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Application of the Feature Selective Validation Method and Kolmogorov-Smirnov Test to Evaluate Handling Effects on Crosstalk of Ethernet Cables

Olusegun Ogundapo[1,*], Charles Nche[1], Alistair Duffy[2], Gang Zhang[3]

[1]School of Information Technology and Computing, American University of Nigeria, PMB 2250, Yola-Nigeria
[2]School of Engineering and Sustainable Development, De Montfort University, LE1 9BH, Leicester, United Kingdom
[3]School of Electrical Engineering and Automation, Harbin Institute of Technology, Harbin, 150001, China
*Corresponding author: olusegun.ogundapo@aun.edu.ng

Abstract The use of Ethernet cables in internet of things (IoT) infrastructure continues to grow due to high demand as the reach of the IoT itself expands. Crosstalk is a major limiting factor in communications systems that need to be taken into consideration when selecting cables for deployment. In typical installations, these cables require a certain degree of manipulation that involves repeated coiling and uncoiling of a few meters which can adversely affect performance. It is thought that this is especially true with counterfeit or copper clad aluminum (CCA) cables often disguised as compliant Ethernet cables. In this paper, four unshielded twisted pair cables of which one of them is a CCA cable were subjected to three rounds of coiling and uncoiling tests representing installation manual handling. Given the visually complex measurements that are a feature of the Ethernet infrastructure, an approach to quantifying chances is needed that is particularly sensitive and nondiscriminatory. The Feature Selective Validation (FSV) method and Kolmogorov-Smirnov test is proposed as an appropriate method to use to assess crosstalk variations between the cables when subjected to this manipulation. The paper shows that the methods do allow quantified measurement of the variations between the tests which can lead to objective decision on the part of the cable installer.

Keywords: *Ethernet cable, crosstalk, FSV method, KS test, NEXT*

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1. Introduction

Ethernet has become the major technology used in Local Area Networking [LAN], [1,2]. The successes achieved in the use of twisted pair cables for Gigabit Ethernet led to an increase in its deployment for Internet of Things (IoT) infrastructure and communication networks [3,4]. The IoT concept is now one of the major directions in the evolution of internet [5].

The IoT system combines information and energy processes to control different objects [6]. The IOT also enables smart city initiatives that permit people and goods to be connected anywhere, anytime, with anything and anyone [7]. The aforementioned applications of the IOT using Ethernet cables requires the deployment of high quality and reliable cables that will not degrade over time.

Selecting Ethernet cables that will meet IOT infrastructure requirements is a big challenge to cable professionals, installers or engineers. A further challenging factor is the prevalence of counterfeit and copper clad aluminum (CCA) cables in the market [8,9] which can lead to both safety issues and poor communication performance. This paper is interested particularly in the later issue.

In most deployments, cables are unwound from the drum, installed where necessary and the excess are re-coiled ready for connectorization. The process could be repeated up to three times before commissioning [10]. When Ethernet cables are handled during installation, the twisted pairs may open up, changing the pair conductors center-to-center spacing and inducing imbalance which can lead to more coupling from pair-to-pair (crosstalk) [11]. This coupling situation could cause a loss of data on the cable, resulting in process downtime or safety issues [11]. It has also been discussed in [12] that crosstalk in unshielded twisted pair cabling can negatively affect digital video signal transmission. In view of the aforementioned effects of crosstalk on Ethernet cables performance, there is the need for an approach that can be used to evaluate the effects of crosstalk on cables. This is to ensure that the cables selected for deployment can be reused without degradation due to the handling stress or installation.

In this paper, near-end crosstalk (NEXT) which is a major source of signal degradation in communication systems [13] is considered using four Category 6 unshielded twisted pair (UTP) cables. The four UTP cables selected from the market are from different manufacturers, of which one of them is a CCA cable. These cables were subjected to three rounds of coiling and uncoiling tests to represent handling stress. The FSV method and KS test which are two are proven methods [15,18] that have been used to objectively compare two data sets were selected to assess the variations in NEXT between the first and third coiling and uncoiling tests.

This is to determine the extent of the NEXT variations and identify the cables with the highest or least resilience to handling stress.

The paper is organized as follows: the introduction and background to the paper are presented in section 1 and section 2 respectively, the measurements methodology is explained in section 3, section 4 deals with the research results and discussions and finally the paper conclusion is presented in section 5.

2. Background

2.1. Feature Selective Validation

The Feature Selective Validation (FSV) method is a validation tool that was introduced to quantify the agreement between two data sets [14]. The tool enables objective decisions and removes the human subjective judgement in the comparison of data [15]. The FSV method was developed to replicate the decision making process of highly experienced engineers [16].

The FSV consists of two parts called the Amplitude Difference Measure (ADM) and the Feature Difference Measure (FDM). The ADM gives the overall agreement of amplitude trend. The FDM on the other hand, deals with the overall agreement of the rapidly changing features between the data sets [14]. The ADM and FDM can be combined to form an overall value called the Global Difference Measure (GDM) [14]. The point-by-point comparison of the data set can be used to create the ADMi, FDMi and GDMi which can help the user in the analysis of the data been compared. The ADMi, FDMi and GDMi can be represented as histograms known as ADMc, FDMc and GDMc respectively, that gives the number of points in various agreement categories [14,17].

The average values of the ADM, FDM and GDM which can be used for quickly evaluating the quality of the result with a single number are known as ADM_{tot}, FDM_{tot} and GDM_{tot} respectively [17]. The interpretation scale of the FSV which gives the average single number indicators is presented in Table 1 [16]:

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 introduced as a technique that can be used to compare data sets to determine if their distributions differ significantly [18,19]. The KS test is robust, makes no assumption about the distribution of data and is not affected by scale changes [20]. It uses the test statistic D and p values to determine whether to accept or reject the null hypothesis. The null hypothesis signifies that the data set are from same distribution, while the alternative hypothesis is that they are from different distributions. A measure of the vertical deviation between two curves of the cumulative distribution function (CDFs) of the two data set compared is given in [20] as:

$$D_{stat} = \max\left(\left|CDF_1(x) - CDF_2(x)\right|\right) \tag{1}$$

where, $CDF_1(x)$ is the proportion of values less than or equal to x in the first data set, while $CDF_2(x)$ is the proportion of values less than or equal to x in the second data set. The critical value which serves as the baseline for the test statistic values can be calculated as presented in [20,21] as:

$$D_{crit.} = k.\sqrt{\frac{N_1 + N_2}{N_1.N_2}} \tag{2}$$

where, N_1 and N_2 is the length of the data sets compared, the value of k for a confidence level of 95% (significance value $\alpha = 0.05$) as 1.36 [18,20].

The baseline value for the p values from the KS test is 0.05 for a confidence level of 95%. It helps the user determine whether the result of data compared is significant or not [20,21]. The null hypothesis is rejected if the p value is smaller than 0.05 and the test statistic (D_{test}) is greater than the critical ($D_{crit.}$) value. On the other hand, the null hypothesis is accepted if the p value is greater than 0.05 or the test statistic (D_{test}) is less than the critical ($D_{crit.}$) value.

3. Methodology

The DSX-5000 cable analyzer was used to measure the NEXT of the four Category 6 UTP cables from different manufacturers. The cable tester consists of two units known as the “main” and “remote” [22]. The cables to be tested is connected through patch cord to standard link interface adapters and then to the main and remote for measurements [22]. The T568B pin connection was used for the cables insertion into registered jack (RJ45) and was tested according to the International standard ISO/IEC 11801 class E. The standard allows performance of up to 250MHz. The four UTP cables were labelled cable 1, CCA cable 2, cable 3 and cable 4 for easy identification. Cable 2 was copper clad aluminum (CCA) cable. To represent the last few meters that could be subjected to handling stress in real installation situations, a 30m length of each cable was used for measurement. The schematic diagram of the measurement set up is shown in Figure 1.

The cable measurements methodology is:

Measurements A: cables of about 30m length was taken from the drum 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 as shown in Figure 1.

Measurements C: cables used for measurements B are reused to form coils of about 30cm diameters and stretched out for measurement as shown in Figure 1.

Measurements D: cables used for measurements C are reused to form coils of about 30cm diameters and stretched out for measurement as shown in Figure 1.

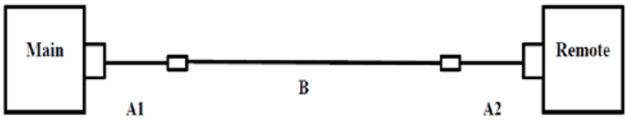

Figure 1. Schematic diagram of the measurement set up (where, **A1 and A2:** Link interface adapters and patch plugs, ***B:*** Cable under consideration (30m))

4. Results and Discussions

The plots of the NEXT measurements of the orange/green pair's combination of the four cables used for illustration are shown in Figure 2 to Figure 5. The one pair has been shown for illustration. A first impression of Figure 2 to Figure 5 shows that it is difficult to quantify the differences between the measurements with the human eye; clearly identifying which are better or worse and by how much. There is therefore, the need for an objective approach to doing this. As stated previously, this paper aims to objectively quantify the variations in NEXT of a cable unwound from the reel (measurements A) which is the baseline and NEXT after they have been subjected to three rounds of coiling and uncoiling tests (measurements D), representing the maximum likely manual handling during installation.

The FSV NEXT results of the comparison between measurement A (first test) and measurement D (third test) of the orange/green, green/blue, blue/brown and brown/orange pairs combinations are shown in Table 2 to Table 5 for cables 1 to 4. The FSV GDM results in Table 2 to Table 5 shows that cable 1 gave the least changes between NEXT measurements A (first test) and D (third test) comparison for the orange/green and blue/brown pairs combinations, while cable 4 gave the least changes for the green/blue and brown/orange pairs combination. On the other hand, the FSV GDM results of Table 2 to Table 5 shows that the CCA cable 2 gave the highest changes between NEXT measurements A and C comparison for all the pairs.

The summary of the FSV GDM results in Table 2 to Table 5 is 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 pair combinations. However, the FSV GDM results in Table 2 to Table 5 show that the variations between the NEXT measurements A and D comparison is fair indicating the impact of the whole length coiling and uncoiling on the cables. The summary of the FSV GDM result of the NEXT measurements A and D comparison in Table 2 to Table 5 is illustrated with a chart in Figure 6. A view of the chart in Figure 6 shows that the NEXT measurements comparison of all pair combinations of the CCA cable 2 has the highest FSV rating indicating that it has the least resilience to the handling stress tests.

The next approach involves using the KS test to determine whether the impact of the handling stress on the cables is significant or not. The method was used to compare NEXT measurement A (baseline) and measurement D (third test) using the orange/green, green/blue, blue/brown and brown/orange pairs combinations of the four cables. The KS test results of the comparison between NEXT measurements A and D are shown in Table 6 to Table 7 for the four cables. The critical value (D_{crit}) was calculated from equation (2) using N_1=N_2=818, k=1.36 at a significance value (α) of 0.05 and D_{crit}=0.067.

The KS test results of the NEXT comparison between measurements A and D in Table 6 and Table 7 shows that cable 1 (orange/green and blue/brown pairs), cable 3(green/blue pairs), cable 4(green/blue, blue/brown and brown/orange pairs) gave no significant difference between NEXT measurements A and D comparison as their D_{test} values is less than 0.067 and p values are greater than 0.05. On the other hand, the CCA cable 2 for all the pair combinations gave a significant difference between NEXT measurements A and D comparison as their D_{test} values is greater than 0.067 and p values are less than 0.05.

The summary of the KS test is that cable 1 and cable 4 showed the highest resilience to the three rounds of coiling and uncoiling tests, as the handling effect on two out of the four pair combinations tested are not significant. However, the CCA cable 2 showed the lowest resilience to the handling stress tests as all the pair combinations showed a significant difference between NEXT measurements A and D comparison.

The summary of the KS test (D_{test}) and p values of the NEXT measurements A and D comparison in Table 6 and Table 7 are illustrated with charts in Figure 7 and Figure 8. A view of the chart in Figure 7 shows that the KS test (D_{test}) values of all the pairs of the CCA cable 2 is above the critical value of 0.067 and other cables pair's indicating that it has the least resilience to the handling stress tests. Similarly, a view of the chart in Figure 8 shows that the KS test p values of all the pairs of the CCA cable 2 is below 0.05 which shows that the null hypothesis is rejected i.e. a significant difference between measurements A and D indicating that it has the least resilience to the handling stress tests.

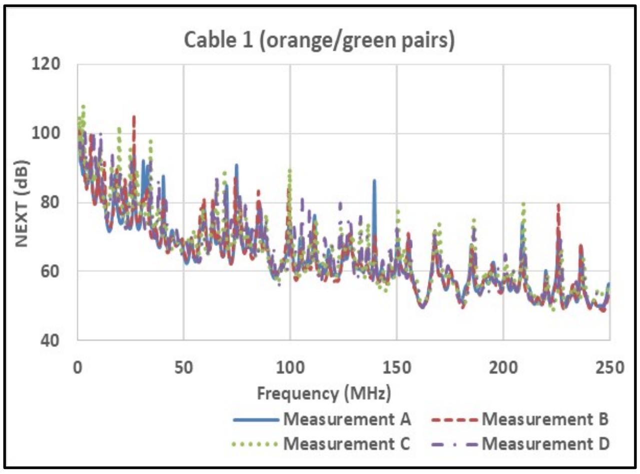

Figure 2. NEXT measurement comparison for cable 1

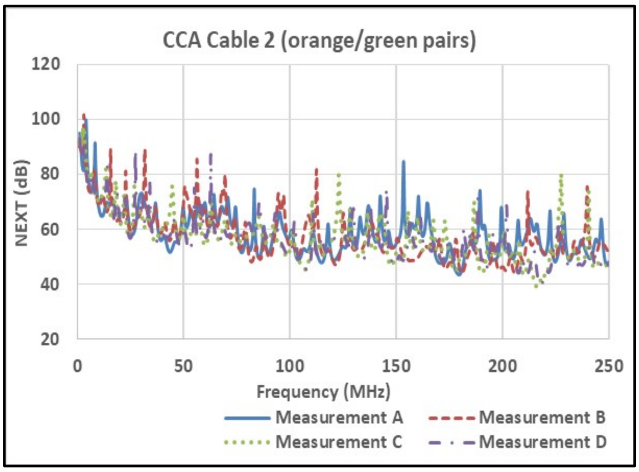

Figure 3. NEXT measurement comparison for CCA cable 2

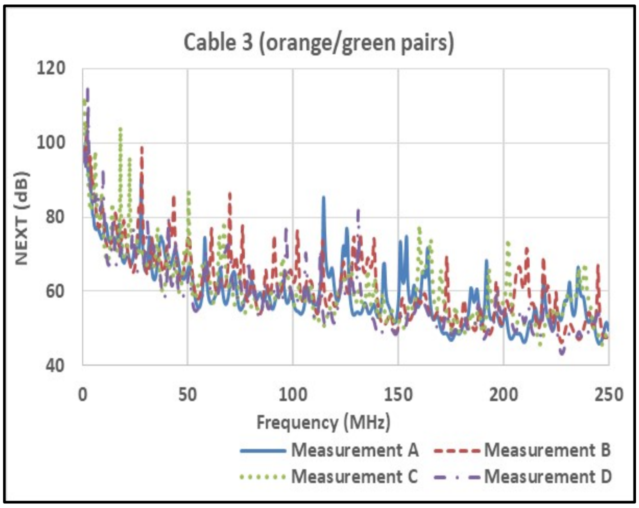

Figure 4. NEXT measurement comparison for cable 3

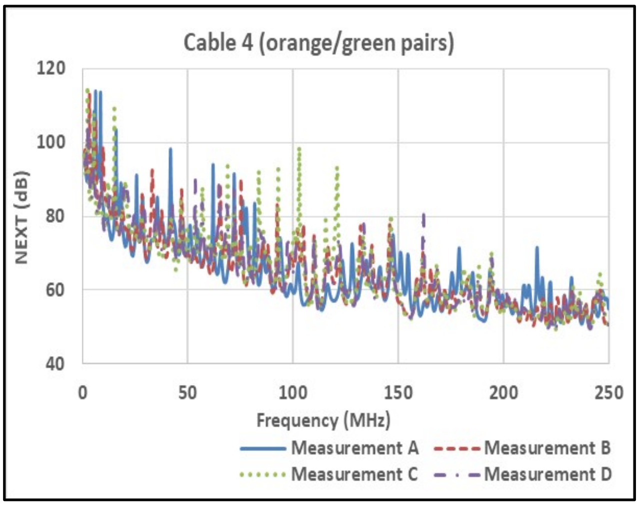

Figure 5. NEXT measurement comparison for cable 4

Table 2. FSV result of the comparison between measured NEXT A and D for the orange/green pairs

A vs D NEXT	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.2844	0.3745	0.3630	0.3655
FDM_{tot}	0.4220	0.5153	0.4544	0.5041
GDM_{tot}	0.5567	0.7107	0.6405	0.6929

Table 3. FSV result of the comparison between measured NEXT A and D for the green/blue pairs

A vs D NEXT	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.2795	0.3507	0.2233	0.2283
FDM_{tot}	0.4171	0.4644	0.3808	0.3371
GDM_{tot}	0.5501	0.6402	0.4783	0.4490

Table 4. FSV result of the comparison between measured NEXT A and D for the blue/brown pairs

A vs D NEXT	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.2794	0.4230	0.3575	0.2988
FDM_{tot}	0.4164	0.5099	0.4951	0.4907
GDM_{tot}	0.5448	0.7253	0.6711	0.6261

Table 5. FSV result of the comparison between measured NEXT A and D for the brown/orange pairs

A vs D NEXT	Cable 1	CCA Cable 2	Cable 3	Cable 4
ADM_{tot}	0.2530	0.4764	0.3000	0.2521
FDM_{tot}	0.4564	0.6513	0.4686	0.3694
GDM_{tot}	0.5678	0.8809	0.6054	0.4946

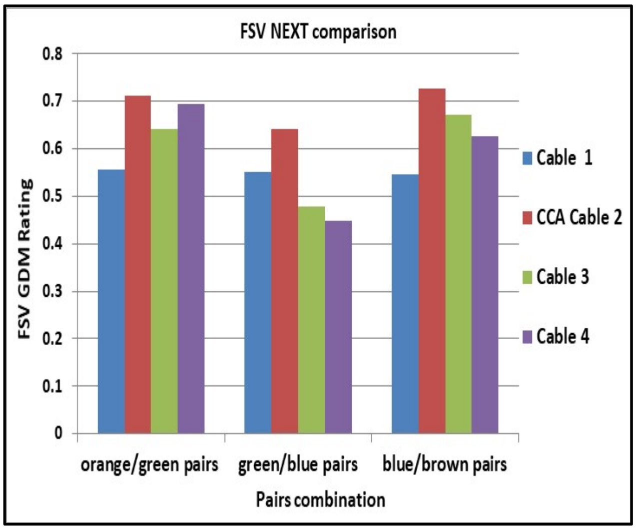

Figure 6. FSV GDM comparison chart for NEXT measurements A and D

Table 6. KS test D values for NEXT comparison between measurements A and D for the four cables

A vs D D_{test} values	orange/green pairs	green/blue pairs	blue/brown pairs	brown/orange pairs
Cable 1	0.0611	0.1394	0.0654	0.1198
CCA Cable 2	0.1333	0.2946	0.2433	0.3509
Cable 3	0.0892	0.0513	0.1406	0.0844
Cable 4	0.0819	0.0379	0.0465	0.0477

Table 7. KS test p values for NEXT comparison between measurements A and D for the four cables

A vs D p values	orange/green pairs	green/blue pairs	blue/brown pairs	brown/orange pairs
Cable 1	0.091	0.000	0.054	0.000
CCA Cable 2	0.000	0.000	0.000	0.000
Cable 3	0.023	0.225	0.000	0.006
Cable 4	0.018	0.592	0.333	0.303

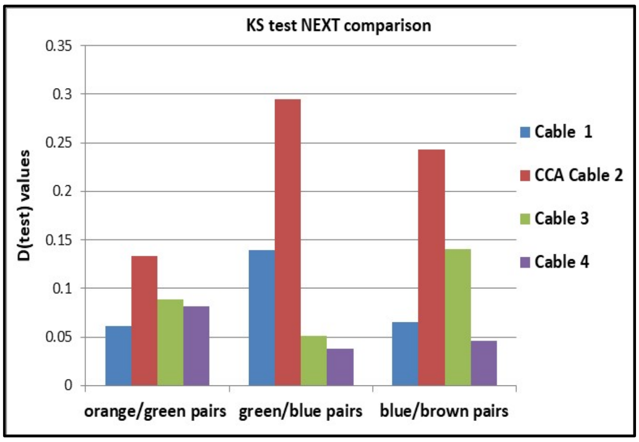

Figure 7. KS test D values chart for NEXT comparison between measurements A and D

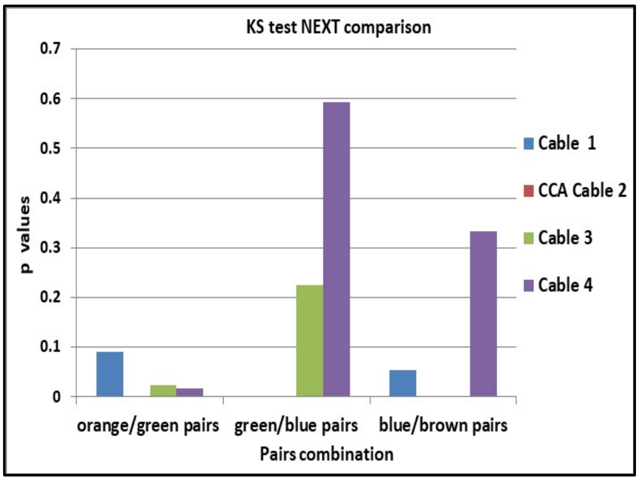

Figure 8. KS test p values chart for NEXT comparison between measurements A and D

5. Conclusion

This paper has presented an approach that can be used to objectively quantify the effects of handling stress on crosstalk of Ethernet cables. Four Category 6 UTP cables from different manufacturers of which one of them is a CCA cable were subjected three rounds of coiling and uncoiling tests. The method assessed the variations in NEXT measurements of the cables when unwound from the reel (measurement A) and after they have been subjected to the third round of tests (measurement D) to stimulate installation manipulation. The FSV GDM result shows that cable 1(orange/green and blue/brown pairs) gave the least changes between NEXT measurements A (first test) and D (third test) comparison, while cable 4 gave the least changes for the green/blue pairs combination. On the other hand, the FSV GDM indicates that the CCA cable 2 gave the highest changes between NEXT measurements A and D comparison for all the pairs.

The KS test results shows that cable 1 (orange/green and blue/brown pairs), cable 3(green/blue pairs), cable 4(green/blue and blue/brown pairs) gave no significant difference between NEXT measurements A and D. On the other hand, the CCA cable 2 for all the pair combinations gave a significant difference between NEXT measurements A and D comparison. Finally, the paper has thus presented a technique that can be used by cable engineers and installers to undertake a detailed analysis of magnitude only data obtained from different UTP cables measurements.

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