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Research into equivalent Bidirectional Telemetry

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Abstract:

The purpose of this paper is to illustrate the efforts made by the Flight Test Centre in Spain towards achieving robust, efficient, and high-quality bidirectional telemetry: from exploring potential uses to integrating it into ground stations and aircraft, including testing and searching for technologies.

The approach involves two main strategies. Firstly, internally redefining the telemetry paradigm to identify new applications benefiting from the technology's advantages. Secondly, exploring the market for suppliers to meet the specific needs of the Flight Test Center.

The goal is to develop bidirectional telemetry with equal capabilities in range, bandwidth, and latency, while also leveraging new features such as mesh networking or beyond line-of-sight (BLOS) capabilities. This requires implementing a new system, integrating high-gain antennas with dipoles, and utilizing various transmitter/receiver technologies like beamforming and MIMO.

Testing and integration of this system are already underway at the Flight Test Centre in Spain, with different configurations and providers being evaluated to gain confidence and measure capabilities.

The paper aims to showcase initial steps taken in this new technology, presenting theoretical and practical results achieved so far and their impact on telemetry practices. It also discusses challenges encountered and expected in the future, with the outcomes determining potential changes in test procedures.

Key words: Telemetry, Bidirectional, RF Design, Receivers, Antennas

1. Introduction

Aeronautical telemetry is one of the mainstays of flight testing, and has been for a long time. Since the 1950s, telemetry has been used to monitor from the ground what is happening in the aircraft. This saves a lot of costs. It is also a safety feature: it reduces the pilot's workload and helps to monitor a multitude of parameters that would otherwise be difficult to monitor (many eyes see more than two).

The future promises to be different. Technology has evolved a lot in recent years, but telemetry has hardly evolved at all, especially from the transmission point of view. In this technological project we address one of the many solutions we can find for the telemetry of the future. We will show the needs we see in the future and justify them. In addition, we will tell the evolution of the technology project we are leading at Airbus DS to address those needs, we will talk about the technologies and need and the tests we are doing.

This is a project with a long history in which we are just beginning to take the first steps. In this paper we will explain the basis of the project, how it came about and the first steps we are taking: needs and technologies that cover it, first tests and results, changes in mentality when it comes to understanding what the system will be like in the future. We will also talk about the next steps, what we want to do and how we want to do them and, of course, what we expect from them.

2. Context and Justification

Recently, the demand for telemetry resources has increased. More and more parameters are requested at higher rates, more and better-quality videos and even more prototypes simultaneously.

The evolution of telemetry transforms the way testing is performed and analysed. This evolution is a competitive advantage that can simplify operations, reduce costs and make testing safer and more efficient. But it also means big and profound changes. Changes in the way aircraft instrumentation is done and changes in how to approach the aircraft/ground radio link.

The Flight Test group has been identifying different needs for improving telemetry for a long time. Although until now these needs may not have been sufficiently important to tackle a technological project like the current one, they have always been present. But the future is coming. And new programmes and new needs appear. It is no longer something desirable, it is a 'necessity'. The platforms of the future will need telemetry with capabilities that are not only far superior to those of today in terms of bandwidth or quality, but also very different. New technologies will have to be integrated with our ecosystem. This is a paradigm shift in the way we approach telemetry.

But let's take a step back. This coming future is starting to be built today. We have to be ready for it and we cannot start tomorrow. That's why we proposed this technology project to develop now the technology we will need tomorrow.

To support this technology, the Flight Test group consulted with a wide range of teams that use or will use telemetry. For them, we developed 'Voice of the Customer' sessions, in which we gathered all kinds of requirements. It was a very interesting exercise in which we unleashed the imagination of the users and found new ways to use telemetry.

Once we are clear about the potential needs, i.e., how this technology could be used, we need to see how to implement it. To do this, in parallel with the VoC exercise, we started to analyse the technical changes needed both in the aircraft and on the ground for this technology to be able to cover these needs. We studied the market and the different technical solutions and started with the different testing stages to validate the solution.

This paper aims to show the first steps we are taking in this technological project, as well as the conclusions obtained so far. We will also present the next steps we plan to take.

3. Voice of Customers

Voice of Customer is the example that technology cannot be ahead of users. Because it is not interesting to develop a new technology or way of working if it is not something that will later be used.

Once we had identified the future need and while we were looking at possible solutions, it was necessary to study with the end users the future uses that the different solutions could have. One must consider that what may be an excellent idea for one system or user may not be necessary for another, and vice versa. The paradigm shift introduced by the use of bidirectional telemetry necessitates a change in the current mode of operation. Consequently, it is imperative that the principal users of telemetry—whether direct, potential, or future—engage in this process to ensure that the forthcoming technological solution is widely adopted.

We therefore consulted all the departments involved. Their responses, which varied widely, often included innovative ideas that enhanced the project and confirmed its necessity.

Some of the most notable suggestions included:

- Regarding instrumentation: being able to replay tests during execution, adjust data rates depending on the point to be tested or cease transmission of certain data to allocate BW for mor critical data at that point and thus be more efficient.
- The possibility of stimulating aircraft systems from ground (flutter, dynamic change of control laws)
- Reducing the workload of the pilot or FTE/FTC by direct intervention of non-critical systems This point is particularly important as it directly impacts flight safety.
- Implementing feedback systems to monitor changes in the aircraft made via other links (e.g. Link16, satcom)
- Integration of tests with simulators, rigs, etc.

In conclusion, the new solutions would enable new types of tests that have not been considered so far, which would be more time-efficient, cost-effective and safer.

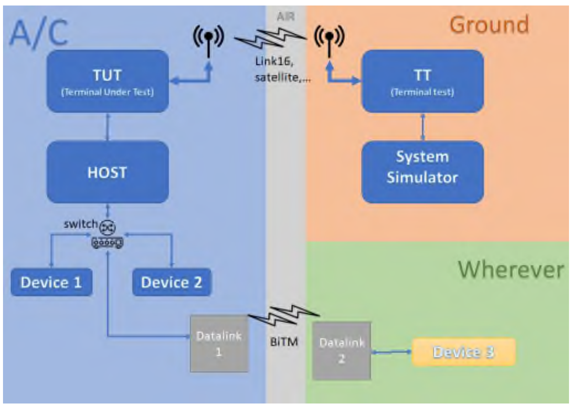


Figure 1. VoC example

4. Description of the project

For the last 50 years telemetry has been mainly an aircraft transmitting and a ground station listening; and its way of transmitting the information has not varied too much, it has always been based on a coded digital signal passing through a pre-equalization filter to become an adapted signal that a modulator (FM, SOQPSK or similar) modulated to transmit, resulting, at the end, in an efficiency of 0.5 Bit/s/Hz [1]. Although there have also been uplink systems, these have always been asymmetric, with very narrow bandwidths and usually using a different channel for uplink (V/UHF radio, satellite, etc.).

With this project at Airbus DS we are looking for a new way to do telemetry, that has new capabilities (uplink/downlink), that is efficient in terms of spectrum and that allows to achieve a new way to do flight tests. This new telemetry will have to be:

- Bidirectional, the new technology must facilitate ground-to-aircraft and aircraft-to-ground connections and to prioritize between ‘must carry’ and ‘sacrificable’ traffic.
- To use MIMO technology that allows different data streams to be managed by different antenna arrays.
- Equalization, signal adapting to changes in the channel
- Diversity, capability to send and receive from different paths
- Beamforming, enabling the signal to better adapt to different aircraft situations and contexts.
- Mesh capability, enabling a telemetry network in its broadest sense, a telemetry network in the air connected to the ground.
- Connection, the technology must be IP-based and capable of managing TCP and UDP connections, with special attention to multicast traffic

But we also have to keep in mind that we do not want to lose capabilities, therefore our project must look for a telemetry that can maintain certain imposed conditions.

- Everything must operate in C-band (5091 - 5250MHz).
- We have to keep reaching long distances or as long as possible. In our case, the limit is at LoS. If this is not achievable, perhaps the solution is to rethink how to cover an area.
- The latency between data recording and data display should be similar to today, or at least should not increase significantly.

Within the broad scope of these limitations, and considering additional constraints (time, resources, budget), we have defined and limited our project to the following:

- The objective is to establish a radio link at a distance of >150 km with LoS and a 2x2 MIMO system.
- The aircraft antenna is limited to two dipoles and also due to aircraft issues the maximum power to be transmitted should be around 20W per antenna.
- The modulation scheme could be variable or fixed, in order to be able to test the behavior of the technology.
- With these premises, we calculated the link budget [2] and the ground antenna has to be a high gain parabolic antenna (>30dB) and 360º continuous rotation.
- The latency of the system should be as low as possible, but always less than 250ms. If this is not the case, needs to be re-evaluated.

In the market we have found different datalinks and antennas that could potentially meet the needs. It has not been easy because although many of them meet the requirements described above, with some of them we have encountered the problem that not all of them work exactly in terms of power and frequency we were looking for, as well as other configuration parameters that did not fit our needs.

In the end, we found a combination of equipment and antennas that met all the needs we required to be able to realize the project. It does not have to be the final technology to be implemented in the future, but it will be the technology we start testing with.

5. Stages of the project

From a testing point of view, we are approaching the project as different testing stages. Initially, as we have already explained, we have done basic research, technological research as well as applied research with proofs of concept. This would correspond to initial TLR1-TLR3 [3] stages of technological maturity. The following stages can be classified as follows:

- Laboratory testing: integration into the ground network and technology awareness. This would conform to a TLR4 level of maturity.
- Proximity testing: distances less than 1km with dipole antennas This would meet TLR4 level of maturity.

- Remote testing. This would conform to a TLR5 level of maturity.
- Testing on the move. This would conform to a TLR6 level of maturity.

At the end of each test we had a decision gate that gives us guidance on the maturity status of the project. Each of these stages and the conclusions are explained in more detail below.

The lab tests were mainly focused on the integration of the new technology into the ground station network. The way of working in a network implies a radical change in the current network configuration and several tests were necessary until the system was mature and perfectly integrated in the station. These tests served to familiarize with the environment and get to know the technology before moving on to the next step. There were traffic configuration problems that implied structural changes in the network configuration. At this stage it was concluded that the system was successfully integrated with the ground station network and that the system was fully integrable and fully operational.

The next step was to go outdoors and we started testing in a close environment (1km). Even without focusing in terms of power, we started to perform static tests in multipath environments, with very good results. In NLoS areas the system capabilities were powerful and beamforming substantially improved the results. Stress tests of the system were performed but still without parabolic antenna, using 1 or 2 streams and going deeper into the different options offered by the system interface. The conclusion of this stage of the project was satisfactory and promising and it was decided to continue with the next stage.

The next stage consisted of remote tests with two main objectives: to validate the link budget and to evaluate the performance of the system, all at a greater distance: between 3 and 65 km. Transmitting in a system that tried to simulate as well as possible an aerial environment, that is, with conditions of few reflections, clear environment at a considerable distance, using amplifiers and antennas, we intended to perform tests to verify the mathematical model of link budget that we were handling. The tests consisted of estimating how realistic the theoretical link budget is. To do this we have to play with the 'safety margin' estimates. This parameter is the safety margin needed to make a theoretical link budget and compare it with a real one. In our case, we estimate losses of maximum 10dB and minimum 5dB. Taking into account that we are transmitting from the ground, we estimate that the results obtained here would be in any case, the worst case of when we would go out to fly. Presented below are several figures illustrating different scenarios:

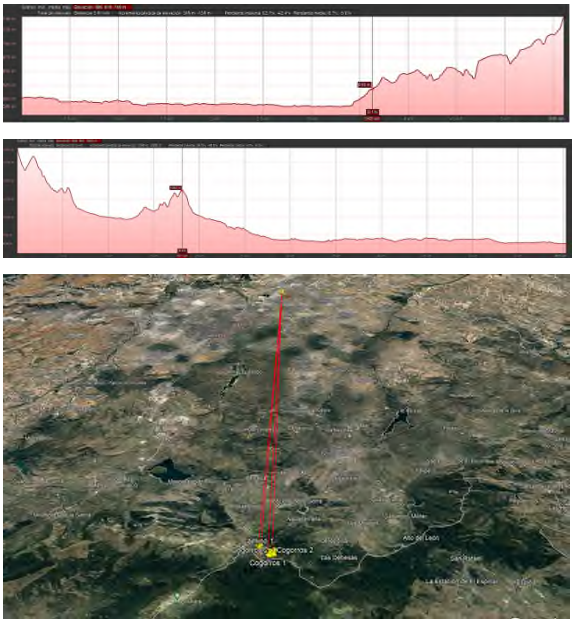


Figure 2. Long range scenarios

These measurements have always been done statically. In the configuration, different bandwidths, data rates and distances have been tested and as a test, UDP multicast and TCP connections have been made to fill the channel as theoretically fixed. Included in these connections there are audio, video, remote desktop connections and latency tests.

Although we have a large number of samples done, this figure serves as a representative result:

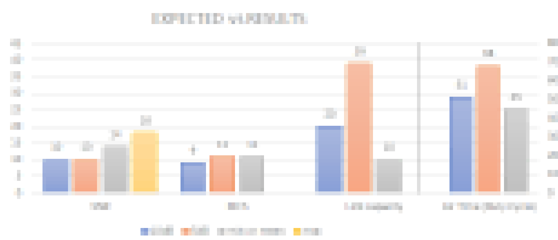


Figure 3. Expected vs result

It can be seen that the measured SNR is better than the estimated SNR in both cases, the modulation scheme is slightly better and the channel utilization time (Air Time) is slightly lower than expected.

Regarding latency, we were able to evaluate that, in general and as long as the channel is not saturated, which logically implies packet loss or excessive delay, the delay was low and acceptable, according to expectations.

Therefore, the conclusion of this stage of the project was satisfactory and we considered the theoretical system to be valid, considering the real results to be slightly better than the theoretical ones.

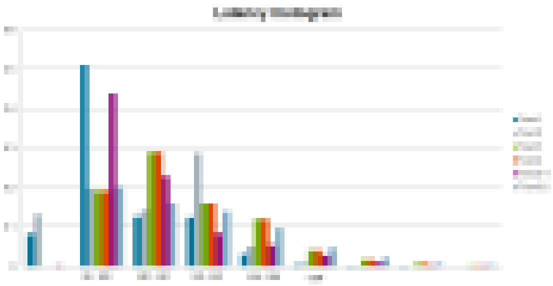


Figure 4. Latency

The next stage of testing is currently under development. In this stage, the system will be evaluated in a more realistic environment, a dynamic mobile environment and in flight. Concepts such as direct link stability or real link balance will be fine-tuned. We will study how it affects the shape of the aircraft, the shadows it can make and the ground-to-air pointing. We will also see in a realistic way how the traffic behaves. In a real flight we expect outages or micro-outages, unexpected link losses, misalignment and a multitude of untested scenarios. In this environment we expect to test what happens to TCP or UDP connections in these cases, how nodes behave and how connections are recovered. We also of course expect to measure latencies and see how the link budget model performs in a real air/ground environment. All this will be key to verify if the stability requirements we are looking for are met or not.

6. Future

In the immediate future we have to mature the current state of the project, we must ensure this state of maturity and finally test the current technology in a completely real environment. But the project goes further and as said at the beginning we seek to achieve an equivalent bidirectional telemetry. To this end, once the necessary maturity level has been reached in a real environment with two nodes, the project intends to continue advancing in different phases.

Next steps:

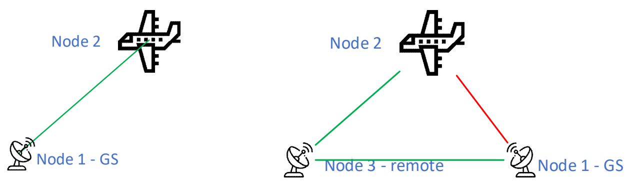
- Deepen the aircraft configuration
- Test the system with a remote centre
- Test the system with 2 aircraft (nodes) on local
- Test the system with 2 aircraft in a remote hub (or 2)
- Test new technology

From a 2-node point of view, we have to integrate the system on a large aircraft and see how the technology performs. Integrating the system on the aircraft will not be as trivial as it was not on the ground network. Recall that we left behind the concept of 2 separate networks where telemetry worked with a 'data extractor' from the aircraft and a 'data injector' on the ground. Of course, with the lessons learned from ground integration, on aircraft it should be less complicated, but the aircraft architecture is very rigid and other problems will arise.

From a testing point of view there is still a lot to do. So far, we have tested a 2-node network [Figure 5, image a)]. which is a first step to get to know and learn how to handle the technology, but it is not representative of what we want to do. To 'replace' our telemetry with the concept of an aircraft flying over a large area where different antennas are following it on its path, we have to confirm that this overlapping area is done correctly and that the overlapping areas are equivalent and compatible in range with the current ones. If this is not the case, it may be necessary to consider a larger number of antennas to cover the same area.

On the other hand, a next step following on from the above, would be to do this same concept but with several nodes, flying first locally (2 ground nodes, one aircraft node [Figure 5, image b)]) and then remotely or remotely/locally (2 aircraft nodes, one ground node; and 2 aircraft nodes and 2 ground node [Figure 5, image c) and d)]). This would increase the complexity of the network to at least 4 nodes and would allow testing the system at what for us would be a high level in complexity, understanding that adding more nodes would already be smaller hops.

Each step of these tests is a leap in complexity and will involve a multitude of tests and keeping an eye on different parameters. From seeing how the different types of connections behave, measuring latencies, bandwidths achieved, etc.



a) *b)*

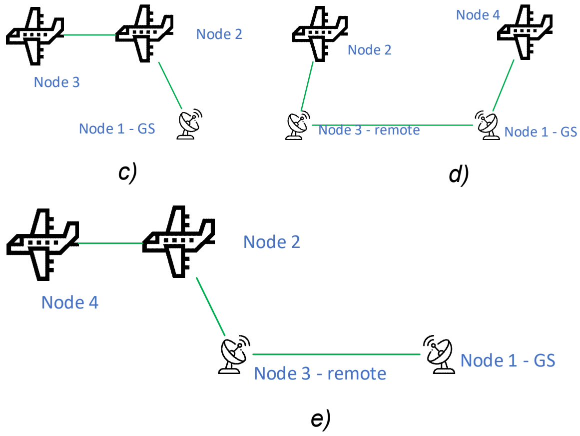


Figure 5. Different kind of scenarios: a) two nodes, currently in use; b) one aircraft with two ground nodes; c) two aircraft one node; d) and e) two aircraft with two ground nodes

But the project does not end here. The market has different datalink providers. We are currently betting on one of them and the results are promising, but technology is advancing very fast. Once the system has matured, changing supplier is neither so expensive nor so complex. Using the test system presented in this paper, testing a second radio system provided by another supplier would be as 'simple' as swapping one for another and repeating the tests. The most complex part is setting up this test bed for the first time. Once built, it could be used as a test bed for testing any similar technology with little change.

7. Conclusions

In this paper we have extensively presented the technological project that aims to study the capabilities of a future new telemetry with radically different capabilities to the current ones. We have identified the needs that are demanded by future programmes, we have presented the solution found and we have identified the uses that could be made of this technology from the different systems. Then we have explained the project and its different stages of maturity so far. Finally, we looked at the steps we still have to take.

Of course, this promising technology has its drawbacks. It implies such a radical change in the way telemetry is done that current systems will not work. New installations would have to be made, or old ones would have to be modified and thus made incompatible with the old system. This will, of course, involve initial investments. This is a hot point when it comes to implementing the technology in the future.

In addition, until now, telemetry under the umbrella of the standard allowed for vendor-independence, with different telemetry datalink providers being compatible with each other. Currently, the providers of this type of datalink have proprietary solutions that are not compatible with other providers, which means that they are dependent only on this new provider. This would be a problem for the more distant future: the adoption of this technology requires a long-term projection of the supplier to keep the system compatible with new versions.

In summary, like any new technology, it has its advantages and disadvantages. So far, the different maturity tests have been passed one by one and we will work to keep it that way until it is fully implemented. It is a very promising technology and will be a paradigm shift in the way we do telemetry, in the way we work with it. It will bring new capabilities to testing, which can be done better and safer, saving a lot of costs both in testing and in direct costs, as this technology promises to be significantly cheaper than its predecessor.

Much remains to be done. We will be ready for them.

References

List and number all bibliographical references at the end of the paper. When referenced within the text, enclose the citation number in square brackets, i.e. [1]

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