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Analyzing Handling Effects on Performance Parameters of Ethernet Cables using the Feature Selective Validation Method and Kolmogorov-Smirnov Test

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Abstract The use of Ethernet cables is a vital, if under- discussed element of the infrastructure for the internet of things (IOT). While there are many cable types on the market, one worrying trend is the wide availability of copper clad aluminum (CCA) cables, which are widely considered unsuitable for infrastructure deployment. The availability of these copper clad aluminum (CCA) cables frequently disguised as compliant Ethernet communication cables calls for a method of assessing their performance, as this is crucial to ensuring quality of service delivery. This paper presents a method of analyzing the measured return loss and impedance profile due to handling stress. In this research, four Ethernet cables of which one of them was copper CCA cable were subjected to three rounds of coiling and uncoiling tests to represent stress from handling during installation. The Feature Selective Validation (FSV) method and Kolmogorov-Smirnov (KS) tests were used to quantify the variations between the tests. The results indicate that the CCA cable has the lowest resilience to physical stress with high potential for degradation.

Keywords: *ethernet cable, feature selective validation, kolmogorov-smirnov test, impedance profile, handling effect*

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1. Introduction

Ethernet cable is one of the fundamental communication channels used in internet of things infrastructure [1,2]. With the evolution of standards for Gigabit Ethernet over twisted pair, there has been a tremendous increase in its deployment as part of IOT infrastructure [3,4].

The concept of Internet of Things (IOT) is one of the recognized directions in the evolution of the internet [5,6]. The IOT enables the combination of sensors, communication, information and energy processes to monitor and control a very large number of different objects [7]. The IOT enabled information processing and communication can support objects in fast decision making, operational efficiency and improved situation awareness leading to its application in a wide range of fields such as transportation, industry, healthcare, energy, information and communication technology and networks [6].

The other motivation behind the IOT is the need to create a smart city that uses information and communication technologies (ICTs) to make services and monitoring more interactive and efficient [8,9]. The smartness of a city is enabled and driven technologically by the IOT [10].

To achieve the aforementioned advantages and applications of IOT requires the use of Ethernet cables that are of high quality and are reliable as a fundamental part of the overall physical layer. The selection or choice of Ethernet cables to meet the standards required in IOT infrastructure is a big challenge for cable professionals, contractors and installers.

The availability of counterfeit and non-standards compliant Ethernet cable coupled with copper clad aluminum (CCA) cables in the market masquerading as Ethernet cables pose a serious threat to the networking world [11,12]. The use of these substandard cables can affect network performance with potential liability to the contractor or installer [11,13]. Typically, for infrastructure deployment, the cables will be unwound off the reel, run-out where they need to go with the excess at the ends re-coiled for convenience, the ends will then be terminated. So, typically the cable could be re-coiled up to three times [14,15]. There is, therefore, the need for methods of evaluating the physical integrity of these cabling channels to ensure that they can be reused and would not degrade due to handling or installation stress. This paper presents a technique that can be used to evaluate the resilience of cables to the kind of handling stress they can be subjected. An additional benefit of this approach is that it provides the tools to undertake a more detailed analysis of partial data (magnitude only). This paper will concentrate on Category 6 cables due to their current popularity. Four Category 6 unshielded twisted pair (UTP) cables from different manufacturers are subjected to a series of coiling and uncoiling tests. The FSV and KS test are used to quantify the differences in return loss and impedance profiles between the first and the third coiling and uncoiling. The FSV and KS test are used due to the difficulty in making objective assessments visually with the human eye. The results of this analysis will be used to determine the cable that has the best, and worst, resilience to handling stress.

The paper consists of five sections. Section I is the introduction to the paper, section II deals with the background to the research, section III is the methodology used in measurements, section IV provides the results and discussions from the research and section V deals with the paper conclusion.

2. Background

2.1. Feature Selective Validation

The Feature Selective Validation (FSV) method is a validation tool that can be used to objectively quantify the similarity between data sets [17]. The method has now been used to quantify data from a wide variety of sources, whether from experimental data, numerical models, computational electromagnetics etc. [17,18]. The method removes the human subjective judgement and enables objective decisions in the comparison of data [19].

The FSV method can be broken into the calculation of two components, the Amplitude Difference Measure (ADM) and the Feature Difference Measure (FDM). The combination of the ADM and FDM gives the Global Difference Measure (GDM) [20].

The ADM and FDM measure the overall differences in amplitude and characteristics or features of the data sets compared respectively [18,20]. The point by point comparison (ADMi, FDMi and GDMi) can be used to create histograms known as ADMc, FDMc and GDMc which can be classified into six quality descriptors: excellent, very good, good, fair, poor and very poor [20].

The single number quality indicators are used for quickly evaluating the average comparison between the two data sets are known as ADMtot, FDMtot and GDMtot [17]. The FSV interpretation scale of these average single number indicators is shown in Table 1[21]:

Table 1. FSV interpretation scale for evaluated results

FSV Value (quantitative)	FSV Interpretation (qualitative)
Less than 0.1	Excellent
Between 0.1 and 0.2	Very good
Between 0.2 and 0.4	Good
Between 0.4 and 0.8	Fair
Between 0.8 and 1.6	Poor
Greater than 1.6	Very poor

2.2. The Kolmogorov-Smirnov (KS) Test

The KS test was used to supplement the FSV comparison results and provide further analysis of the data sets. The KS test aims to determine if the distributions of two datasets differ significantly and have been explained in detail in [22,23]. The KS test has the advantage of making no assumption about the distribution of data [23,24]. The KS test uses the maximum vertical deviation between the two curves of the cumulative distributive functions (CDFs) as the statistic D given in [22,23] as :

$$D_{stat} = \max\left(\left|CDF_1(x) - CDF_2(x)\right|\right). \tag{11}$$

In equation (11), $CDF_1(x)$ is the proportion of values less than or equal to x in the first data set and $CDF_2(x)$ is the proportion of values less than or equal to x in the second data set. The critical value for different significance value is given in [23] as:

$$D_{crit.} = k.\sqrt{\frac{N_1 + N_2}{N_1.N_2}}. \tag{12}$$

In equation (12), N_1 and N_2 is the length of the data sets compared and the value of k is given in [22,23] for a confidence level of 95% (significance value $\alpha = 0.05$) as 1.36.

The p value determines if the difference is significant or otherwise [24]. The null hypothesis means that the two data sets can be regarded as being from the same distribution [23]. The null hypothesis will be rejected if the p value is smaller than the significance value or the test statistic D is greater than the critical value [23].

3. Methodology

3.1. Measurement Procedure

The impedance profile across the length of four Category 6 unshielded twisted pair (UTP) cables from different manufacturers were measured using an industrial standard DSX-5000 cable analyzer. The analyzer consists of two units: “main” and “remote”. The cable to be tested is connected through patch cord plugs to standard link interface adapters. The main and remote units have openings in which these link interface adapters are connected [25].

The DSX-5000 cable tester uses HDTDR (High-Definition Time Domain Reflectometry) to measure the impedance profile across the cables. The four Ethernet cables were tested according to International Standard ISO/IEC 11801 Class E, T568B pin connection for four pairs which allows performance of up to 250MHz [25]. The four cables considered were marked as cable 1, cable 2, cable 3 and cable 4 for easy identification. Cable 2 was copper clad aluminum (CCA) cable. A 30m length of each cable was used for measurement to represent the last few meters that could be subjected to handling stress in real installation situations. The schematic diagram of the measurement set up is shown in Figure 1.

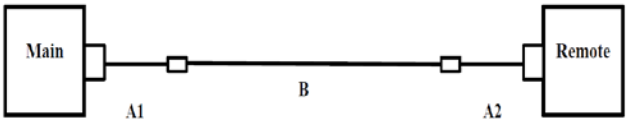

Figure 1. Schematic diagram of the measurement set up (where, A1 and A2: Link interface adapters and patch plugs; B: Cable under test)

The cable measurements method was:

Measurements A: cables are used to form coils of about 30cm diameters and stretched out for measurement.

Measurements B: cables used for measurements A are reused to form coils of about 30 cm diameters and stretched out for measurement.

Measurements C: cables used for measurements B are reused to form coils of about 30cm diameters and stretched out for measurement.

4. Results and Discussions

The plots of the return loss measurements of the orange pair of the four cables, for illustration, across their length with Category 6 limits [16] are shown in Figure 2 to Figure 5. A view of the plots in Figure 2 to Figure 5 indicates that only the CCA cable 2 in Figure 3 crosses the Category 6 return loss limit. The CCA cable 2 therefore appears to be worse but needs objective confirmation. The aim of this paper is to objectively (quantitatively) compare the data. Which in this case, is to quantify the changes between the return loss measurement A (first test) which is the baseline and return loss measurement C (third test) of the four cables under examination.

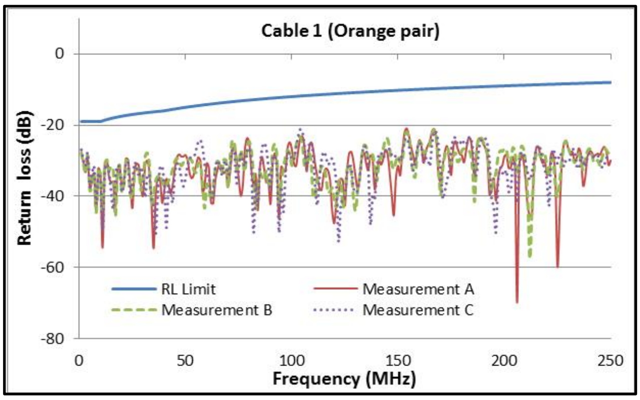

Figure 2. Return loss measurements of cable 1

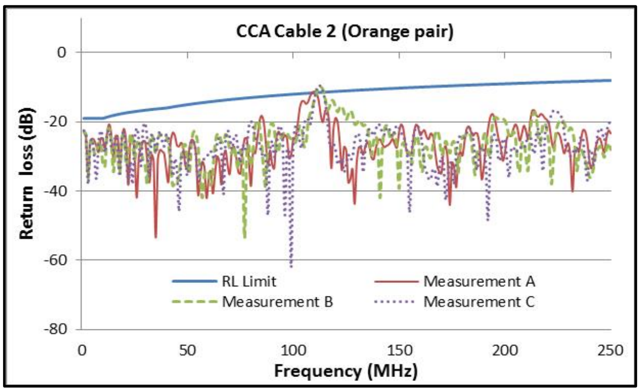

Figure 3. Return loss measurements of CCA cable 2

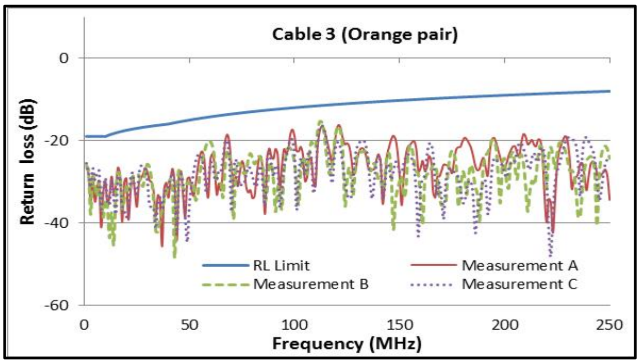

Figure 4. Return loss measurements of cable 3

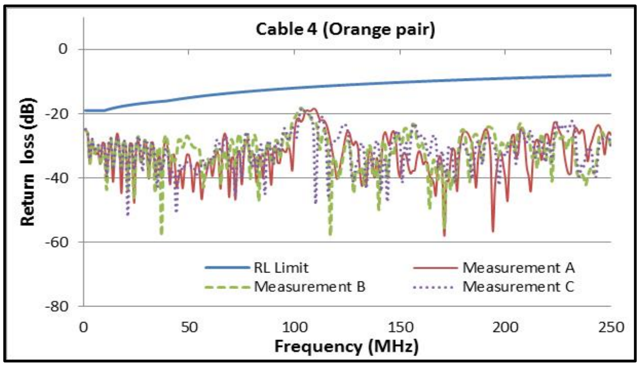

Figure 5. Return loss measurements of cable 4

The FSV return loss results of the comparison of measurement A (first test) and measurement C (third test) of the orange, green, blue and brown pairs are shown in Table 2 to Table 5 for cables 1 to 4. The FSV GDM results in Table 2 to Table 5 shows cable 1 (orange and brown pairs) and cable 4 (green and blue pairs) gave the least changes between return loss measurements A and C comparison. On the other hand, the FSV GDM results of Table 2 to Table 5 shows that the CCA gave the highest changes between return loss measurements A and C comparison for all the pairs. In summary, the FSV GDM result indicates that cable 1 and 4 showed the highest resilience to the three rounds of whole length coiling and uncoiling tests, while the CCA cable 2 showed the lowest resilience to the stress tests for all the pairs. However, all the cables show a fair comparison between return loss measurements A and C indicating the impact of the whole length coiling and uncoiling. The summary of the FSV result of the return loss measurements A and C comparison is illustrated with a chart in Figure 6.

Table 2. FSV result of the comparison between measured return loss A and C for the orange pair

A vs C Return loss	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3279	0.3917	0.3517	0.3790
FDM_{tot}	0.4120	0.4576	0.3881	0.4613
GDM_{tot}	0.5812	0.6645	0.5832	0.6555

Table 3. FSV result of the comparison between measured return loss A and C for the green pair

A vs C Return loss	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3355	0.4374	0.3910	0.3443
FDM_{tot}	0.4113	0.5452	0.4290	0.3986
GDM_{tot}	0.5903	0.7686	0.6371	0.5854

Table 4. FSV result of the comparison between measured return loss A and C for the blue pair

A vs C Return loss	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3508	0.4244	0.3601	0.3417
FDM_{tot}	0.4568	0.4502	0.4628	0.3996
GDM_{tot}	0.6418	0.6877	0.6359	0.5844

Table 5. FSV result of the comparison between measured return loss A and C for the brown pair

A vs C Return loss	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3337	0.4239	0.3846	0.3804
FDM_{tot}	0.4237	0.4440	0.4349	0.4186
GDM_{tot}	0.5998	0.6745	0.6409	0.6265

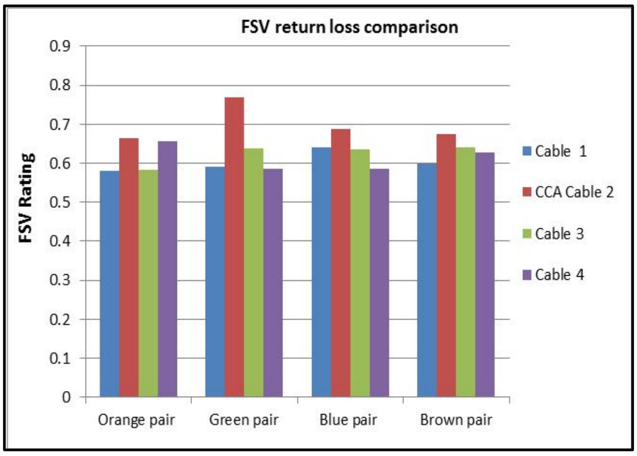

Figure 6. FSV return loss comparison chart for measurements A and C

To determine if the impact of the handling stress on the cables is significant or not, the KS test was used to compare measurement A (baseline) and measurement C (third test). Table 6 and Table 7 show the results of the KS test comparison of return loss measurements A and C using the orange, green, blue and brown pairs of cables 1 to 4. The critical value ($D_{crit.}$) was calculated from equation (12), the value of k is 1.36 at a significance value (α) of 0.05, N_1 and N_2 is equal to 818 and (D_{crit}) was found to be 0.067.

Table 6. KS test D values for the return loss comparison between measurements A and C

A vs C D values	Cable 1	CCA Cable 2	Cable 3	Cable 4
Orange pair	0.045	0.099	0.042	0.105
Green pair	0.075	0.169	0.045	0.037
Blue pair	0.065	0.084	0.138	0.075
Brown pair	0.056	0.068	0.082	0.093

Table 7. KS test p values for the return loss comparison between measurements A and C

A vs C p values	Cable 1	CCA Cable 2	Cable 3	Cable 4
Orange pair	0.329	0.000	0.427	0.000
Green pair	0.017	0.0001	0.327	0.585
Blue pair	0.052	0.005	0.0001	0.017
Brown pair	0.128	0.035	0.006	0.001

The KS test results in Table 6 and Table 7 shows that cable 1(orange, blue and brown pairs), cable 3 (orange and green pairs) and cable 4 (green pair) gave no significant difference between return loss measurements A and C as their P values are greater than 0.05 and D values is less than 0.067. On the other hand, the CCA cable (all pairs) showed significant difference between return loss measurements A and C as the P values are lower than 0.05 and D values greater than 0.067. The KS test D values of the comparison between return loss measurements A and C for the four cables is illustrated with a chart in Figure 7. Similarly, the KS test p values of the comparison between return loss measurements A and C is illustrated with a chart in Figure 8. In summary, the KS test result indicates that cable 1 showed the highest resilience to the three rounds of whole length coiling and uncoiling tests, while the CCA cable 2 showed the lowest resilience to the stress tests.

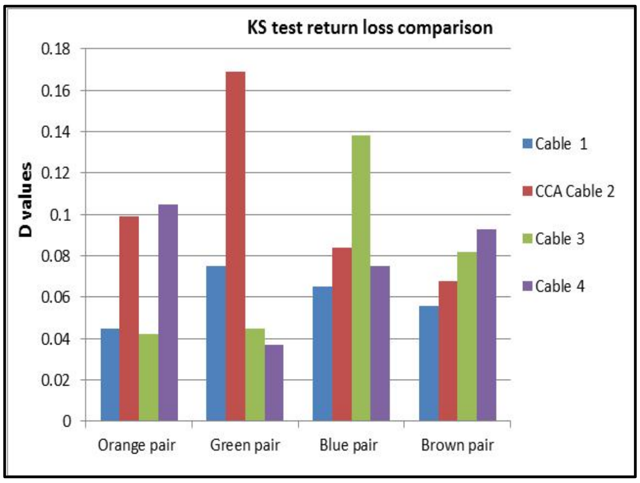

Figure 7. KS test D values chart for return loss comparison between measurements A and C

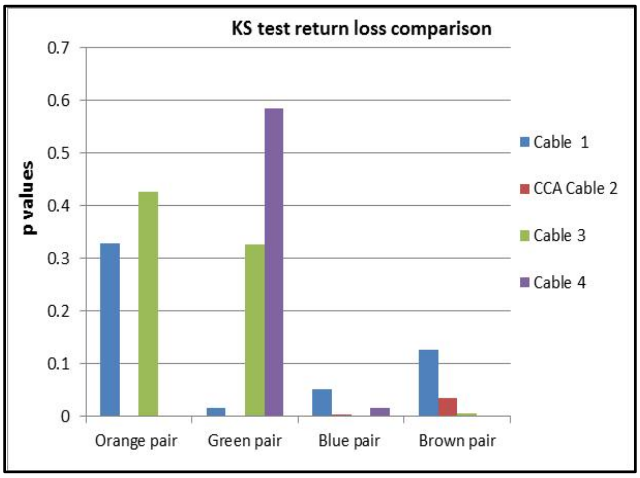

Figure 8. KS test p values chart for return loss comparison between measurements A and C

The graphs of the impedance profile measurements of the orange, green, blue and brown pairs of the four cables across their length are shown in Figure 9 to Figure 12. The FSV results of the comparison of impedance profile measurements A and C of the orange, green, blue and brown pairs are shown in Table 8 to Table 11 for cables 1 to 4. The FSV GDM results in Table 8 to Table 11 shows that the green, blue and brown pairs of cable 1and the orange pair of cable 3 gave the least changes between impedance profile measurements A and C comparison. On the other hand, the FSV GDM results of Table 8 to Table 11 shows that the CCA cable 2 (orange and brown pairs) and cable 4 (green and blue pairs) gave the largest changes between impedance profile measurements A and C comparison. The summary of the FSV GDM result indicates that cable 1 showed the highest resilience to the three rounds of whole length coiling and uncoiling tests, while the CCA cable 2 showed the lowest resilience to the stress tests. However, they all show a fair comparison between impedance profile measurements A and C comparison.

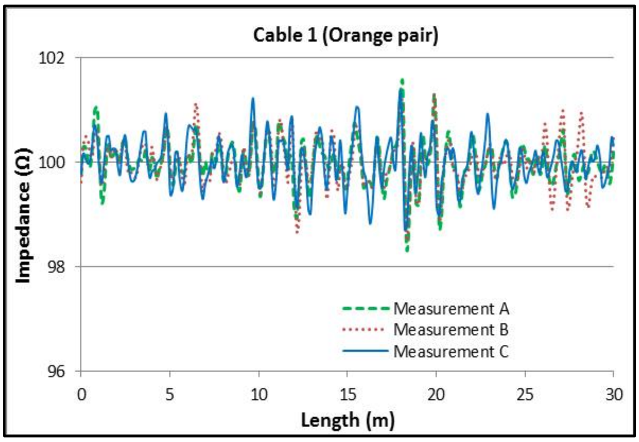

Figure 9. Impedance profile measurements for cable 1

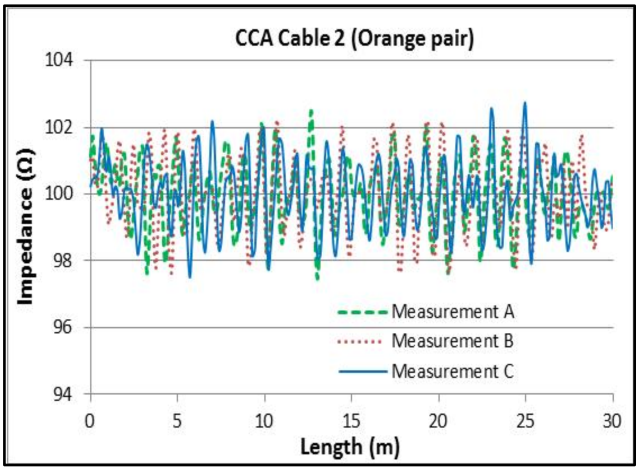

Figure 10. Impedance profile measurements for CCA cable 2

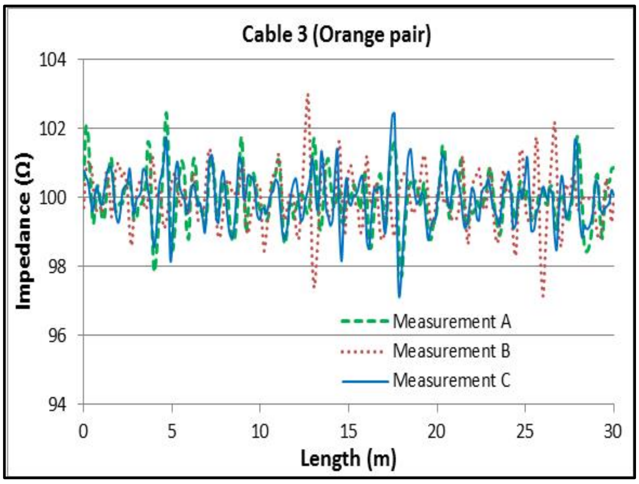

Figure 11. Impedance profile measurements for cable 3

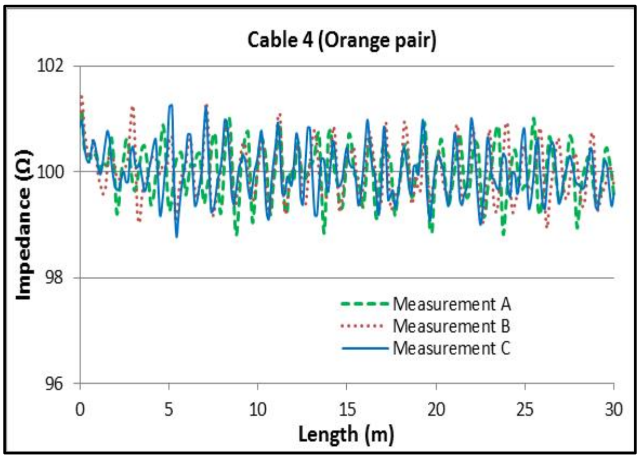

Figure 12. Impedance profile measurements for cable 4

Table 8. FSV result of the comparison between measured impedance profile A and C for the orange pair

Impedance A vs C	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.2977	0.3493	0.2825	0.3227
FDM_{tot}	0.3353	0.4052	0.3314	0.3480
GDM_{tot}	0.5101	0.5886	0.4872	0.5287

Table 9. FSV result of the comparison between measured impedance profile A and C for the green pair

Impedance A vs C	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3103	0.3521	0.3413	0.3897
FDM_{tot}	0.3745	0.3790	0.3567	0.4432
GDM_{tot}	0.5479	0.5692	0.5490	0.6570

Table 10. FSV result of the comparison between measured impedance profile A and C for the blue pair

Impedance A vs C	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3137	0.3211	0.3095	0.4008
FDM_{tot}	0.3109	0.3750	0.4080	0.4667
GDM_{tot}	0.4969	0.5546	0.5694	0.6864

Table 11. FSV result of the comparison between measured impedance profile A and C for the blue pair

Impedance A vs C	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.3494	0.3820	0.3321	0.3577
FDM_{tot}	0.3359	0.4395	0.3813	0.3934
GDM_{tot}	0.5462	0.6408	0.5661	0.5822

The results of the KS test using the orange, green, blue and brown pairs of cables 1 to 4 are shown in Table 12 and Table 13. The critical value ($D_{crit.}$) was calculated from equation (12), the value of k is 1.36 at a significance value (α) of 0.05, N_1 and N_2 is equal to 233 and (D_{crit}) was found to be 0.126. The KS test results in Table 12 and Table 13 shows that the test values D of all pairs of the four cables are below 0.126, while the P values of all pairs of the four cables are greater than 0.05. The D and P values in Table 12 and Table 13 show that the null hypothesis cannot be rejected or is accepted. The summary of the KS test D and P values of the comparison between impedance profile measurements A and C for the four cables are illustrated with charts in Figure 14 and Figure 15. In summary, this means the difference between the impedance profile measurements A and C is not significant to be considered as failure on the part of the cables. The KS test results obtained is true as none of the cables impedance profiles falls outside the +15/-15 of the 100Ω standard often specified for UTP cables.

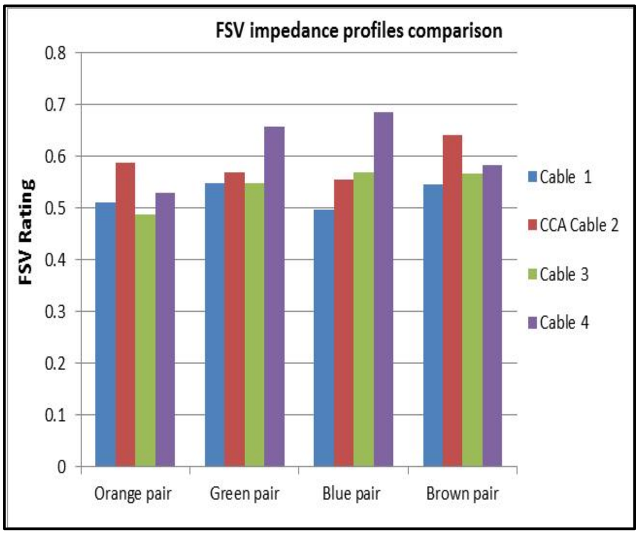

Figure 13. FSV impedance profile comparison between measurements A and C

Table 12. KS test D values of the impedance profile comparison between measurements A and C

A vs C D values	Cable 1	CCA Cable 2	Cable 3	Cable 4
Orange pair	0.082	0.052	0.064	0.077
Green pair	0.073	0.069	0.069	0.060
Blue pair	0.060	0.064	0.086	0.039
Brown pair	0.047	0.090	0.064	0.060

Table 13. KS test p values of the impedance profile comparison between measurements A and C

A vs C p values	Cable 1	CCA Cable 2	Cable 3	Cable 4
Orange pair	0.366	0.901	0.687	0.449
Green pair	0.520	0.617	0.601	0.692
Blue pair	0.754	0.690	0.322	0.983
Brown pair	0.936	0.284	0.674	0.759

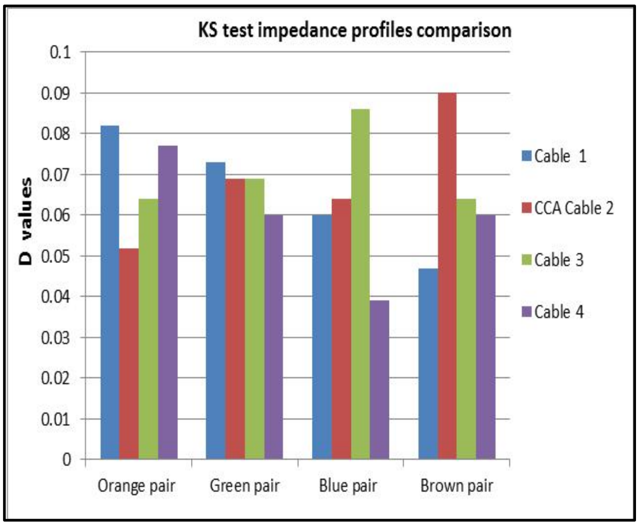

Figure 14. KS test D values chart for impedance profile comparison between measurements A and C

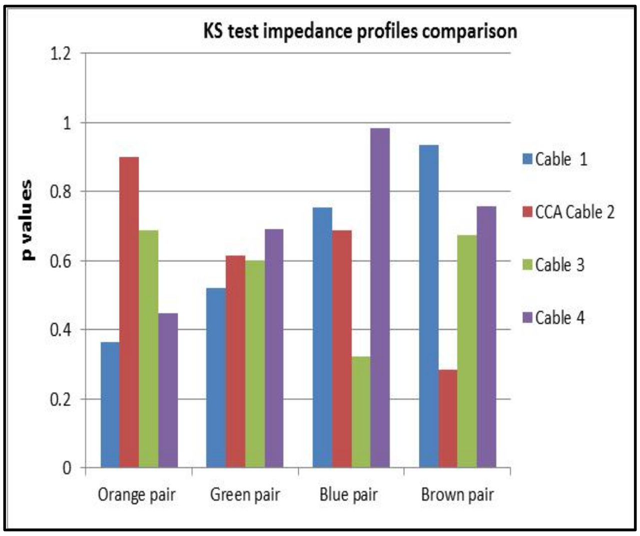

Figure 15. KS test p values chart for impedance profile comparison between measurements A and C

5. Conclusion

This paper has presented an approach that can be used to evaluate cables resilience to handling stress and also undertake a more detailed analysis of the partial data (magnitude only). The research subjected four Category 6 UTP cables from different manufacturers to three rounds of coiling and uncoiling tests. The FSV GDM and KS test results for return loss shows that cable 1 presented the highest resilience to handling stress as it gave the lowest variations between measurements A (baseline) and C (third test) in most of it cable pairs. On the other hand, the CCA cable 2 gave the lowest resilience to handling stress as it gave the highest variations between return loss measurements A and C comparison for all pairs. Similarly, the FSV GDM for impedance profile measurements shows that cable 1 presented the highest resilience to handling stress as it gave the lowest variations in three of it pairs, while the CCA cable 2 gave the lowest resilience to handling stress as it gave the highest variations in two of it pairs. The KS test for impedance profile measurements A and C comparison indicates that they are not significant to be considered as failure on the part of all the cables pairs. The paper has therefore presented a technique that can be used by cable professionals to undertake a more detailed analysis of the partial data (magnitude only) obtained from UTP cable measurements.

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