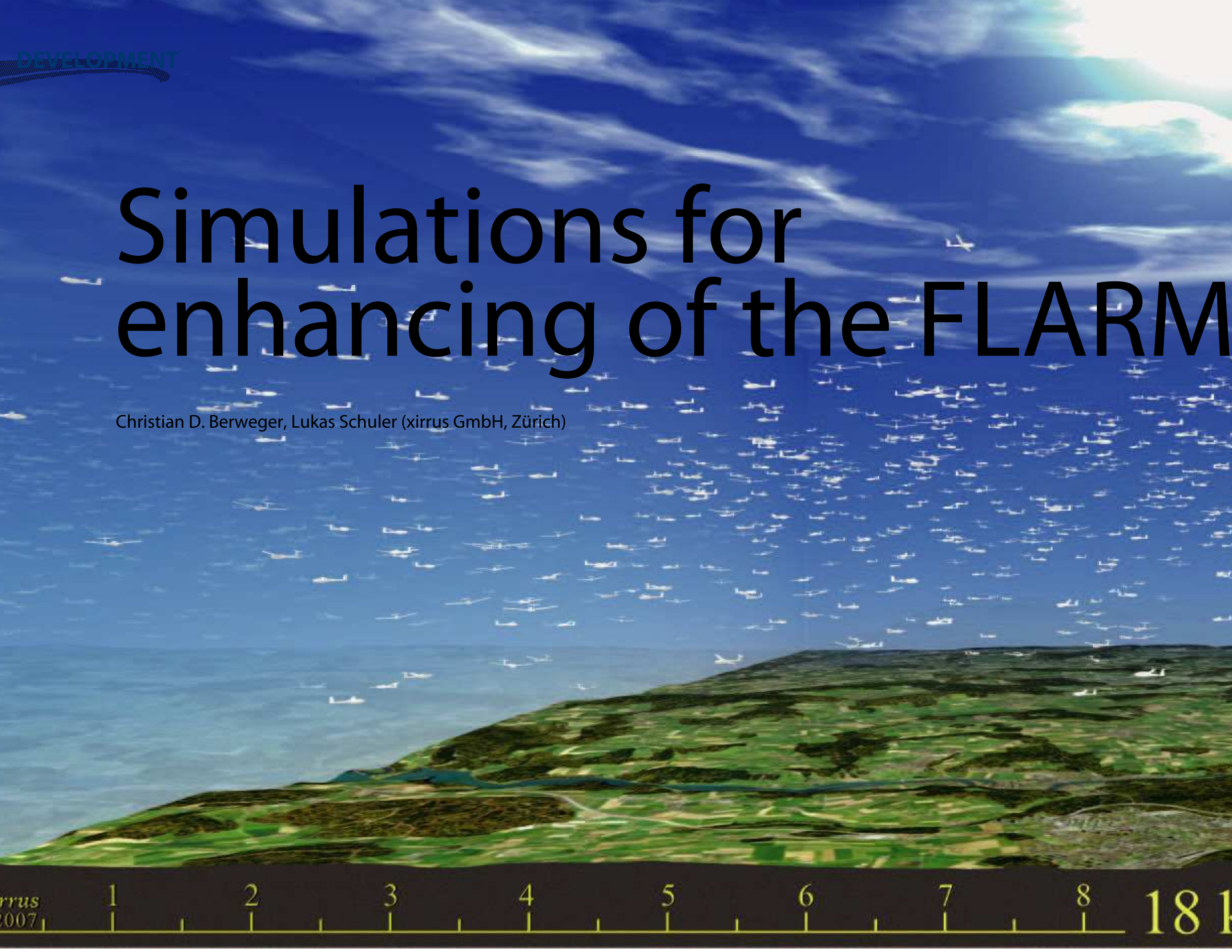


Even if FLARM has proven to function since four years in practice, the technical capacity limits must be understood. Simulations of the applied communication protocol between the devices have clarified some of these aspects. Thereby its concern are the minimization of collisions of messages (not airplanes). This text shows how these problems have been addressed and that one does not pilot airplanes to do this.

Splendid weather conditions in early summer, fresh air, cumulus clouds – ideal for a glider pilots flight. Peak period on the gliding airfield. Uninterrupted, the whinch catapults gliders into the sky. Several planes circle under a promising cloud. Additional gliders are joining them, FLARM beeps. Is FLARM capable to receive the messages of the neighboring planes in a sufficient manner?

It can, as a simulation study of the underlying communication protocol showed. xirrus GmbH – a specialist in computer aided simulation methods – has elaborated and implemented this study in contract with FLARM Technology GmbH, especially towards the improvements of the communications protocol that has been updated to the software version 4 since April 2008. Thereby it was important to verify data throughputs, analyse perfomance restrictions as well as optimal message protocol parameters according to realistic scenarios.

Maximum coverage above 10 km

A core function of FLARM and of compatible devices is based on the fact that each device sends periodically – most of the time once in a second, in certain situations also more often – its own predicted flight path, an identification as well as additional appropriate data in a short radio message. Devices within reach will receive this message and calculate in comparison with their own flight path prediction and the many received flight path predictions possible risks. From these informations the warnings and the display of surrounding air traffic is derived.

Several factors are affecting hereby if the radio message is in fact receivable and can be recognised. Not considered in this study are the performance limits in the calculations of correctly received messages. This simulation on the other hand contains a reference which computational effort has to be potentially considered and which filters therefore should be applied.

remark by xirrus simulation: this article has been published in German and was translated by the authors

communication protocol

For example, the mounting of the antenna into the airplane is of importance for emittance and reception, since the signals are dampened by insulating parts of the airplane. FLARM provides a web-based tool for this issue, which extracts these informations from an IGC-File and visualises them intuitivly [www.flarm.com/support/analyze/] – use this charge free service to optimize your mounting. For good mountings in glider planes, analysis show typical coverages between 3 and 6 km, with maximum coverage significantly above 10 km.

At a given transmitter power the reachable coverage also depends on how the antennae of both planes are oriented relative to each other. In case of the FLARM mounting, antennas orientation should be parallel to the airplanes vertical axis. Then the coverage is best, if two neighbouring antenna are parallel to each other. And that is well done.

Potential problems at reception

If now two airplanes are positioned such, that they are within reach of coverage, then it is not yet guaranteed that they will be able to receive a radio message. E.g. a device cannot send at the same time as it receives. This way currently around one in 200 messages gets lost. Under circumstances, several devices may send at overlapping times, such that received messages become too noisy and have to be rejected as invalid. This only is a problem, if different incoming messages have similar transmission levels, which rarely is the case. It's important that every receiver decides autonomous at any time whether to accept a message as valid or not. This has been implemented in FLARM.

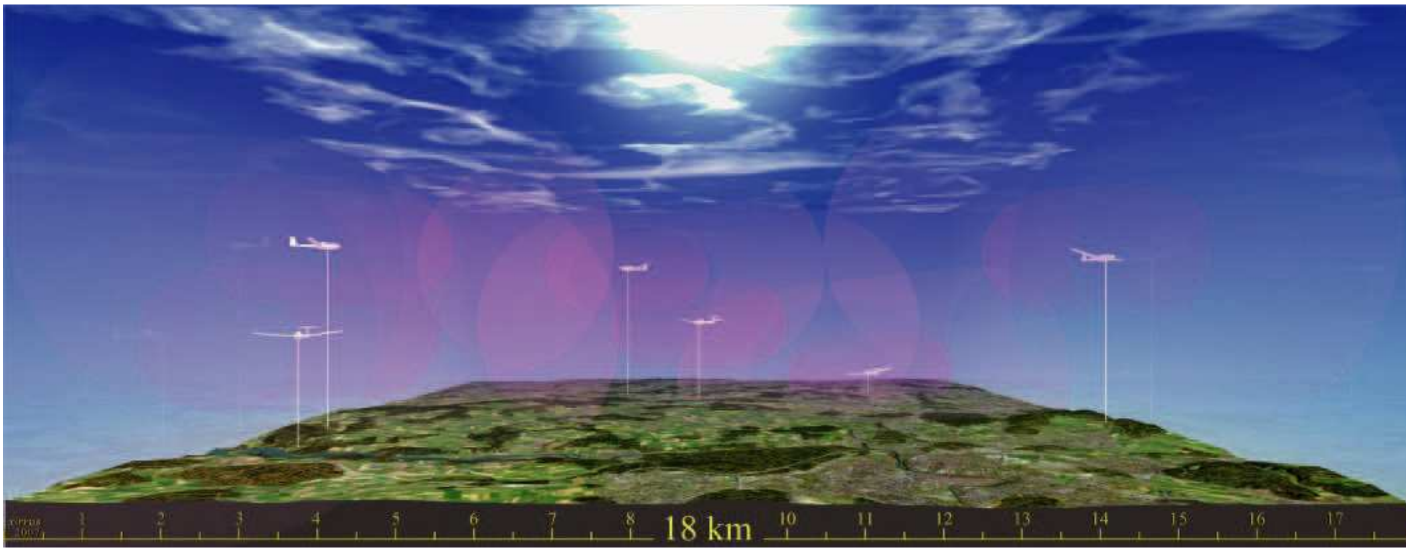
Ideally it is ensured, that simultaneous sending never occurs. However, the practical realisation of this has to cut back. The goal of the communication protocol is to reach a maximal bandwith utilization at a given transfer rate and with given technical components, but at highly variable traffic density. And thereby strictly keep certain minimal standards for every single participant in extreme situations.

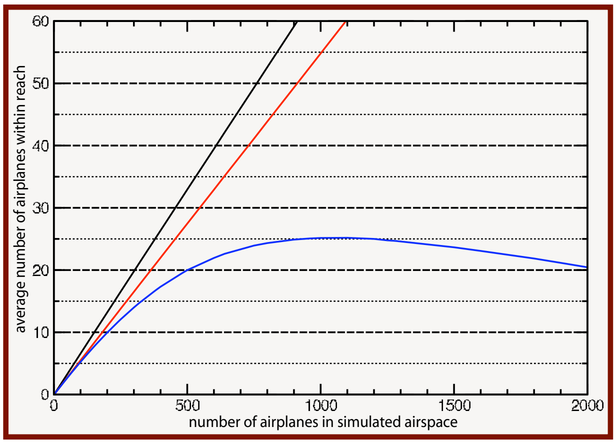
Numerous technical tricks are applied for this. Thereby many parameters can be optimised for realistic scenarios, amongst these are synchronised transmission windows, listen-before-talk, multi and part-transmissions or message lengths.

Some of these parameters have been optimised and then used as constants in the message protocol, others are dynamically adapted by the devices to the current situation.

Advantages of the proprietary communication protocol

As a central element of the proprietary communication protocol holds that the message not only contains a position, but also three dimensional predictions of the flight path as well as a fixed identification. This leads to crucial benefits that should not be missed, as comparisons in simulations have shown: Firstly the flight path prediction is immediately available and has not to be derived by the recicipent from earlier – or eventually missing –





Top: Six airplanes, each 50-times enlarged, with corresponding receiver coverage. (Picture 1)
Right: Static scenario simulation of receiver statistics at variable traffic density. (Picture 2)

messages; this would lead to less accurate, less reliable and more often delayed data and as a consequence lead to a bigger number of unnecessary warnings. Secondly it can be easily recognised if a radio transmission data updating has not taken place. Thirdly in this case it is possible – although a message got lost – to update the position from the just beforehand received flight path prediction to a high precision. Additionaly the used computational power is minimized, since each device only has to calculate its own predictive data precisely and just has to compare it to the completely received data of other devices.
In each second each device determines a randomly chosen transmission time point within the valid transmission time frame. Through the GPS it is possible to synchronize all devices such that the second starts approximately the same time for each. This synchronisation does not comply the strict applications like in passenger airline traffic (e.g. such as a VHF Data Link 4), which makes it cheaper, but also costs some of the bandwith. Our simulation has led the fine tuning of the valid transmission time frame to a fixed optimal value. Below a certain traffic density, (a part of the) messages are sent multiple times. Thanks to the simulation this threshold could have been optimized.
Immediately before a device starts to send, it verifies if an other message is received. If yes, its own transmission is delayed. We have optimised for FLARM, how this delay should be time-phased.
Hereby it has to be considered, that the delay is not allowed to lead to a non-transmitting device and that the device should never delay an emission twice in a row. Additionally it has to be ensured that at a higher (radio) traffic density not nearly all devices are delayed at the same time to just a moment later trying to send nearly all at the same time again. This situation has some similarity to the dynamic noise level in a concert hall when everybody is waiting before for the concert starts.
Although the quite simple initial state, many of these analytic questions are highly complex and not very intuitive to derive. At the same time they are not accessible through experiments with real airplanes. On the other hand these questions are well suited for so called Monte-Carlo-Simulations, since the basic mechanisms are well defined. With computers numerous scenarios are created. In every of these scenarios the air space is randomly occupied by a number of airplanes, which are selected from realistic conditions. For example the air traffic density, the hight level profile, the number of circling airplanes as well as the banking angles are calibrated from OLC data.

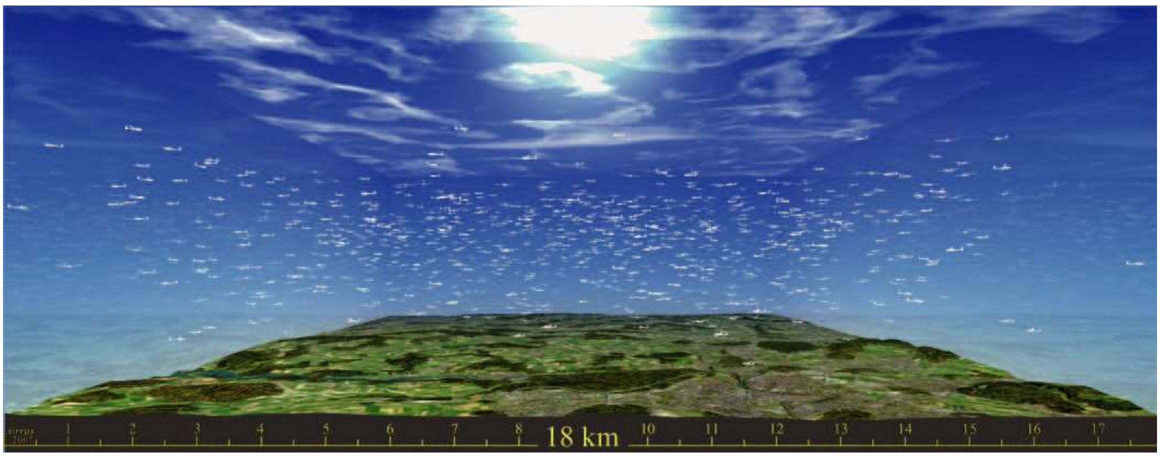
Scenarios in a virtual air space

Picture 1 shows how one could imagine a single scenario in an illustrative manner. A virtual airspace above a plane of 18 x 18 km (bigger than the usual maximal coverage) is used periodically to the sides and occupied by six airplanes. The translucent rose swimming ring spaces around each plane illustrate the transmission coverage. When two planes are positioned within their respective coverage spaces – e.g. both to the left – they can communicate. An airplane to the upper right is on its own. It does not exchange informations, but there is no necessity either.
In the simulation the transmission efficacy for each of the possible sender-receiver-pairs – in the illustrated case 15 pairs – is looked at and analysed statistically. The number of simulations influences the spread of the results. Certain simulations are static, others cover a time

sequence, e.g. if it is considered how lost messages are recognised as such and can be reconstructed.
To estimate the average capacity at congestion the above described airspace was loaded with thousands of airplanes. **Picture 2** shows the corresponding statistics, where up to 480.000 scenarios have been analysed depending on the airplane density. The vertical axis shows the average number of neighbouring planes within 6 km radius (black line), the number of airplanes within coverage of the transmission with respect to the antenna characteristic (red line), and the number of correctly received messages while applying the effective static transmittance of FLARMs radio protocol (blue line).
At low flight traffic each device is received correctly. If the number of airplanes increases, there is a slow degradation due to message collisions. The static communication capacity reaches a maximum at 25 received neighbors. The corresponding airplane density is with 1.000 airplanes very big, and will not be encountered in practice. **Picture 3** shows this situation for illustration.
Although in this constellation we receive 25 neighbors on average, more than 60 are in the proximity of one device. In this extreme situation we only receive about a third of the proximity on average. Within the simulation we can look into the details of this situation, since we have collected all the informations about each airplane in every scenario.
Here it is essential, that we are not depending on one message per second from each of the airplanes, and that the transmission of each device gets actually redefined every second. Therefore the cards for which pair of devices cannot communicate within a second are shuffled again each time.
Above we have seen that the probability of receiving a single message in an extreme situation correctly lies about at 35 %.

The probability, that this situation occurs several times in a row, decreases rapidly. This also can be derived analytically, for example after three additional seconds 98.5 % of all messages have been transmitted successfully. With simulation we now also can investigate the question, whether the changing orientations and distances between the airplanes affect the capacity of the system. The simulation shows here, that the transmission capacity between two approaching airplanes is increasing over time, because the received signal power is higher at shorter distance, which makes the message better receivable, even with many overlapping, but weaker signals of third neighbors. FLARM is typically warning 18 seconds before collision and switches to highest alert phase at 8 seconds. Even at very high simulated air traffic densities it is nearly excluded, that no message was received over such a long period.

Conclusion: The modular, computer assisted simulation platform which we have developed on behalf of FLARM Technology GmbH, allows us not only to look at the actual situation of this successful system in detail, but also to test different enhancements and adaptions in advance to implementation and to optimise them. E.g. is it reasonable to transmit additional informations, to improve further analysis on the receivers side? Or are the advantages of an information plus eliminated through the longer transmission times and due to more colliding messages?
Additionally the single modules can be fed with real data, such as antenna characteristics or airplane trafffic constellations in the virtual airspace.



Extreme scenario: 1.000 airplanes, each at 12-times magnification. (Picture 3)