Executive Summary

Telefonica sought to enhance the traditional process of antenna sourcing with specific objectives to (i) gain a high level of overall network performance and (ii) reduce the number of antennas entering service with inadequate performance and poor quality that later lead to premature replacement with consequent site works and logistical burdens.

Telefonica has no doubt that antenna vendors establish robust processes to ensure the integrity of manufactured products. Indeed, these processes have been witnessed by Telefonica staff from time to time. However, there is also no doubting that antennas with substandard performance, quality and reliability are entering mobile networks, with resulting inefficiencies, cost and associated burdens to network operators.

One industry-wide response has been to encumber vendors with additional contractual obligations to be applied in the event of product failure. These liabilities might include extended warranty terms, obligations to replace defective antennas which may include mobilisation costs associated with site recovery and replacement work, and even consequential loss provisions. While these measures appear to be adequate safeguards for an operator, the reality is that establishing cause (failure mode), stakeholder responsibility and enforcing penalties are all difficult to achieve. There is an argument that these additional liabilities result in flow-down costs to the operator. Even so, supplementary if not alternative remedies are being sought by Telefonica to achieve more efficient mechanisms.

This White Paper sets out a collaborative process involving antenna vendors and Telefonica, which delivered mutually beneficial outcomes. Undertaken in the 2015/2016 period, a mutual understanding of possible antenna deficiencies under normal and stressed conditions, together with associated rectifications was achieved. Importantly, a regime of controlled testing was undertaken to provide indicators of likely performance beyond what can be expected from typical field trial testing. During this process, several antenna vendors were invited to demonstrate technical performance under benchmark conditions through the use of an independent commercial test house in accordance with a defined set of rules.

As a result of this activity, there is ample evidence to satisfy the objective that antennas offering better value, quality and reliability were sourced for deployment in Telefonica networks. It is firmly believed that this will lead to reduced life-cycle cost through fewer antenna failures and associated field rectification work. A further consequence of this process was a simplified vendor selection process based more holistically on demonstrated data.

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1. Overview of Antenna Challenge

The antenna solution installed at any form of cellular base station is a significant factor in the overall RF performance of the system. Telefonica GCTO-RAN technical team were faced with two opposing positions from the antenna vendor supply base:

1. Select "**my solution**" as it is the best technical solution offering significantly better performance and quality justifying any additional expenditure.

2. Select "**my solution**" as it is significantly better value but provides performance and quality equivalent to more expensive alternatives.

Clearly both positions presented above could not be correct and a process was established to collaborate with the supply base so that mutually, a clearer position on this topic could be gained.

Additionally, a series of generic issues had been identified with antenna products, namely:

I. Network performance not always achieving design standards.

II. Quality issues were perceived with several delivered antenna models/types.

III. Costs associated with fault finding and resolving antenna problems post-deployment were high and growing,

IV. Determining antenna deficiencies as the root cause of network performance issues in the post-deployment period has always been difficult, as has attributing logistical and financial responsibility within the stakeholder group comprising Telefonica, antenna vendor and contractor.

V. Providing a qualitative assessment of competitive antenna solutions to review relative performance with a view to improving procurement decisions.

The BASTA[1] standardisation process has proven difficult to produce effective data capable of benchmarking antennas and whilst it does allow operators to perform better analysis, it has some significant challenges.

Telefonica invited several antenna vendors to collaborate in an independent benchmark testing process based on each vendor covering test fees for their own products. This was achieved through the engagement of an independent commercial test house. A common Test Plan defined measurement parameters and methods of performing particular measurements in a contolled and repeatable environment.

A series of principles were drafted to promote the process and offer vendors a guarantee of independence ensuring that their specific test results would be anonymous but allowing them to gauge their own relative performance against rivals in a truly impartial test environment.

[1] BASTA -NGMN sponsored Minimum Base Station Antena Standards and specifications developed in cooperation of manufacturers and other industry players.

This activity resulted in both Telefonica and each vendor receiving qualitative data. For Telefonica this enabled enhanced sourcing decisions, to satisfy the principle objectives of better performing networks and reduced life-cycle costs associated with antenna longevity.

Appendix 1 'Antenna Benchmarking Process' outlines the steps undertaken in this activity.

2. Test Facility Considerations

Telefonica selected two of the most complex and flexible antennas available in the market at the time, which were wideband solutions with 12 and 8 port options (low band 698-960MHz and high band 1710-2690MHz) as the samples for benchmarking tests. All arrays whether low band or high band were required to cover the entire band.

Two phases were adopted in the benchmarking activity. Phase 1 included visual and mechanical inspections together with RF measurements undertaken in a laboratory environment to determine performance under normal and stressed conditions. This phase enabled a view of build quality and fundamental design principles. Phase 2 determined actual pattern performance with the same antenna migrating from the test lab to a proven far-field antenna range.

The process established by the selected test house utilised two rounds of range testing with lab testing before and after each.

2.1. Telefonica To Conduct Testing

Arguably the optimal solution for the field phase would be an actual cell site however this has obvious logistical and technical challenges as antennas would need to transit potentially long distances (internationally) between the lab and the selected site. Additionally, there were several other factors to consider as outlined below.

Telefonica also evaluated its own lab test facilities but the amount of dedicated resources needed and costs associated with the purchase or rental of complex test equipment to run these tests was not financially viable.

2.2. Operator Site Deployment

Previous evaluation attempts at benchmarking different antenna solutions on a single site (needed for like to like benchmarking) had proven cumbersome and impossible to evaluate in field conditions due to the issues identified below:-

Landlord contractual positions on antennas are complex and may involve specific conditions such as maximum size or width. Variations naturally exist between vendor solutions and whilst this was covered in the issued Test Specifications, the physical differences created issues with landlords on-site.

The prospect of aggravating a site provider with circa seven or more antenna solutions per benchmark was deemed to be an onerous and complex task.

The period of benchmarking above could have led to other factors potentially impacting the results, including but not necessarily limited to new software

deployments, frequency plans, marketing plans impacting on cell loading or new handset types entering the market and natural seasonal variations in user behaviours. The potential planned period for benchmarking meant that the environment used to test vendor 1 and vendor 7 (for example) could potentially be significantly different, to the point of threatening the comparative test process.

These limitations led Telefonica to pursue an alternative and much more structured, repeatable and consistent approach in benchmarking that allowed vendors to witness the entire test process.

2.3. Antenna Vendor To Conduct Their Own Testing

Antenna vendors for the most part use their own test facilities to validate product design, quality and performance under normal and stressed conditions rather than external test houses. Even so there is ample evidence of antennas with substandard performance, quality and/or reliability being deployed. One option available to Telefonica for benchmarking was to request each antenna vendor to test their solution to defined criteria and submit their own results. This option was rejected because of the lack of independence, enabling the possibility of golden samples and variations in the precision of the Test Plan and equipment. Clearly this approach could lead to challenges to the validity of the results and may question the integrity of the process. This being the case, any vendor might argue responses such as:

“Testing was done differently; we did it the best”

“Golden samples must have been used to obtain those results”

“The test range aspects were not calibrated as well as ours” etc. etc.

“The shipper must have mishandled”

“The contractor must have let it roll around in their vehicles”

2.4. Testing At Facility Of A Single Antenna Vendor

Whilst several antenna vendors offered their own internal facilities for use to test products from all vendors, the politics involved and disquiet in delivering state of the art antennas to a rival vendor were obvious. The likelihood of objection from any vendor threatened the integrity of the process and consequently this option was dismissed.

2.5. External Independent Commercial Test House

This was considered to be the most pragmatic, cost effective and viable solution. Telefonica was keen to ensure that the validation process was robust and cost effective for all parties. A commercial model was proposed whereby selected antenna vendors would be invited to send one antenna sample of each type for evaluation by a nominated independent commercial test house, using a common published Test Plan.

The antenna samples for evaluation would be selected at random by Telefonica from built product serial numbers present in the warehouse thus minimising the option for

golden samples or special production runs. Each antenna sample would be subjected to the same controlled and repeatable process (Test Plan) using the same test equipment. This would ensure the objective of a repeatable test process under a highly controlled and repeatable environment.

A key element in Telefonica's endorsement of this approach was that vendors would be able to attend the external test house to witness all aspects of the process, and that each vendor would approve the release of the final Test Report before Telefonica gained any awareness of the outcome. Vendors were given the authority to prevent the release of a report to Telefonica, at any time.

3. Test Regime

3.1. Test Specifications

Antenna vendors were involved in defining a list of recommended tests to be performed both in the lab and test range phases. These were analysed in conjunction with Telefonica's own specifications and a draft test specification was circulated for approval by antenna vendors prior to approaching test houses under consideration.

It should be noted that Test Specifications were reviewed and modified as necessary in consultation with the nominated test house, to better reflect the capabilities and facilities available from that organisation. Also, refinement took place as international test standards and conditions (e.g IEC and ETSI) were implemented as far as practically possible.

In this way, Test Specifications were agreed in an iterative process involving Telefonica, vendors and the test house.

3.2. Test Plan

The test house developed the established Test Specifications into a Test Plan, providing very particular details of individual test objectives, equipment set-ups and test conditions. In conjunction with the test house, Telefonica established a single agreed Test Plan for each antenna variant.

The test house communicated the Test Plan to each vendor as part of the negotiation process. Importantly, while much discussion was necessary to effectively communicate the detail of the Test Plan, no deviation from the Test Plan would be allowed, to ensure identical test conditions for like-antennas from all vendors.

Importantly, the test house encouraged in-person meetings or teleconference calls with each vendor to step through every aspect of the Test Plan.

Appendix 2 'Example: Antenna Qualification Test Plan' Summary Test Plan' outlines the Test Plan adopted for antenna variants and the flow of lab tests and range tests.

3.3. Deliverables

The basis of the approach was for the test lab to use the Test Specifications to develop the Test Plan. This then generated a series of defined benchmark tests that would lead to a set of standard reports:

3.3.1 Test Report

The selected test house drafted a comprehensive Test Report based on exceptional reporting. Non-exceptional outcomes (loosely attributed to PASS conditions) were not substantiated while exceptional outcomes (loosely attributed to FAIL conditions) were substantiated with technical data and detail. A draft Test Report specifically related to a single vendor product was communicated to each vendor by the test house. At this stage Telefonica had no sight of the draft report nor any advice on test outcomes.

Subsequently, each vendor entered discussions with the test house and a further meeting or teleconference took place to ensure the vendor had a full understanding of those test outcomes. Vendors were encouraged to provide comments relating to measurements and process.

While the test house was obligated to consider all comments, suggestions and requests from any vendor, the content of the final Test Report was at the sole discretion of the test house.

Once the vendor had reviewed the draft report, a final Test Report was issued by the test house simultaneously to Telefonica and relevant vendor.

3.3.2 Inter-Vendor Performance Report

An Inter-Vendor Performance Report format was agreed in advance of the commencement of testing with each defined test having an overall weighting criteria. This allowed the aspects that Telefonica deemed most important a higher ranking e.g. far-field range performance aspects were deemed more important to criteria x, y z. The test house delivered this to Telefonica only.

Telefonica modified this to make it anonymous and therefore fit for distribution to all vendors. This report was sent from Telefonica to each vendor allowing them to gauge their own performance and ranking compared to their rivals. As this was factual, measured and signed-off data, the results could not reasonably be challenged. Some minor challenges were observed but Telefonica made final decisions based on the available factual evidence. Feedback meetings were then set up with management and design teams from each vendor to review the results in detail.

4. Test House Selection

Antenna vendors were approached to identify credible independent commercial test houses. Radio Access Infrastructure vendors were also approached as for the most part they do not actually produce antenna's and use 3rd party labs to validate their turnkey solutions.

A list of independent test houses was therefore available and approaches made via the recommending party. Selection would be made based on the following criteria:

- Technical capability relevant to testing of BSA (Base Station Antenna) specifications, and preferably extending to the design and manufacturing characteristics of BSA
- Near and far field capabilities
- Technical certification qualifications and independence
- Ease of doing business after initial scoping phone call
- Flexibility
- Language skills
- Geography
- Cost

This proved more complex than initially expected. European based test labs proved relatively disappointing, despite Telefonica presenting and positioning this type of benchmark testing as innovative, with the potential of a new market geared towards network operators rather than antenna vendors.

Some test houses appeared uncomfortable providing the Test Reports to Telefonica as a 3rd party while the contractual relationship existed between the vendor and test house. Additionally, test houses to the most part were not prepared to provide any form of relative performance between vendors, despite all parties being obliged to execute NDA's agreeing to the process. These positions undermined the essence of the mutual collaboration necessary in this process, through the sharing of information.

Telefonica had addressed the issue of independence and confidentially of information supply in some detail so this issue was a surprise. Each vendor would have signed a 3-way NDA between themselves, the test house and Telefonica and would grant permission for their anonymous data to be presented in a specific report. Any vendor would be able to identify their own results viewed against the anonymous data of the other providers. This did prove to be a complex and difficult issue to overcome.

The International ISO/IEC Standard 17025 'General requirements for the competence of testing and calibration laboratories' is the pre-eminent standard for test houses. An element of this standard requires test house personnel to have relevant knowledge of the technology used for the manufacturing of the items, materials, products, etc. tested, or the way they are used or intended to be used, and of the defects or degradations which may occur. Clearly, this demands that an independent test house must have certain expertise in antenna design and manufacturing, together with measurement expertise in antenna patterns and PIM performance relevant to mobile networks. This ISO/IEC requirement limited the choice of available commercial organisations.

One test lab currently in use by a RAN vendor was initially selected with a view to resolving any outstanding issues. More in-depth analysis by Telefonica showed that this test house was unable to provide basic Passive Intermodulation (PIM) testing.

With PIM testing being one focus in the benchmark process, it became apparent that none of the approached test houses could demonstrate that they would be able to provide an acceptable test suite.

Telefonica therefore widened the search for antenna test houses to those outside of Europe, in an endeavour to identify an organisation that was better able to provide all the desired elements of the intended process.

4.1. Vecta As Nominated Test House

Vecta offered a pragmatic approach to the business challenges as presented above, offering flexibility, willingness to project-manage the entire activity end to end and could prove with their background in antenna development a key knowledge in PIM.

Vecta offered a far-field test range with a history of use with cellular antennas and could also demonstrate a lab based test facility capable of dealing with the full breadth of required measurements.

Vecta satisfied Telefonica of its understanding of the International ISO/IEC Standard 17025 'General requirements for the competence of testing and calibration laboratories' and could demonstrate appropriate expertise in mobile antenna design, manufacturing and measurement including antenna patterns and PIM performance.

All antenna vendors were approached and eventually alignment was made on using Vecta. Vecta took a lead on these proceedings thus minimising Telefonica's need to project-manage the activity in detail.

Prior to the commencement of testing, detailed rules of engagement were fully defined with Vecta and agreed by all parties covering:

- Specific antenna profiles to be used and number of samples required
- Serial numbers to be shipped (selected from warehouse not pre-production run)
- Dates for testing
- Agreement for vendor on-site observation and verification of own antenna testing
- Protocols for communications from the antenna vendor to the test house
- Issue escalation protocols
- Test Specifications and Test Plan
- Test Report content and format
- Deliverables to both Telefonica and antenna vendors

5. Conclusions

The outcomes from the benchmarking activity are impossible to quantify directly in economic terms. However, as a result of the testing, Telefonica has been able to better understand the full value proposition from each vendor with regard to product performance, quality and reliability in a formal qualification environment. Importantly, a regime of controlled testing was undertaken to provide indicators of likely performance beyond what can be expected from a typical field trial. This is a significant step forward when compared to acquisition cost, datasheet benchmarking and vendor performance factors typically applied in the past.

A further consequence of this process was simplified vendor selection considerations, based more holistically on demonstrated data.

The process demonstrated a range of outcomes for various antenna vendors and several design and manufacturing defects were observed which would not normally be visible without removal of the radome. The incidence of some deficiencies in the performance of antenna samples was not in itself necessarily problematic, but the response of the vendor to dealing with the situation was more telling.

The process identified one significant design defect with one antenna solution. The antenna vendor as a result of this testing and feedback completely redesigned the antenna rear housing to rectify the defect. Also, another manufacturer had a significantly better design for immunity to lightning strikes. Following this activity that vendor has gone on to specifically target and market that brand in high lightning strike areas with a clear view to increasing sales.

One vendor who did not attend the process due to administrative difficulties and communication problems has since been excluded from several commercial activities and is struggling to regain confidence within Telefonica. The post-installation cost of finding and rectifying probable issues caused by this vendor has been eliminated.

Vendors who had significant manufacturing or design defects were excluded for a period from delivering products to Telefonica to allow a process of corrective action to take place. Stronger preforming vendors are most likely to prosper within Telefonica through this process.

This process of utilising an independent commercial test house is now available and being used as a benchmark for any new vendors wishing to supply their products into Telefonica. Several new vendors have been directed to send their equivalent antenna products to the test house for evaluation as pre qualification for potentially future activities.

6. Recommendations

Based on this benchmarking activity, Telefonica would recommend mobile operators focus more deeply on the antenna portfolio as it is a critical element in terms of network performance. Importantly antennas contribute considerably to the total cost of equipment failure, fault diagnosis, recovery and replacement.

The pragmatic view is that base station sub-systems and products that achieve a proven level of performance and reliability at the time of commissioning will generally continue to offer adequate performance through the base station life-cycle, notwithstanding exceptional events.

It is therefore recommended that other operators adopt similar processes for not only antennas but possibly a range of RF infrastructure products. While this clearly would benefit network performance, vendors participating in this type of process are most likely to derive benefit and in so doing, strengthen their position in the market.

Such a process if universally adopted by a larger group of network operators may well significantly improve the supply chain for all network operators mutually.

Appendix 1

Antenna Benchmarking Process

- Operator enhances sourcing strategy to include qualification using a test house

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- Operator selects appropriately qualified commercial independent test house

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- Operator agrees with test house (i) Test Plan, (ii) Inter-vendor Performance Report template and (iii) commercial terms to be applied to vendors

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- Operator informs selected vendors of qualification process and invites collaboration

⇩

- Vendor contacts test house to understand process including detailed Test Plan, vendor specific involvement and schedules, investment and outcomes

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- Vendor contracts directly with test house under terms approved by operator and submits samples to test facility

⇩

- Qualification undertaken with optional involvement of vendor and operator

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- Test house drafts Test Report and submits to vendor for review / comment, prior to any sight by operator. May include telecon or in-person interaction with test house

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- Test house considers vendor comments and finalises Test Report. Report distributed to vendor and operator. Vecta invoices vendor

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- Operator releases anonymous customised Inter-Vendor Performance Report to each vendor

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- Operator meets with each vendor to review outcomes and corrective actions Vendor provideds feedback to operator regarding the process

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- **KEY OBJECTIVE: Operator flows data from qual process to aid price, performance, quality and reliability assessments of vendor products, and ultimately vendor selection recommendations.**

Appendix 2

Example : Antenna Qualification Test Plan