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# Simulation of the Data Transmission from the Aerobatic Plane

***Abstract***. *This article deals with the optimization of data transmission from the fast-moving objects. Optimization is performed on the second layer of the RM OSI and uses multiple transmission channels. For simulation were created two cases using multiple transmission channels. These cases were compared with case of common wireless system with a single channel. Proposed cases reached better error rates and proved their usefulness. They are also independent on the transmission technology (due to implementation on the second layer of RM OSI), therefore are versatile.*

***Streszczenie.*** *W artykule opisano zagadnienie optymalizacji transmisji danych z szybko przemieszczających się obiektów, z wykorzystaniem drugiej warstwy RM OSI oraz transmisji wielokanałowej. Do symulacji opracowano dwa przypadki transmisji wielokanałowej, które porównano z działaniem wspólnego jednokanałowego systemu bezprzewodowego. Wyniki potwierdziły redukcję ilości błędów oraz niezależność badanych przypadków od metody transmisji, co świadczy o ich uniwersalności.* ***(Symulacje transmisji danych z samolotu akrobacyjnego)****.*

**Keywords:** Wireless communication, simulation, Wi-Fi, high availability.
**Słowa kluczowe:** komunikacja bezprzewodowa, symulacja, Wi-Fi, duża dostępność.

## Introduction

The High Speed Mobile Communication project is focused on the design of the transmission system that would enable wireless transmission of the video and telemetric data from aerobatic plane during air show. Systems for transmission audio-visual data from fast-moving objects exist (Formula 1 or Red Bull Air Race), there, however, the machines move over a relatively well-defined route. Therefore, demanding on the radio part is not so high, it is just necessary to deploy properly the basic stations along the assumed trajectory and the connection is stable and good enough to transfer these data [1]. Nevertheless, this is not possible at aerobatic show because of unpredictable airplane trajectory. Presented solution is designed to increase the robustness of data transmission and reduce the impact of lower transmission conditions by using multiple independent data channels. Fading, that increase error rate, is arise during movement therefore, is necessary include it in considerations too. The proposed methods should reduce the impact of these losses and increase the overall robustness of the system. A common way to improve the transmission characteristics is the MIMO technology (multiple-input multiple-output), thus the use of multiple antennas at the receiver and transmitter. The proposed method is independent of the physical layer and modifies only the second layer of the RM OSI. Therefore, it is universal and it is also possible to use it with e.g. MIMO technology. Looking for optimal parameters, it requires a number of the tests, which is technically and financially very exhausting and demanding, specifically in the case of the aerobatic plane. For this reason, the usage of the simulation is very useful because of an adequately accurate description of the system, which allows quick adjustment and evaluation. Therefore, an OMNeT++ was used, the network simulation framework, and library INET that includes support for the international standards that are used in the simulated real device.

## Implementation

The implementation of the second layer optimization can be done in the different ways. Two goals were chosen for our approach to increase the resilience of transmission (reduce error rate) and consequently to increase the overall transmission speed. To comply with these requirements, we simulated two new methods and one typical method to compare them. In the selection of the first method, we proceeded from the assumption that if we create N parallel data streams and each will transmits 1/M of input data, then, thanks to a lower bitrate for a single data channel will be achieved higher resistance using more robust modulation. In the second case, we counted that the N parallel channels will always transmit the same data. The total bitrate will not increase, but due to parallel transmission of data will be preserved high durability and low error rate. Thus, the resulting bitrate would not be significantly changed from the nominal speed at physical layer in given modulation.


Fig.1. Block diagram for Case 1

These two approaches were compared with the case using only one radio interface. Its second layer of RM OSI is not modified in any way; the data on the transmitter side comes directly to a single radio module that provides data transmission of one radio channel. The receiving part is again only a single radio interface, and no frames selection is applied. This network was created because of the possibility of comparing the resulting statistics from the other two cases, because this case corresponds to a commonly used method of data transfer - with a one radio interface. This case simulates the situation of the basic wireless data transmission, as indicated by the Fig. 1. Second and third case has functionality differentiated by a distinct block that controls distribution of data for each interface. This block operates on second layer of RM OSI, is independent on the particular transmission technology or the physical layer. Second case contains the control block on the transmitter side, provides an exact alternate use of both radio interfaces. The principle is shown in the Fig. 2.

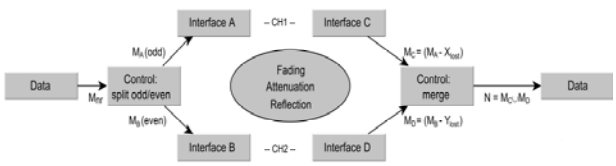


Fig.2. Block diagram for Case 2

Output gates of block are tied to their own separate radio interfaces transmitting at a different radio channel. The data are collected alternately from the first and the second channel on the receiving side. The simulated network should do this matter, because the load is divided into two channels and provide better error rate compare to a first case, because is viable to use more robust modulation and thus ensure higher availability. It should also lead to increased availability since that there is different interference on each radio channel. Distribution of frames on each channel shows the following set of expressions which operates with frames indexes:

(1)

$$DataIndex = CH1 = CH2$$
$$CH1 = \{nr \mid nr = 2k, k \in N^{+}\}$$
$$CH2 = \{nr \mid nr = 2k, k \in N^{+}\}$$

The third one, with mirroring of sent messages, generates the duplicate frames in the control block on the transmitter. The original frame and the exact copies have different radio channel again, but this time, these frames are always sent in one moment. On the receiving side, there will be selected only one of them. The selection is performed at the receiver side in a way to avoid the duplication of the same data. This case is schematically illustrated in the Fig. 3.

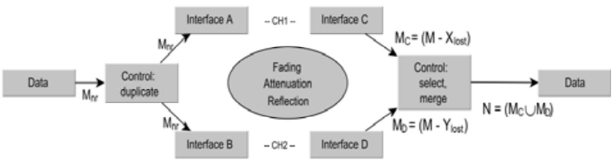


Fig.3. Block diagram for Case 3

Due to high redundancy, the increased availability should results also in this case. The proposal was made for two radio interfaces, but it can be used for a greater number of independent interfaces. This network should show the best resistance to loss of data in the given modulation. Because if a frame will be dropped on one interface (due to faulty transmission, frame damage), there is still the possibility that on the second interface, working on another channel, the error may not occur and therefore the data will be delivered. In fact, it does not matter from which interface the data arrived. Usage of channels describes this set of expressions:

(2)

$$DataIndex = CH1 = CH2$$
$$CH1 = \{nr \mid nr \in N^{+}\}$$
$$CH2 = \{nr \mid nr \in N^{+}\}$$

Free space model was used as a propagation model in the first set of simulations. It was used because of precisely defined conditions, where the airplane can move. This is so called aerobatic box (shown in Fig. 4), in which could be always assumed direct visibility and space with no terrain obstacles, so is no need to solve problems by shading the first Fresnel zone. The right direction of antennas was assumed in the simulation. Aerobatics is conducted only in good weather, so the occurrence of rain or fog is not to be expected. In simulation was calculated with zero gains to the antennas, zero losses caused by unadapted polarization as well as attenuation of the cables and connectors.
The same model of propagation was used in all three cases:

(3)

$$FSL = 10\log\left(\frac{4\pi d}{\lambda}\right)^{2}$$

is free space loss [-], where λ is wavelength [m] and $d$ is antennas distance [m].

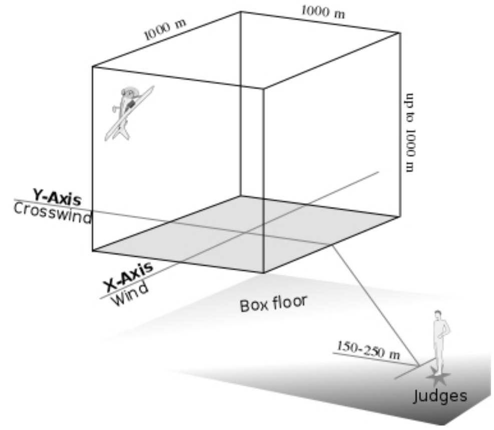


Fig.4. Aerobatic box

It is possible to derive the formula for calculating of the dimensionless signal to noise ratio, which has impact for the error rate.

(4)

$$SNR = \frac{P_r}{P_n}$$

(5)

$$SNR = 10\log\left(\frac{P_t G_t G_r \lambda^{2}}{P_n (4\pi d)^{2}}\right)$$

where: $P_r$ is singal power [mW] and $P_n$ is noise power at the receiver input [mW]; $P_t$ is transmitting power [mW] and $G_t$, $G_r$ gain of the antennas [–].

Wireless channel is very complicated system to model; signal does not follow only one path, every obstacle brings many influences for the propagation. In our case is one of the easier one, because there are no obstacles in aerobatic box, first Fresnel zone is should be free and there is a strong line-of-sight in signal propagation path. We compared our models in Free Space model which is from deterministic propagation models. In this model is counted just radio propagation attenuation for certain distance regardless of reflection, scattering, or fading. Although the aerobatic box is usually not placed in area with lot of buildings or hills and planes usually take off only in good weather (so there is minimal reflection on raindrops), still the multipath propagation must be taken into account because of reflection from ground or trees and the like. Therefore was decided to repeat every simulation with more precise radio waves propagation model. INET library offers not just deterministic models like Free Space or Two Ray Ground model, but also probabilistic models Log-Normal Shadowing, Rayleigh, Nakagami and Rice wave propagation. There is a very good line-of-sight (LOS) part in situation with aerobatic box, thereby, dominant stationary signal component is present and the Ricean fading envelope distribution is suitable for it [2]. Rice model counts with random multipath component, which is described by the Rayleigh distribution [3], and, mainly, with a coherent LOS component.

a) b)

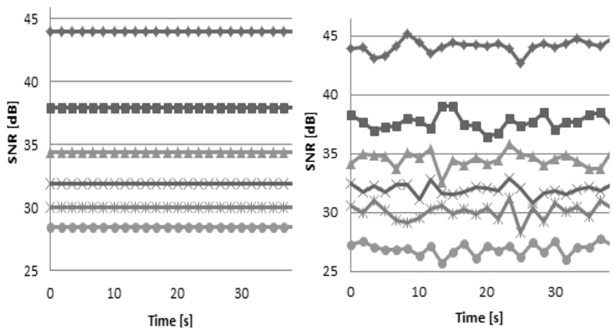


Fig.5. SNR progression for Free Space (a) and Rice (b) model

The Ricean distribution is given theoretically by:

(6)

$$p(r)=\begin{cases}\frac{r}{\sigma^2}e^{-\frac{r^2+A^2}{2\sigma^2}}I_0\left(\frac{Ar}{\sigma^2}\right) & \textit{for } (A \geq 0, r \geq 0),\\ 0 & \textit{for } (r < 0),\end{cases}$$

where $\sigma^2$ is the variance of the multipath part, $A$ denotes the peak amplitude of the dominant (LOS) signal part and $I_0$ is the modified Bessel function of the first kind and zero-order [2]. Rice model is defined by parameter K in INET framework. This parameter is known as Ricean factor that completely specifies the Ricean distribution. Parameter K is defined as the ratio between the deterministic signal power and the variance of multipath [2]:

(7)

$$K(dB)=10\log\frac{A^2}{2\sigma^2}$$

With a lower K value, bigger variance happens.

With K = - ∞ dB is Ricean distribution same as Rayleigh, on the other side, when K >> 1, than model has Free Space Loss (FSL) model behaviour. Value K = 20 proved to be large enough to meet the situation with main LOS part and still not big enough to reach FSL behaviour.

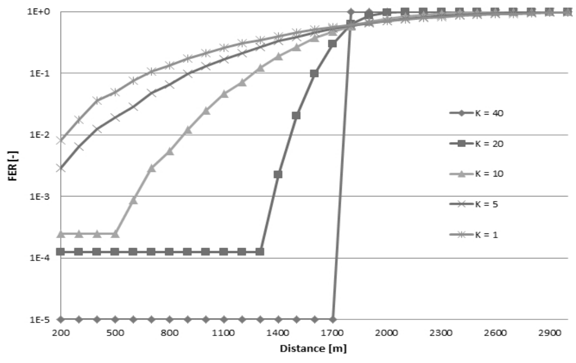


Fig.6. Comparison of different K value for INET Rice model

The impact of different K in simulations with INET library of Rice model is demonstrated in Fig. 6. Line for K = 40 has same characteristic like simulation with Free Space model. With lower K are lines closer to Rayleigh model and further from situation of dominant LOS signal part which is specific for situation described in this article. Rice model from INET library covers fast fading and path loss parts of radio waves propagation model. Shadowing is another often mentioned task to solve in such simulations. Shadowing is caused by obstacles like hills and buildings therefore, in our situation with aerobatic box without any obstacles is this part of fading neglectable.

Main difference between deterministic and probabilistic propagation models could be easily shown at SNR. Fig. 5 shows record of SNR during simulations with deterministic Free Space model and probabilistic Rice model for different distances (200 m to 1200 m with 200 m step). Deterministic model gives us value of SNR exactly same for chosen distance during whole simulation. However, shape of SNR curve in second case has elements of coincidence, which makes it closer to reality.

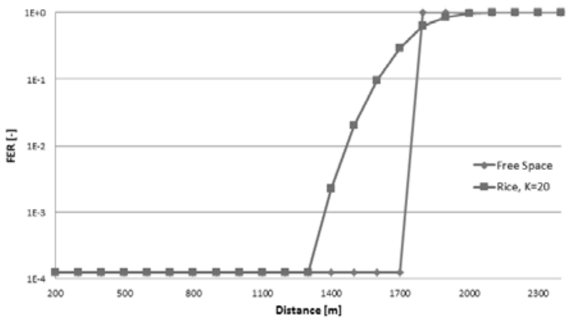


Fig.7. Propagation models comparison

Result of this different behaviour is depicted in the Fig. 7. There are two lines describing the values of FER (Frame Error Rate, described in equation 14) for distances from 200 m to 2400 m (greater distances are meaningless). Deterministic model has exact distance (so-called communication range) before which can be communication established and error rate is in low numbers. Nevertheless, after that distance is everything dropped that result in error rate equals to one. On the contrary, probabilistic model is still able to maintain connection although with higher error rate, of course. There is no exact threshold, error rate varies in certain interval and directs with longer distance to zero probability reception of frame.

Because the aerobatic plane should be rate as a fast moving object (maximal speed about 100 $ms^{-1}$), fading caused by Doopler shift should be taken in consideration.

Doppler shift (change in frequency) $f_d$ is shown in equation 8 [3].

(8)

$$f_d = f_c\frac{v}{c}\cos\alpha ,$$

where: $fc$ denotes frequency of transmitted signal, $v$ speed of receiver, $c$ speed of light and α is angle between incoming signal and direction of moving object. Because the plane can move along very various trajectories, we counted with the worst case of zero angle. In this situation is change of frequency maximal. From this equation and an assumed speed of the plane 100 $ms^{-1}$ and central signal frequency 2,412 GHz with plane in a direction towards the signal or away from it in account is possible to get $f_d$ = ±804,5 Hz as shown in equation 9.

(9)

$$f_d = 2{,}412\cdot10^9\frac{100}{2{,}998\cdot10^8}\cong 804{,}5Hz$$

Standard IEEE 802.11g [4] defines that nominal frequency should not vary more than ±10 kHz. Our value is more than ten times lower than this value; therefore, we can neglect this factor.

There is no connection of mobility with signal propagation modelling in INET library. For our purposes, this means that was created several batches of tests with different distances although there are several types of mobility (e.g. linear, circle, random) offered in this library. Simulation of data transfer was simulated on every distance and value of error rate was evaluated for every distance separately.

Table 1. Simulation parameters

| Parameter | Value |
|---|---|
| Distance [m] | 200 – 3000 |
| Transmitter power [mW] | 20, 50, 100, 300, 500, 800, 1000 |
| Transmission rate [Mbps] | 6, 9, 12, 18, 24, 36, 48, 54 |

The simulation for all three cases was made with the same parameters. One of the changed parameter was the distance between receiver and transmitter, it was necessary to cover the situation where the aircraft occurs in different places in the aerobatic box. The selection of distances (from 200 m to 3000 m with 100 meters step) is given by the conditions in which the aerobatic planes are moving. These conditions are set by the contest rules, as shown in Fig. 4. The maximum distance could be 1500 m, which roughly corresponds to the largest distance achievable in a given area. Although plane theoretically could not be further than this distance, simulations were intentionally performed up to 3000 m to demonstrate behaviour of cases two and three to the first case (the common wireless model). The lower limit is again determined by the conditions in which the planes moves normally and is around 200 m above ground. The progression of attenuation in these distances is shown in Fig. 5. The next changed parameter was transmitter power; its value was in range from 20 mW to 1000 mW (particular values are in Table 1). Selected values were given by the binding of simulation with already realized project. In particular, values below 10 mW were insufficient even for the realization of the transmission on the lowest distance in combination with the most robust modulation. The last changed parameter was transmission rate; values were taken from IEEE 802.11g standard [4] shown in Table 2. This standard was chosen due to its common availability and ease of use. The appropriate modulation and coding rate according to the selected transmission speed automatically provides INET library in compliance with the selected standard. Modulation scheme has essential impact on bit error rate, when with higher modulations (like 64-QAM – Quadrature Amplitude Modulation) is occurrence of bit error higher than with robust modulation like BPSK – Binary-Phase Shift Keying. Robustness is decreased with the greater number of symbols in modulation constellation. The bit error rate depends on the bit to symbol mapping, for SNR >> 1 and Gray-coded assignment is possible to assume each symbol error causes only one bit error, than probability of bit-error per carrier is [5, 6]:

(10)

$$P_{bc} \approx \frac{4}{b}\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{3b}{M-1}SNR}\right),$$

where $Q(x)$ is:

(11)

$$Q(x)=\frac{1}{2}erfc\left(\frac{x}{\sqrt{2}}\right)$$

In this calculation, the SNR is represented by following formula:

(12)

$$SNR=\frac{E_b}{N_0}$$

Since the carriers are independent, the overall bit error rate is the same as the per-carrier error rate.

(13)

$$BER \approx P_b = P_{bc},$$

where is: $P_{bc}$ – probability of bit-error per carrier, $P_b$ – probability of bit-error, $E_b$ – energy per bit, $N_0$ – noise power spectral density [W/Hz], $M$ – number of symbols in modulation constellation, $Q(x)$ – Gaussian error function.

In simulations described in this article are frames and their error rate evaluated, the relationship between bit error rate and frame error rate is:

(14)

$$FER = 1-(1-BER)^{F_L}$$

with $F_L$ as a frame length in bits.

Modulation techniques and code rates, which indicates the ratio of the number of bits of useful information to the total number of bits (including the added redundancy), for each type of modulation is defined by standard [4]. These are presented in Table 2.

This standard defines the minimal value of sensitivity (the last column in Table 2) too, values for simulations were set as same as IEEE 802.11g compatible device R52 from the RouterBoard [7] company which is widely used for wireless communication. These values were chosen instead of minimal sensitivity values from the standard due to fact that every Wi-Fi compatible device has this parameter usually better than standard demands. Simulations were performed for all permutations of the above parameters for each of the proposed case. In total, there was evaluated data from more than 1000 simulations.

Table 2. Modulations and transmission rates for simulation

| Modulation | Coding rate | Bitrate | Sensitivity | Minimal sensitivity |
|---|---|---|---|---|
| BPSK | 1/2 | 6 Mbit/s | -90 dBm | -82 dBm |
| BPSK | 3/4 | 9 Mbit/s | -88 dBm | -81 dBm |
| QPSK | 1/2 | 12 Mbit/s | -85 dBm | -79 dBm |
| QPSK | 3/4 | 18 Mbit/s | -83 dBm | -77 dBm |
| 16-QAM | 1/2 | 24 Mbit/s | -80 dBm | -74 dBm |
| 16-QAM | 3/4 | 36 Mbit/s | -77 dBm | -70 dBm |
| 64-QAM | 2/3 | 48 Mbit/s | -74 dBm | -66 dBm |
| 64-QAM | 3/4 | 54 Mbit/s | -73 dBm | -65 dBm |

**Simulation framework**

To simulate the transmission protocols and technologies, there are the most suitable discrete simulation tools, as directly derived from the nature of the analysed and simulated problem. One of the representatives of the discrete event systems is OMNeT++, which was used to create a model representing the transmission system. OMNeT++ is object oriented, modular system, based on the processing of discrete events. Possibilities of its use include a wide range of areas, it can be used to create simulations of any system that can be described using discrete events, which can be decomposed into an elements communicating together with messages [8]. There are a number of preconfigured models for it, standards and technologies in libraries targeted to a specific area. Due to the implementation of common standards is feasible to reduce number of simplifications in the model. For simulations of data transmission from the aerobatic planes was used INET library, which contains models for several wired and wireless networking protocols, including UDP, TCP, IP, Ethernet, PPP, 802.11, and many others [9]. Part of the library is also implementation of the behaviour of the physical layer, such as different models of signal propagation, modulation type, sensitivity, or transmitter power.

## Analysis

The simulation of error rate in network framework is provided by a set of experimentally obtained data from INET library. The set of data contains lines on which is defined SNR (in dB units) and the probability of loss for a certain bit rate and frame size [10]. Some values obtained by this approach, paradoxically, with greater distances descend. This is due to the set of data, which models the probability of error. Its function is based on comparison of the size (in Bytes) and SNR of frames that arrives on the radio interface, with the line of that set of data on which is defined loss rate of the frame for a given speed (modulation type). In simulations with deterministic propagation models is this approach beneficial, because inserted additional errors could simulate behaviour that is more real. However, probabilistic models, such as one that was used for described simulations, have certain level of instability in self therefore, another inserted loss is needless.

Value of FER (frame error rate) rising with increasing bitrate (related to the used modulation and code ratio). Sufficient value of frame loss for transmitting high-speed video signal with H.264 compression (10% according to [11]) achieved all cases at bitrate up to 12 Mbps for all required distances (up to 1500 m). At the highest bitrate defined in standard IEEE 802.11g (54 Mbps) is maximal distance 400 m, only the Case 2 (with alternate sending) goes little bit further, like for every other bitrate. The Fig. 8 shows the growth of error rate with increasing distance between receiver and transmitter for transmitting power of 100 mW. Case 2 shows more robust modulation, the BPSK with code rate equal 3/4, while the other two cases are in the QPSK modulation with coding rate 1/2. Case 1 (common case) remains below the desired limit of error rate up to the distance 1500 m, at 2000 m is connection already broken. Case 3 (mirroring of sent messages) ends connection at this distance as well, but it is able to maintain a significantly lower error rate up to this value compared to the Case 1.

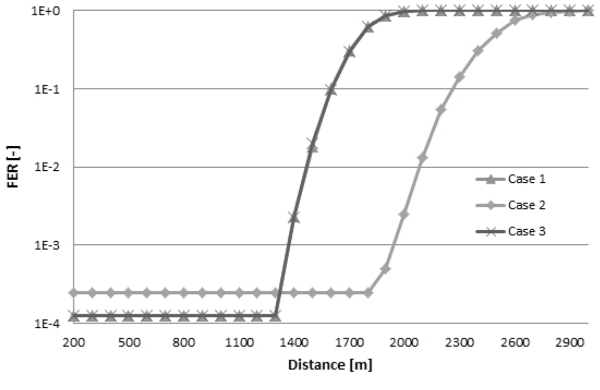


Fig.8. Comparison of presented solutions with common case

Case 2 benefits from lower and thus more robust modulation, which is more reliable, therefore is capable sustain the required error rate limit up to a distance of 2200 m. This method shows, in the same range of distances, similar or better characteristics to a first case. Therefore, is confirmed that for the given modulation scheme is the Case 3 the most suitable because of keeping a very good error rate. Usage of the Case 2 is very advantageous to keep the error rate below a certain threshold even for longer distances.

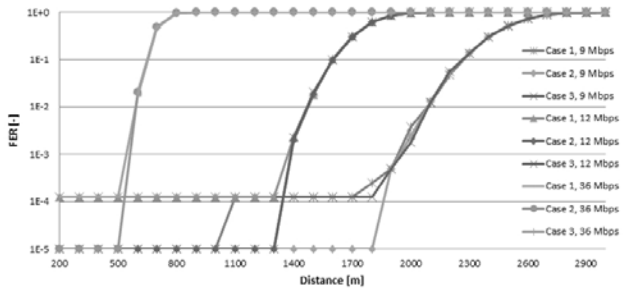


Fig.9. Comparison of models at different modulation techniques in use

There is a comparison of all three cases for few selected bitrates with appropriate modulation techniques with 100 mW of transmitting power in the Fig. 9. On this overall view is easily to see tendency that, with more robust modulation (and lower bitrate), the distance, over which is communication possible, is increases. Likewise is depicted benefit of Case 2 and 3 that are able to reach lower error rate in every point compare to common system (Case 1). This benefit for FER value for examples in Fig.9 is shown in Table 3. These percentage values are based on repeated simulation with different random seeds from OMNeT++ simulation framework. All simulations were performed with Traffic generator was set to maximal channel usage with same MTU for all simulations.

Table 3. Percentage advantage in FER for chosen bitrates

| Bitrate | Case No. | Improvement | Std. Deviation |
|---|---|---|---|
| 9 | 2 | 77,831 % | 0,029 |
| 9 | 3 | 33,229 % | 1,903 |
| 12 | 2 | 67,965 % | 0,020 |
| 12 | 3 | 51,765 % | 0,320 |
| 36 | 2 | 62,671 % | 0,022 |
| 36 | 3 | 43,929 % | 0,795 |

## Conclusion and future work

Simulation of transmission system of the aerobatic aircraft was created by network simulator OMNeT++ and its library INET. Two types of modified methods of sending data were compared with usual wireless transmission on this simulation model. The modified transmission is based on the usage of the multiple independent radio channels and it is carried out at the second layer of the OSI model; is not dependent on the particular transmission technology, physical layer is not affected as well. This option increases the versatility of the solution. The case using two radio interfaces on both sides of the transmission system sends the same data from both interfaces, but on different channels. This method proved to be very robust, because the receiver, in case of a damaged frame from the first channel, automatically receives data on the second channel. This way achieved the lowest error rate for a given modulation. The case using alternating sending frames on the two interfaces on different radio channels confirmed the benefits of maintaining a higher overall data rates for longer distances, thanks to the use of stronger modulation in both channels. The results presented in this article were gathered with optimal set of parameters therefore, these results represent maximal improvement for the proposed cases. The future work will aim at improving the proposed design for more accurate description of real situation. That involves implementation of movement in the 3D scene with usage of data that was measured during aerobatic competition. In addition, there is a possibility to utilize the GPS (Global Positioning System) data to connect the model with real position above surface in a map. In addition to the simulation video broadcasts of the fast moving objects, we would like to incorporate the possibility of the transmitting voice data into the model, focusing on the SIP (Session Initiation Protocol) network infrastructure. The issue of real testing of SIP is very well described in the [12] and [13]. New simulation model, which will be incorporated into the new version of the developed simulation library, is now created according to the information and procedures described in these articles.

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