A Close Look on the *Corona Impact* on Surveillance Radar Channel Loads

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Abstract. Civil aviation surveillance is carried out on two radio channels and has seen a growing demand in the last decades. Not only that more and more applications have been added to the channels but the number of flights had been growing constantly. This was true until the corona crisis almost brought the air traffic over Europe to a standstill and by mid of April 2020 the number of flights dropped to around 12% compared to the year before [3]. In this paper the consequences for the civil aviation surveillance channels and the success rates for telegrams on those channels are discussed.

Keywords: Surveillance Radar · Mode-S · ADS-B · Civil Aviation · COVID-19 · Corona

1 Background

The world's first air traffic control tower on Croydon Airport is celebrating its 100th anniversary this year. From the very beginning, air traffic controllers needed to be aware of the positions of the surrounding aircraft in order to separate them safely. While the air traffic controller of Croydon Airport queried their pilots to state their positions, modern surveillance is nowadays able to retrieve a wide range of information from aircraft and can therefore deliver an accurate air situation with high update rates. This technical improvement allows more aircraft to manoeuvre in a dense airspace while maintaining a high level of safety. Radar stations send out interrogations on a 1030 MHz channel and receive replies from the aircraft that are sent back on a 1090 MHz channel. The most common setup is to have a grid of secondary surveillance radar stations that query surrounding aircraft for their altitude, their ID and further necessary information needed by the air traffic control. The position is calculated by the round-trip time of the signal and the angle of the radar-station under which the interrogation was carried out. Aircraft equipped with a transponder receive these requests and answer on the 1090 MHz channel with the queried data. Besides that, there are other applications that are using these channels, for example the Traffic Collision Avoidance System (TCAS) that is used by aircraft to query the surrounding planes in order to be aware of possible unintended approaches.

Another common application is Automatic Dependent Surveillance Broadcast (ADS-B) that is using the aircraft transponder to send out information about the aircraft in a pseudo-spontaneous manner without an interrogation on the 1030 MHz channel. ADS-B has seen a growing popularity in the last years and will soon be mandatory in the European airspace.

All these applications are carried out in parallel on the two surveillance radar channels that are used in civil aviation. Over the last years the need to measure the load of these channels has become more and more important for the air navigation service providers (ANSP) around the world. [10, 2, 7]

1.1 Channels

The communication is carried out on two channels, 1030 MHz and 1090 MHz, that each have their dedicated purpose:

The 1030 MHz channel is used for interrogations. These interrogations can be one of four possible protocols, that either query all surrounding aircraft or interrogate single aircraft for specific information. These queries are either sent out by secondary surveillance radars or TCAS equipped aircraft [1]. However, this report focuses on the the 1090 MHz channel only.

The 1090 MHz channel is used for the replies to interrogations sent through the 1030 MHz channel. It is usually more crowded than the 1030 MHz channel, since a single interrogation can result in multiple replies. Additionally, some applications like ADS-B only use the 1090 MHz channel. The information is transmitted using three types of telegrams:

Mode A/C Reply is the reply to an *A* or a *C* interrogation by a radar-station, respectively. It can either return the altitude (Mode-C) or a flight-id of the responding aircraft (Mode-A). It encodes a four-digit octal number using 12 Bit. Together with the necessary framing pulses it has a duration of $20.3\,\mu s$ on the channel.

Mode-S Short Reply is one of the possible reply types for Mode-S interrogations. This telegram is also used by TCAS and transports small portions of data. It consists of a preamble, a data field and a checksum field. The short reply lasts $64\,\mu s$ on the channel and has a payload of 56 Bit.

Mode-S Long Reply is the second type of Mode-S replies. This Extended Length Message (ELM) is used to retrieve more detailed data from the aircraft. Its structure is the same as Mode-S Short Replies but it has a longer payload of 112 Bit and has a duration $120\,\mu s$ on the channel.

To measure on that channel, a measurement system had been created that uses affordable hardware and is able to monitor the receivable traffic on a time span of various days [12]. This system does now allow a comparisons of the channel loads, prior and during the corona Crisis

2 Measurement System and Setup

The system setup as described in our previous work [12] consists of a standard receiver that is used for multiple applications by ANSP. A software defined radio (SDR) sends well-known telegrams to the receiver by coupling the telegrams into the radio frequency (RF) channel on the input of the receiver.

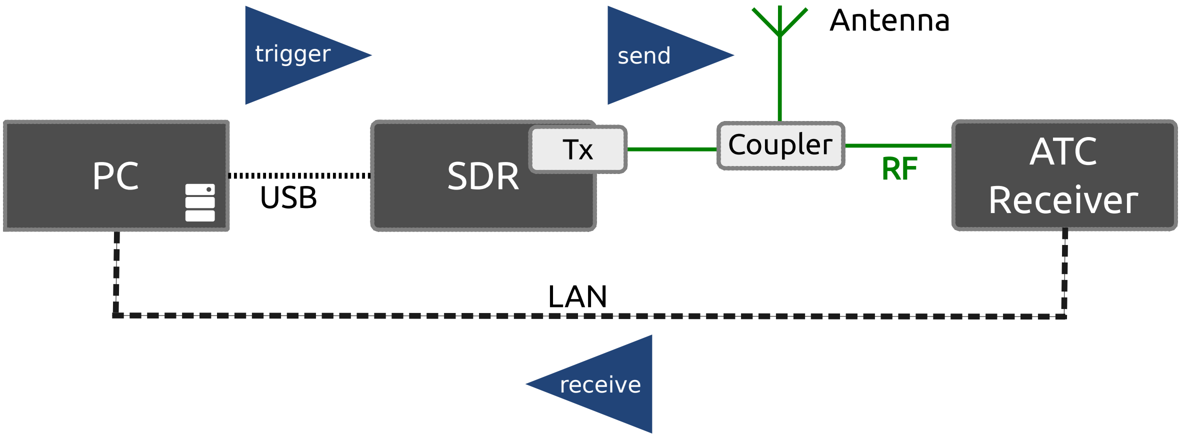

Fig. 1. The principle of the measurement system

A standard PC is used to trigger the SDR and receive the data from the mixture of the test telegrams and the *real* RF environment as shown in figure 1. This data is used to create a database of the success rates of the test telegrams in the current environment. The results are recorded in a continuous manner containing the rates of successfully decoded telegrams and the environment under which the data has been recorded. This approach has already been described in previous works [11, 15] but the advantage of using a SDR is to be able to adaptively change the constellation of telegram-types, rates and levels with respect to the current RF environment and therefore be able to gain knowledge about lesser known telegram constellations when environmental changes on the channel are detected.

This setup is under continuous improvement and will be expanded throughout the work on this research. Currently a team of students from Hochschule Darmstadt (h_da) is working on an even more cost-efficient approach which shall be achieved by the deployment of open-source tools in combination with cheaper hardware (see Section 4).

Figure 2 indicates the measurement location in Germany in the area of Frankfurt International Airport (EDDF). The system was using a 90° segment antenna heading north-west. It is one of the most crowded areas in the German airspace and thus features high channel loads.

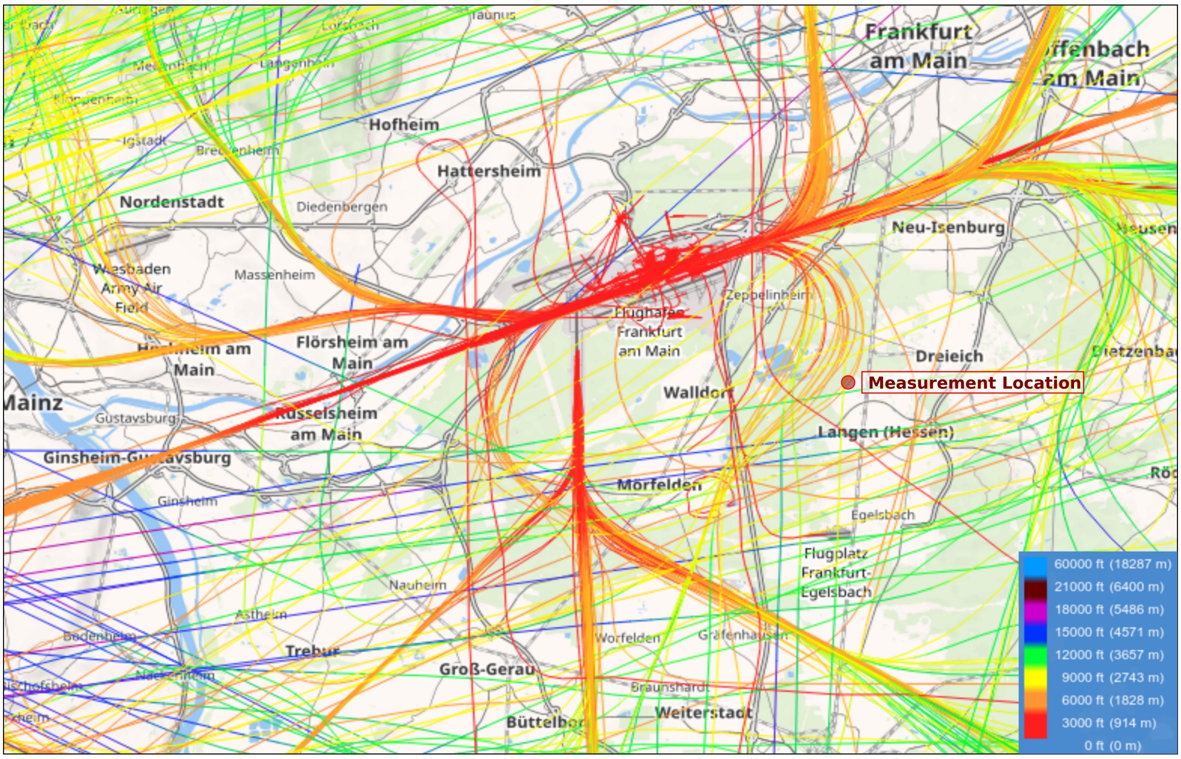

Fig. 2. An indication of the measurement location, and all flights between 14th and 21st April in the area of Frankfurt.

3 Results

The results shown in this paper have been recorded in two time windows. The first measurement session has been carried out from the 5th to the 12th of February 2020. The second session was carried out from the 15th to the 25th of April 2020. During this period the number of telegrams and the success rate have been recorded together with a wide range of additional information like the number of planes in view and the types of telegrams that were seen in each time frame.

3.1 Time Variance

The number of receivable telegrams varies very strongly throughout each day and shows strong impacts on the channel. There is a clear recurring behaviour in Figure 3 over each day. The communication increases as soon as Frankfurt airport opens. At the beginning of each day there is a small peak that is followed by a little drop. That is when the intercontinental flights arrive in Frankfurt in the early morning. The second and largest peak of the day is around 6am to 8am local time where most of the departures are taking place. There is also a weekly dependency on the traffic, on Friday the 7th of February the "departure peak" is the largest in the entire record as this is usually one of the busiest days of the week.

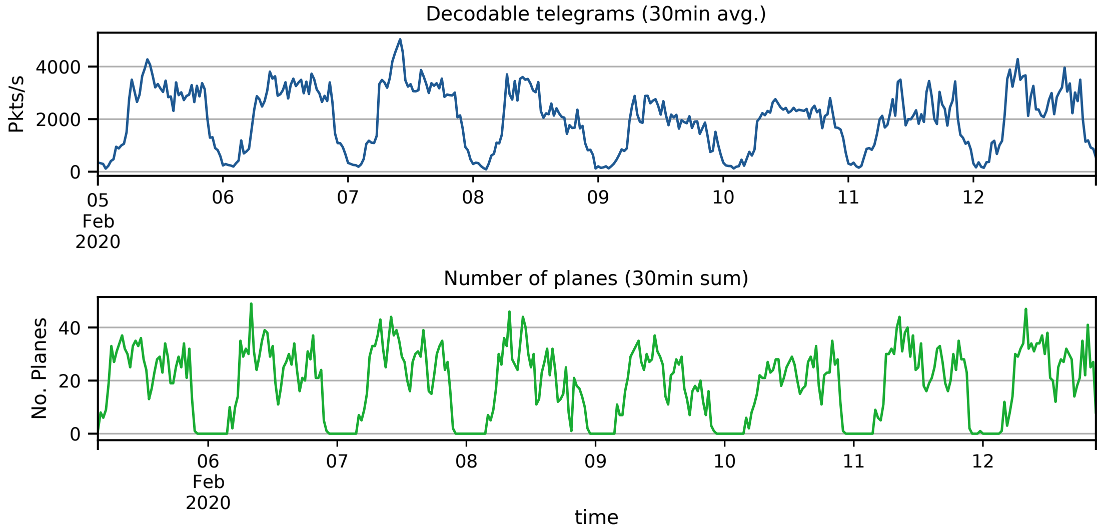

Fig. 3. The number of telegrams and planes over several days in February

3.2 Special Events and the Corona-Impact

In Figure 3 one can also see that special events do have a direct impact on the channel utilisation. There is a sharp drop in the traffic from noon on the 8th of February until the 11th. This drop was caused by storm Ciara that hit Germany during that time and led to a large number of cancelled flights. On the 12th of February the traffic is back to a normal level causing a equally normal amount of packets on the channel. This is one of the strongest declines since the outbreak of the Eyjafjallajökull in April 2010 [4, 8] where for a period of 4 days almost 100% of the flights were cancelled. However, this drop in flights was very soon surpassed by the lockdown due to the corona crisis [5].

Figure 4 shows the traffic during a week in April 2020, where most of the flights were cancelled due to the shutdowns associated with the corona virus. The figure displays the same axis as Figure 3 but with data recorded in April 2020. It shows that almost all of the characteristics have changed. Not only has the total amount of packets per second dropped significantly, but also the day and night periods differ only very slightly and due to the low number of aircraft the graph is very unstable. As shown in Table 1 the decrease of communication on the 1090 MHz channel is very obvious. While the minimum of packets per second has not changed significantly due to low numbers of flights in the night during the observation period in February, the maximum in April reaches only around 32% compared to February. The mean over the entire inspection period drops to around 23% compared to *pre-corona times*. The distribution of the telegrams has also changed completely as there is only a very small difference between daytime and nightly traffic which can be seen in the low standard deviation (std. dev.).

One can see the strong relationship between the actual number of flights and the telegrams that were received on that channel. The recording of our data is

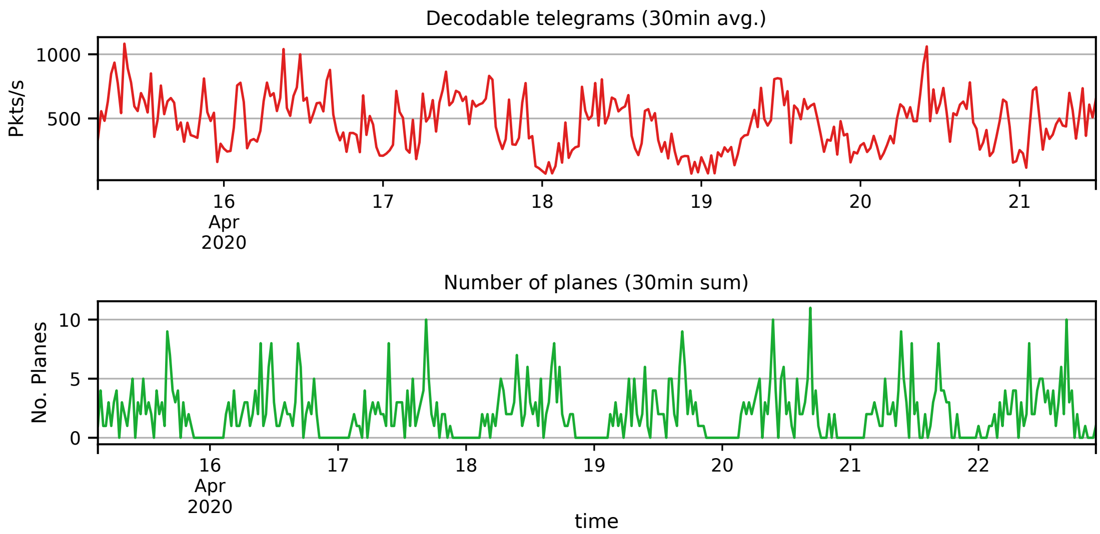

Fig. 4. The number of telegrams and planes over several days in April

supported by the observations from the OPENSKY NETWORK, a research project that enables full exploration on MODE-S and ADS-B data [13].

The data from the network is gained from a distributed set of sensors that listen on the 1090 MHz channel and feed decodable telegrams to a central server. Due to ADS-B the network is able to monitor a certain amount of flights and track their movement in the airspace. Currently, more than 60% of all flights over Europe are equipped with ADS-B [14]. It will become mandatory for all aircraft with a maximum takeoff mass (MTOM) greater than 5700 kg or a maximum airspeed capability greater than 250 knots by end of October 2025 [6]. Overall, this already gives a valued estimate from a different source to prove the measurements from the described setup. The figures show a strong correlation of aircraft identified by the OPENSKY NETWORK from or to Frankfurt international airport (EDDF) to the number of telegrams detected by the measurement setup. While the number of telegrams increases by a factor of 90 between day and night, there are approximately 80 times more flights during the day and none during the night. Eventually, this may be caused by other aircraft not heading to nor departing from EDDF. However, this correlation needs to be investigated, as it could also imply a saturation on the channel not allowing to decode all telegrams during the day peak anymore.

Table 1. Comparison of the datasets

	February	April	Relative
min	54 Pkt/s	62 Pkt/s	114%
max	4863 Pkt/s	1575 Pkt/s	32%
mean	2223 Pkt/s	525 Pkt/s	23%
std. dev.	1262 Pkt/s	258 Pkt/s	20%

The corona lockdown gives the opportunity to gain new insights into the surveillance radar channels as only the number of planes has changed in this crisis whereas other parameters like the number of radar stations and interrogation pattern kept unchanged. The *corona dataset* from April allows a comparison of the impact of the number of aircraft in an otherwise unchanged environment.

The contribution of the planes to the decodable traffic on the channel can be calculated by the number of received telegrams divided by the number of planes which gives the rate *packets per aircraft*.

In February the maximum amount of packets per second (f_{pkt}) as an average during one hour was $f_{pkt} = 4863/s$. In this hour 84 planes were heading to or departing from Frankfurt ($f_{FRA} = 84/h$), while in April the maximum average of packets per second was $f_{pkt} = 1575/s$ with $f_{FRA} = 16/h$. So, in February the system was able to detect $\approx 2.08 \cdot 10^5 Pkt/Plane$ while in April a maximum of $\approx 3.54 \cdot 10^5 Pkts/Plane$ where received.

In the high traffic environment the contribution to the number of decodable telegrams per plane is much lower than in the low traffic environment. However, this stands in strong contradiction to the fact that all planes are interrogated in the same manner. Additionally, the TCAS system that queries surrounding planes for their positions should add an increasing amount of telegrams per planes the denser the airspace is being used.

The number of packets per second is not growing linearly with an increasing number of aircraft on the surveillance radar channels.

3.3 Channel Load

In order to calculate the impact of traffic on the 1090 MHz channel it is necessary to inspect the decoding probability during changing channel loads. However, the system is only able to see the channel throughput (Tp_{Ch}) on the receiver side and does not know the *real* amount of telegrams that were transmitted on the channel.

The channel throughput equates to

$$Tp_{Ch} = \frac{1}{t_{\Delta}} \cdot (N_{AC} \cdot T_{AC} + N_{SS} \cdot T_{SS} + N_{SL} \cdot T_{SL}) \tag{1}$$

This rate is calculated by the number of decodeable telegrams N_x of each type of telegram $x \in \{Mode\,A/C, Mode\,S\,Short, Mode\,S\,Long\}$ times the duration these telegrams occupy the channel T_x (see also section 1.1) divided by the time of observation t_{Δ}. A value of $Tp_{Ch} = 1$ would refer to a 100% channel usage where the channel is permanently occupied.

Figure 5 shows the channel throughput for changing numbers of aircraft that were in sight during the 6$^{\text{th}}$ of February and the 16$^{\text{th}}$ of April. Each point represents a 15 minute time interval throughout the day. With growing traffic, the channel usage is increasing very fast and varies between 0.10 and 0.35 for the majority of the time. During that time 50 to 90 aircraft where sight for the February data set. In this region it seems like there is already some saturation on

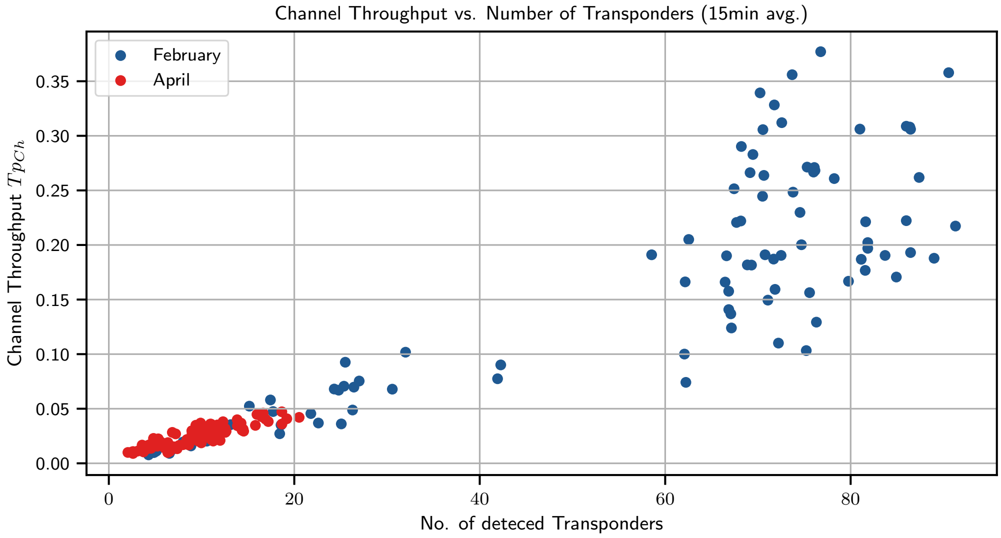

Fig. 5. The channel throughput on two days in February and April

the channel as the Tp_{Ch} increases faster than the number of planes. This topic needs further inspection in the future. However, this implies that the channel is already near or beyond its maximum throughput. The decodable channel throughput of around 0.30 is already more than the maximum that could for example be achieved with the ALOHA access protocol where the maximum is reached around 0.18 [9]. In contrast, the channel access on the 1090 MHz channel is a mixture of a pseudo-random access by individual aircraft (e.g. ADS-B and TCAS) plus a mixture of scheduled access like Mode-S and Mode A/C replies to multiple surrounding radar stations that can be scheduled and adapted in a coordinated manner by the air navigation service provider.

Each of these applications have measures to reduce the channel load: For example Mode-S radar stations can coordinate the interrogations and interchange data for individual aircraft in order to reduce interrogations of the aircraft. Additionally, there are measures to reduce the impact of the spontaneous transmitted packets. For example, TCAS is reducing the transmission power for the interrogations, if a high number of surrounding planes is detected thus reducing the range of interrogations and the number of replies. The higher decodable throughput rate shows that these measures have a valuable effect on the channel performance and lead to a channel load that is higher than a random access channel would be.

Figure 6 shows the number of telegrams per identified transponder for the February and April data set. This is calculated by the number of identified aircraft transponder IDs divided by the number of telegrams per second. This is done because it is not always possible to identify the sending aircraft only by listening to its replies. Therefore, only individual aircraft IDs have been used to calculate the amount of aircraft even though it might not have been possible to determine their position or altitude during the reception. Figure 6 clearly states

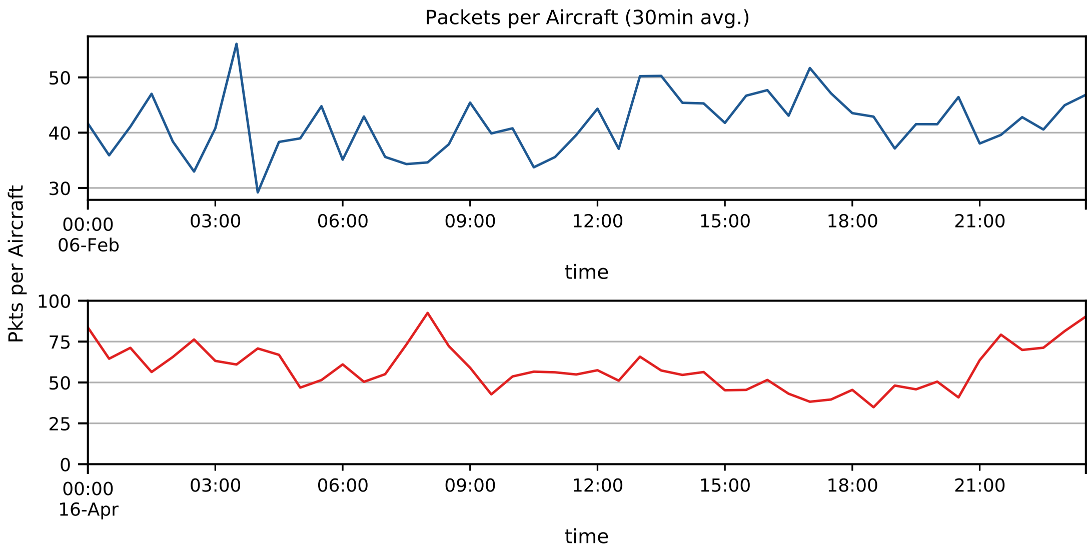

Fig. 6. The number of telegrams per plane.

that in average there were less telegrams per plane received in February with a high amount of flights.

There are several possible reasons why this is the case. As of yet, the recorded data is not sufficient to answer this completely but together with the lost test telegrams it stands to reason that more and more telegrams are not decodeable as the channel is already close to its maximum throughput capability. To determine the reason for this behaviour further research is necessary. However, it can be observed that the number of decodable messages doesn't increase linearly with the number of planes. This implies that the channel is crowded and telegrams will be lost due to collisions. The more crowded the airspace the lower the rate of detected telegrams per aircraft. The details of these relations are scope of our future research where we will investigate the rate between successfully and falsely decoded telegrams with respect to the channel load.

3.4 Training samples

Training samples in the form of test telegrams play a key role in these measurements. We assume that the distortions, interference and other disruptions have the same effect on *natural* telegrams as they have on the test telegrams. So test telegrams are used in order to gain and improve the knowledge of the characteristics on that channel. The test telegrams are continuously injected into the channel with changing power levels (see section 2).

It is therefore possible to see the impact of changing radio environments on the test telegrams with changing levels. Figure 7 shows the median of the success rate for a single day in the February dataset. The figure clearly shows the strong inverse proportionality. The higher the number of telegrams per second the lower the chance for the test telegrams to survive. For this chart, only telegrams with

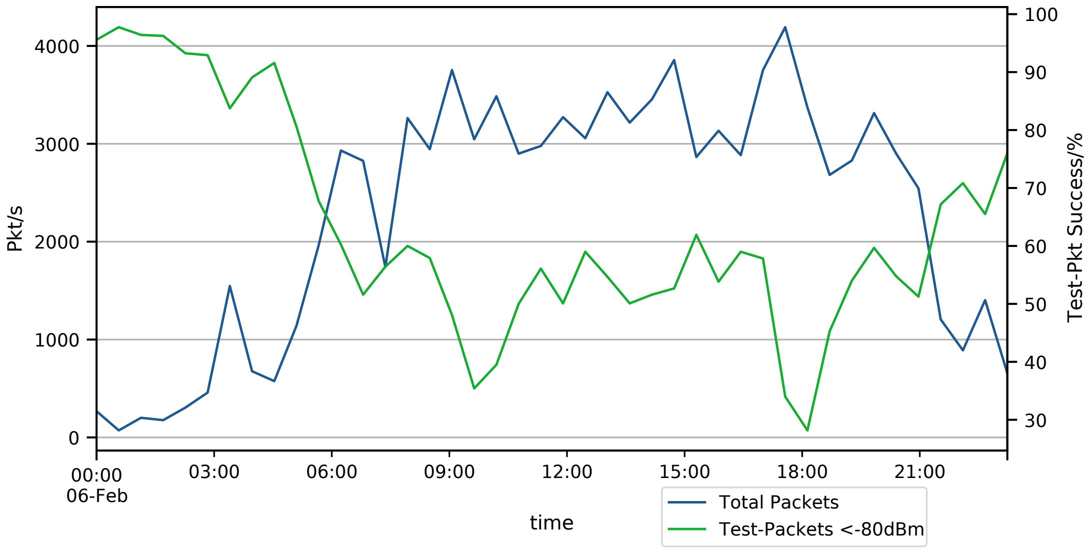

Fig. 7. Success rate and packet load on 6$^{\text{th}}$ of February

levels around -80 dBm have been taken into account which is the approximate average of all received telegrams.

Figure 8 shows a similar result for the April dataset but the overall success rate is much higher than in February. The success rates throughout the day are around the values that were achieved during the night in February.

Figure 9 is showing the success rate for the 6$^{\text{th}}$ of February and indicates that the level of the test telegrams plays a crucial role in the success rate. The graph shows three lines throughout the day. The light-green line shows the average success rate for telegrams with high levels. It shows that the high levelled test telegrams hardly suffer from the increasing communication on the channel (refer to Figure 7) but even these high levelled telegrams suffer from that communication and drop from 100% to around 90% during the day. For lower levelled telegrams ($s_l < -80\,\text{dBm}$) the success rate is not only in general worse, but the impact of the radio environment is significantly stronger than for the high levelled telegrams.

4 Conclusion and Future improvements

As the described setup looks promising, a team of students from Hochschule Darmstadt (h_da) is currently working on an even more reduced measurement system. It uses a Realtek SDR RTL2832U based system that was designed for Digital Video Broadcasting–Terrestrial (DVB-T) reception. It is able to decode the 1090 MHz packets and transport them to a PC via USB Interface. A wide range of Open-Source software is already available for that. The test data generator is realised with an Adalm Pluto® SDR by Analog Devices. This SDR evaluation board is able to send on the 1090 MHz channel and synthesise the

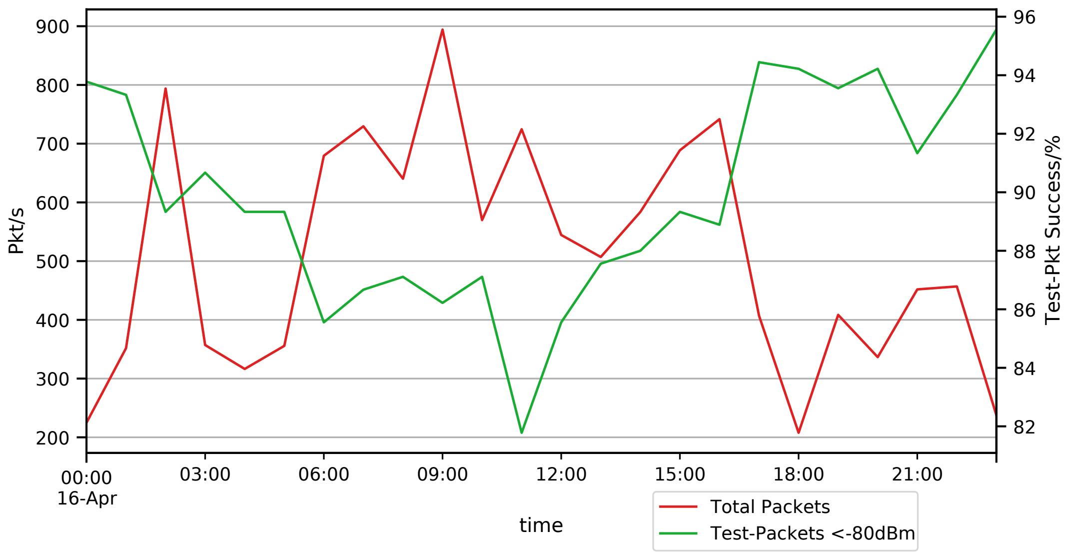

Fig. 8. Success rate and packet load on 16^{th} of April

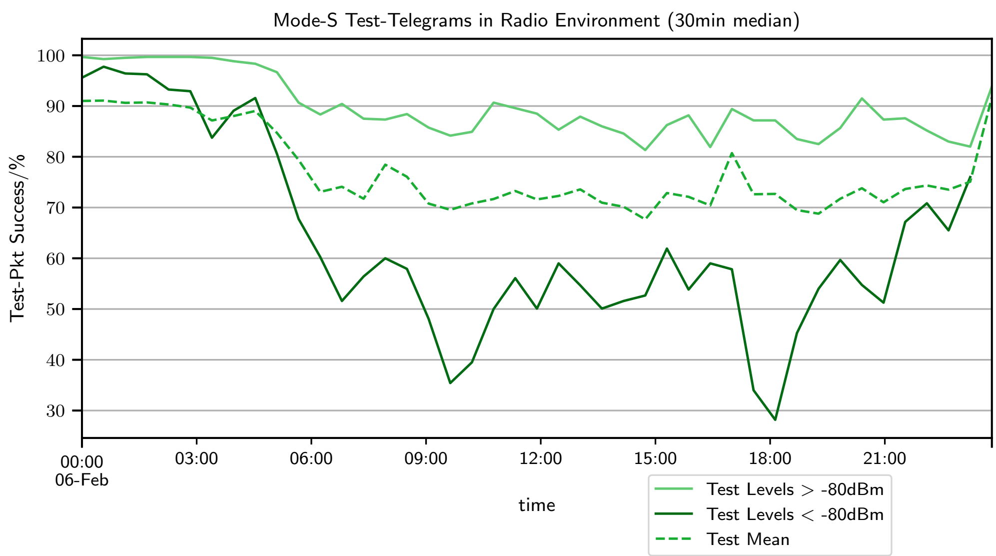

Fig. 9. Success rate for different levels on 6^{th} of February

needed test telegrams. These devices are very affordable and can be used out of the box to generate the test data on the 1090 MHz channel. Together with a standard PC this setup should be sufficient to measure on the channels. As the losses of the receiver shall be estimated by machine learning, the impact of decoding capabilities are expected to be relatively low as long as a reasonable rate of the traffic can be received. The quantification of the losses and in a second step the extrapolation to the *real* amount of data should be possible with this equipment just with the professional Air Traffic Control receiver.

The comparison between the two approaches will be further investigated. If it turns out that the RTL2832U and the ADALM PLUTO® can be used to create a semi-supervised data generator for a machine learning based correction, the system can be set up at multiple locations over Germany in order to create a wide range of data with changing characteristics. This might also lead to the conclusion, whether there is a need for detailed monitoring with a high spatial resolution or if there are little advantages for such a distributed measurement network.

This data could then be joined with the data from the OPENSKY-NETWORK and used to create a large scale radio field monitor. Overall, the entire communication structure on the channel has changed since the corona lock-down stopped the majority of flights over Europe. This involuntarily allows a view on the surveillance radar channels and the communication that could not be expected before.

The described measurement setup delivers results that strongly relate to the results of the OPENSKY NETWORK and the reported decline of flights by the European authorities [5] but also allows new insights on the number of telegrams per aircraft and the saturation on the channels. These new insights do also raise new questions that need to be investigated in future works.

The low number of aircraft have a significantly higher probability to successfully transmit their results. As the number of telegrams dropped the channel is less occupied. This shows that the effects of interference and disruptions decline as the number of aircraft in the surrounding airspace is reduced.

The measurement system is able to show the effects on the surveillance radar channel in total and can give new and deeper insights into the communication on this channel. It has been shown that the number of aircraft does not linearly correspond to the traffic on the surveillance radar channels, thus a measurement and observation system is necessary to assess the channels' states and the remaining capacity. This is one crucial part to maintain a secure surveillance in civil aviation that will hopefully recover to its old strength very soon.

Acknowledgement

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