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ON THE LAST MILE CAMPUS AREA NETWORKS' ASPECT OF THE INTERNET SLUGGISHNESS PROBLEM

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ABSTRACT

With the large-scale deployment of computer networks in the campuses of higher educational institutions around the world in order to avail staff and students of these institutions the means of accessing the Internet for educational and collaboration purposes, network sluggishness when downloading information from the Internet or uploading information to the Internet at certain times of the day and at certain days of the week became a generally observed problem. Researchers in different higher educational institutions around the world have been carrying out researches into this problem in efforts at proffering solution(s) to it: but so far, the problem still persists. The solutions that have been recommended by different researchers for tackling the problem include bandwidth overprovisioning and bandwidth management approaches that involve deploying appropriate bandwidth and network access policies. We aim to illustrate in this paper, utilizing a practically (physically) installed university network the fact that, the sluggishness of these networks is the result of inappropriately installed buffers (in the context of the buffers' sizes) in the switches/routers that interconnects the end-devices (host equipment) in the networks.

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1. INTRODUCTION

There have been several phases in the evolution of the physical structure of the Internet from its US Department of Defence (DoD) ARPANET (Advanced Research Projects Agency Network) internetworking days; but an important segment of its current structure is what is generally referred to as CANs (Campus Area Networks): this class of networks is a subset of last-mile networks. CANs are computer communication networks which are made up of interconnections of LANs (Local Area Networks) within limited geographical areas. These networks are usually associated with the Communication Networks of educational institutions, most especially, higher educational institutions.

With the wide-spread deployment of computer networks in the campuses of higher educational institutions in order to avail staff and students the means of accessing the Internet for educational and collaboration purposes, a problem became evident to the users of these networks. Researchers in different parts of the world became interested in this problem and also began to carry out researches into the problem, with a view of finding solution(s) for it. The problem has to do with the sluggishness in uploading to the Internet, and downloading from the Internet, information at certain times of the day, and at certain days of the week. We have here termed this problem: CANs' aspect of the Internet Sluggishness Problem.

Several researchers in different parts of the world have been conducting researches into this problem; for example, the researcher in [1] - Obafemi Awolowo University, Nigeria; the researchers in [11] - Himachal University, Summer Hill, Shimla, India; the researchers in [3] - University of Mines and Technology, Tarkwa, Ghana; the researchers in [13] - Tadulako University, Central Sulawesi, Indonesia and others. However, to the best of our knowledge, researchers have not been able to proffer any enduring solution for the problem anywhere in the world. The above cited researchers basically made similar recommendation(s) as possible solution(s) to the CANs' sluggishness problem; but their recommended solution(s), have not had noticeable lasting positive effect on the operational performances of this class of networks.

In summary, the recommendations of the previously cited researchers on the CAN sluggishness problem are mainly centred on bandwidth overprovisioning; managing the subscribed for, Internet Service Providers (ISPs) bandwidth; and introducing appropriate policies' measures that serve as guides to accessing, controlling, and managing the available bandwidth. For example, Akpah, Mireku-Gyimah & Aryeh in [3] made recommendations which entails: A bandwidth management approach that involves deploying appropriate network policies, which encourages bandwidth saving practices among the users of the network. Using squid-Guard (an application software with advanced network access capabilities) to deploy effective bandwidth management control policies'. They made this recommendation because, according to them, there is lack of effective bandwidth management policies in the CAN that was studied by them. Bandwidth overprovisioning; which these researchers put this way: Even though the download and upload capacity of the University of Mines and Technology, Tarkwa, Ghana, CAN is 60MB, which is considered sufficient, the University can consider further increasing the bandwidth to at least 100MB; as this will effectively cater for any envisaged annual increase in the population of staff and students in the next five years, at which time another upgrade of bandwidth can be considered. It should be clear to any discerning person that these quantitative values are just guess quantities, as no empirical or mathematical or statistical basis were adduced for arriving at these values.

According to Akpah, Mireku-Gyimah & Aryeh [3], despite the fact that the 60MB bandwidth capacity of the CAN at the University of Mines and Technology, Tarkwa, Ghana is considered sufficient, the network appears to be slow and that, it sometimes gave signals of insecurity - a result of virus attack. These authors have contradicted themselves, and it's like they lack good understanding of the CANs' slowness (sluggishness) problem. This is because, 60MB cannot in one breath be considered to be sufficient for the network and in another breath the network appears to be slow: the correct fact is that, if the network appears to be slow, 60MB cannot then be sufficient for the network.

However, the crux of the matter is that, in a way, researchers have not been able to proffer any approach by which the bandwidth requirement of any CAN, including any LAN (CANs consists of internetworked LANs), at any point in time, can be determined. This led Sharma, Kumar & Thakiu to assert in [11] that: as a result of the continuous increase in the number of network users, no amount of bandwidth capacity can be said to be enough to meet the ever-increasing demands for bandwidth by the users' community; and Akpah, Mireku-Gyimah & Aryeh to contend in [3] that: Universities spend huge sums of money to buy more bandwidth and for network infrastructure upgrade; but most universities' networks still do not offer reliable and usable Internet access.

What these researchers have not factored into the different attempts at finding solution(s) to the CANs' sluggishness problem is that, cognizance has not been taken of the fact that, CANs' are basically engineering infrastructures, and therefore, solution(s) to the sluggishness problem should of necessity involve to a large extent, engineering concepts and approaches. Even Original Equipment Manufacturers (OEMs) like CISCO do not seem to yet understand how to quantify the bandwidth requirement of any LAN/CAN; which means, the issue of quantifying the bandwidth of a CAN/LAN is still a black art to the computer networking and data communication research community.

Consider the following statement that is made in CISCO LAN Switching and Wireless [5, p. 2] : For small, medium, and large-sized organizations, digital communication with data, voice and video is critical for performing the day-to-day functions of these organizations; the ability therefore, to select appropriate switches to support the network specifications of these organizations is very critical. But the question that needed to be answered is: How should a network (CAN or LAN) be specified? No approach or method is provided in CISCO LAN Switching and Wireless [5] for specifying a network, then, how can appropriate switches be selected for the network? Take for example, Fig. 1 which was extracted from CISCO LAN Switching and Wireless [5, p. 4]. The CISCO model as shown in Fig. 1 breaks the switched LAN into three layers, which are: the access layer, that interfaces with end-users' devices, such as personal computers and printers to provide access to the rest of the network; the distribution layer, where switches aggregate the traffic received from the access layer switches, before being transmitted to the core layer switches, which also aggregate the traffic from the distribution layer devices for routing towards the final destination

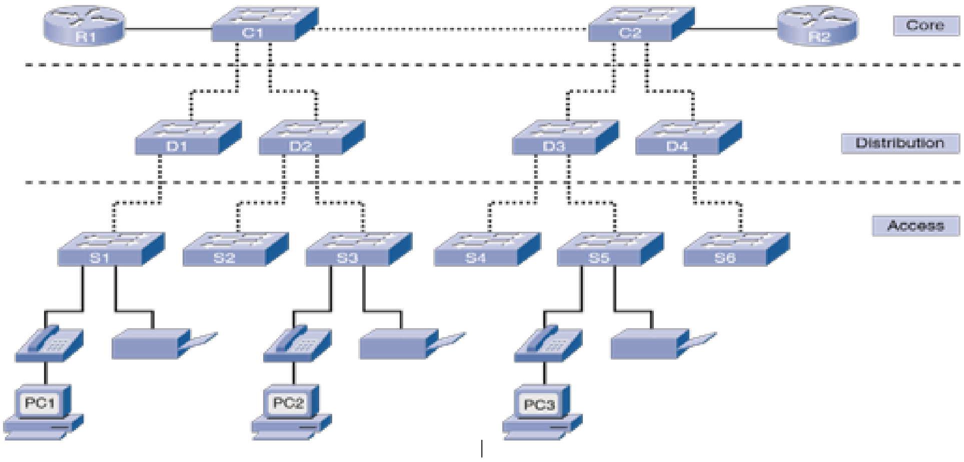

Fig. 1 The Hierarchical LAN Model by CISCO, extracted from [5, p. 4]

The CISCO documentation went on to suggest that, when selecting switch hardware, it is necessary to determine which switches are needed in the core, distribution, and access layers, in order to accommodate the bandwidth requirement of the LAN; and that, the switch hardware should also be selected by taking into account future bandwidth requirements (CISCO LAN Switching and Wireless [5, p. 15]). But nowhere in the documentation was approach(s) or method(s) or formula(s) given for determining the present bandwidth requirement or the future bandwidth requirement(s) of a LAN. The question that is supposed to be answered by the CISCO documentation, but is not answered, and to the best of our knowledge has not been answered elsewhere, put succinctly, is: How should a switched LAN's present and future bandwidth requirements be determined by an Engineer/Installer? It is clear therefore, that this CISCO switched LAN 'design' model and guide (this is what it is referred to in the documentation) is very short in the meaning of the word 'design', in the context of the term: 'Engineering Design'; as switched LANs are engineering infrastructures. The supposed answer to the previous question that is provided in the CISCO documentation (CISCO LAN Switching and Wireless [5, p. 18]) goes as thus: traffic flow data can be used to help determine just how long one can continue using existing network hardware, before it makes sense to upgrade, in order to accommodate additional bandwidth requirements; and that, the traffic flow on a network can be monitored in many ways: for example, by manually monitoring individual switch ports to get the bandwidth utilization over time. Apart from the fact that, seeking to upgrade hardware by monitoring bandwidth usage have no engineering basis, and therefore, incongruous, how will the hardware and bandwidth for new installations be specified and/or determined, if we are to go by this monitoring bandwidth usage logic? Nonetheless, we wish to elicit the attention of researchers to the fact that Eyinagho & Falaki in [9] and Eyinagho in [10] reported a novel approach for determining the bandwidth of any switched LAN.

However, Shipner, Zahavi & Rottenstraich contend in [12] that, network and switch designers encounter a buffer-size/bandwidth (link speed) trade-off problem; as designers can choose between two methods to deal with temporal increase in network traffic (congestion): they can either increase the buffer sizes of switches and routers, or, increase the link bandwidth; but according to these researchers, that is the researchers in [12], little is known about the trade-offs between these two methods. Also, Ahmad et al. in [2] has opined that, the choice of buffers' sizes has great effect on the overall performance of a computer network; while Wang [14] asserts that, large switches/routers' buffers increase network latency; that is, large switches/routers buffers lead to sluggish networks. The point-of-views of the previously cited researchers shows that, the CAN/LAN go-slow (sluggishness) problem also ought to be attacked from the switches/routers' buffers sizes angle, rather than from the bandwidth overprovisioning and bandwidth management angles alone, as has been suggested by several researchers, including the researchers in [1], [3], and [11]. Even as was previously mentioned in this paper, the bandwidth point-of-view researchers to the CAN/LAN sluggishness problem have not been able to give any approach(s) or formula(s) for quantifying the bandwidth of a CAN/LAN. We will now illustrate with a practically (physically) installed CAN/LAN the fact that, the sluggishness of these class of networks as a result of network congestion is more a result of inappropriately installed buffers (in the context of the buffers' sizes) in the switches/routers that interconnects the end-devices (host equipment) in these networks.

2. PRACTICAL ILLUSTRATION OF A POORLY INSTALLED AND OPERATED LAN/CAN

Figure 2 shows the line diagram of the LAN of one of the Colleges of Afe Babalola University, Ado Ekiti, Nigeria. The University is structured into Organizational units known as Colleges; with each College housing the offices, laboratories, lecture rooms and theatres pertaining to each College. The LANs' installed in all the Colleges have the same basic structure as is illustrated in Fig. 2. The LAN in Fig. 2 is indicated encircled by an orange-coloured circle. The LAN itself is connected to the University CAN through a CISCO 3750 switch, labelled as S_0 in the figure; the CISCO 3750 switch is located in the University Data Centre. The College LAN is composed of 14 switches interconnected as shown in the figure, and the switches are labelled S_1,S_2, …,S_{13}, S_{14} as indicated in the figure, using the right-pre-order labelling approach (see [7]) for an explanation of the right-pre-order labelling approach).

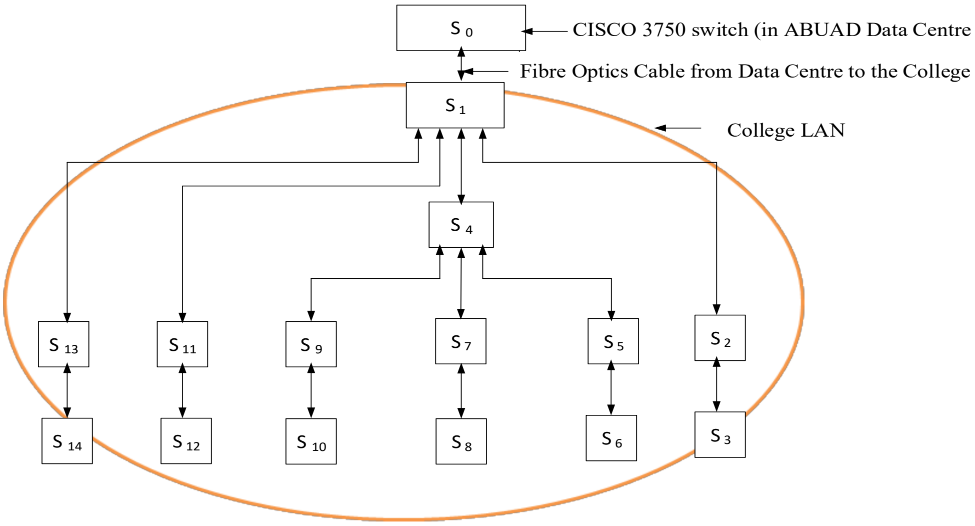

Fig. 2 College LAN (encircled) Connected to the University CAN through CISCO 3750 Switch

While carrying out a study of the sluggishness problem of the University's CAN, we made a most profound discovery as one of the main causes of the CAN's sluggishness problem: we have not come across any mention of a similar discovery in the literature pertaining to studies of the CANs' sluggishness problem. And what is the discovery that we made? All the switches in the LAN, that is, S_1 to S_{14} are of the same capacity and of the same specification, including having the same installed buffer capacity; which should normally not be the case. Recall that, in our brief mention of the CISCO three-layers model that is illustrated in Fig. 1, we mentioned the fact that, in the CISCO documentation (CISCO LAN Switching and Wireless [5]), it is stated that: when selecting switch hardware, it is necessary to determine which switches are needed in the core, distribution, and access layers, in order to accommodate the bandwidth requirement of the LAN. This instruction simply means that, the capacities of the switches at the three layers cannot be the same, or of the same specifications, including the fact that, the switches at all the three layers of the CISCO model cannot all be of the same buffer capacities: but here in Fig. 2, the switches S_1 to S_{14} are of the same type and having the same installed buffer capacities. Specifically, switches S_1 to S_{14} in Fig. 2 are the CISCO CBS 11a 24T switch, with 2 Mbit buffers installed in them. But several researchers, including Ahmad et al. [2], Wang [14], Shipner, Zahavi & Rottenstraich [12] have variously argued that, the sizes of the buffers that are installed in the switches and routers that are installed in communication networks affect the operational performance, including the delay (sluggishness) performance of the networks. Buffers get filled quickly if too small, leading to drops in arriving traffic, thus resulting in retransmissions that clog the network – that is, congestion; if buffers are too large, large queues build up in the switches and routers – necessitating arriving traffic to wait for too long a time before being transmitted at output ports– a delay or sluggishness situation: thus, an optimal buffer capacity that lies somewhere between too small and too large is needed. We will now illustrate the fact that, having installed switches of the same type, including having the same installed buffer capacities in the LANs' is one of the main cause of the sluggishness problem of these networks. Do not forget the fact that, switch S_0 (switch S_0 is located in the University's Data Centre) connects the LAN to the University's CAN; and that CANs are basically interconnections of several LANs – so, sluggishness of each of the interconnected LANs imply sluggishness of the CAN.

Consider Fig. 3 that is extracted from Fig. 2. Fig. 3 consists of the interconnection of switches S_{10}, S_9, and S_4 (see Fig. 2 for this interconnection). Switches S_{10}, S_9, and S_4 all have host equipment (end devices) like users' personal computers connected to them. The host equipment accesses other parts of the LAN/CAN and the general Internet through S_{10}, S_9, and S_4. Now, for the host equipment that are attached to switch S_{10} (S_{10} is actually a leaf node in the LAN) to access the Internet, their traffic must go through switches S_{10}, S_9, and S_4, and then go through switch S_0 - switch S_0 is not part of the LAN, but it is part of the CAN (see Fig. 2). Similarly, for the host equipment that are attached to switch S_9 to access the Internet, their traffic must go through switches S_9, S_4, and S_0. But for the host equipment that are attached to switch S_4 to access the Internet, their traffic only go through switches S_4, and S_0: this is what the CISCO documentation (CISCO LAN Switching and Wireless [5]) refers to as aggregation of traffic at higher layers, as was previously mentioned in this paper. Switch S_9

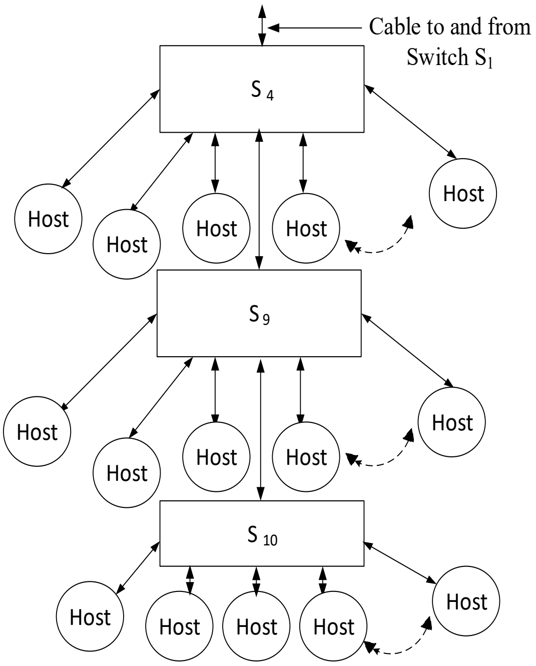

Fig.3 The interconnections between Switches S_4, S_9, and S_{10}; with Hypothetical Host Equipment shown

aggregates the traffic from the hosts that are attached to it, with the traffic from the hosts that are attached to switch S_{10}. Similarly, switch S_4 aggregates the traffic from the hosts that are attached to it, with the traffic from the hosts that are attached to switch S_9 together with the traffic from the hosts that are attached to switch S_{10}. So it is very strange for switches S_{10}, S_9, and S_4 to have the same buffer capacities of 2 Mbit (the 2 Mbit itself is an arbitrary value, as no formula or algorithm was used to determine it): Buffers being temporary storage locations for queuing incoming traffic before being transmitted on the output port. S_{10} buffers only traffic from the hosts that are connected to it; S_9 buffers traffic from the hosts that are connected to itself and from the hosts that are connected to S_{10}, while S_4 buffers traffic from the hosts that are connected to itself, with the traffic from the hosts that are connected to S_9, and the traffic from the hosts that are connected to S_{10}. So, S_4, S_9, and S_{10} ought not to have the same buffer capacities. A similar analysis and explanation can be made for traffic in the reverse direction; that is, traffic from the Internet to host(s) in the LAN/CAN. An example of queued traffic in a buffer is illustrated in Fig. 4. Following the preceding explanation, it should be clear that, if switch S_{10} for example, has enough buffer capacity for one queue as illustrated in Fig. 4, then S_9 should have enough buffer capacity for at least two queues of the type illustrated in Fig. 4,

TABLE I SWITCHES IN Fig.2 AND CORRESPONDING ESTIMATED REQUIRED MAXIMUM BUFFER CAPACITIES

Switch Number	Required Maximum Buffer Capacity (Mbit)	Required Maximum Buffer Capacity (MB)
S_1	58.23	7.28
S_2	8.32	1.04
S_3	4.16	0.52
S_4	29.12	3.64
S_5	8.32	1.04
S_6	4.16	0.52
S_7	8.32	1.04
S_8	4.16	0.52

S_9	8.32	1.04
S_{10}	4.16	0.52
S_{11}	8.32	1.04
S_{12}	4.16	0.52
S_{13}	8.32	1.04
S_{14}	4.16	0.52

S_4 should have enough buffer capacity for at least three queues of the type illustrated in Fig. 4, and S_1 should have enough buffer capacity for at least four queues of the type illustrated in Fig. 4. In other words, if the buffer capacity of S_{10} is for example, x Mbit, the buffer capacity of S_9 should be at least 2x Mbit, the buffer capacity of S_4 should be at least 3x Mbit, and the buffer capacity of S_1 should be at least 4x Mbit: the four switches cannot have the same buffer capacities as is presently the case.

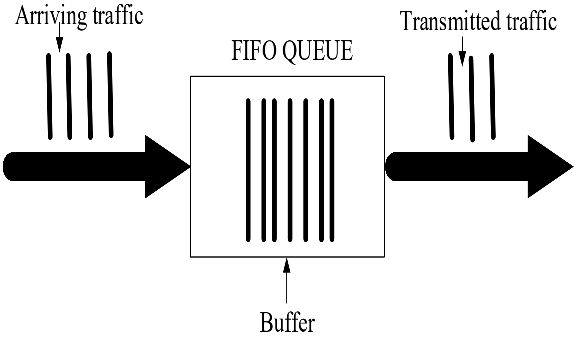

Fig. 4 Illustration of a FIFO queue

The maximum buffer capacities that should be provisioned in each of the switches in Fig. 2 (instead of the 2 Mbit that is presently provisioned in each of them) as obtained utilizing a novel approach and formula, which we developed, and will be reported and empirically justified in detail in a sequel paper, are as tabulated in Table I. Interested researchers can consult Eyinagho & Falaki [8], for a description of a similar approach for carrying out buffer capacities computations for nodal devices (switches and routers) that serve as the interconnection devices in the core of the Internet.

III DISCUSSION OF TABLE I

In Fig. 2, switches S_3, S_6, S_8, S_{10}, S_{12}, and S_{14} are at layer 1 of the tree diagram that is Fig. 2; these switches are leaf switches and are children to switches S_2, S_5, S_7, S_9, S_{11}, and S_{13} respectively, which are at layer 2; switches S_5, S_7 and S_9 are children to switch S_4, with S_4 the only switch at layer 3; while switches S_2, S_{11} and S_{13} are children to switch S_1, which is at layer 4. From Table I, we see that, 0.52 MB is specified for each of the switches at layer 1.04 MB (exactly 2×the buffer capacity specified for each of the switches at layer 1) is specified for each of the switches at layer 2. 3.64 MB is specified for switch S_4, which is about four times the buffer capacity specified for each of the switches at layer 2; this arises as a result of the fact that, while S_4 services six(6) switches, each of the switches at layer 2 services only one(1) layer 1 switch. 7.28 MB (which is 2×the capacity specified for S_4) is specified for switch S_1 that is at layer 1. So we see that, all the switches in Fig. 2 cannot all be of the same buffer capacity, as is currently the case with the actual (physically) installed LAN.

Another important point to note is that, all the values in Table I are in consonance with literature's tiny and small buffer specifications; in addition to what we refer to as very tiny buffers. Literature's small buffer's formula according to Appenzeller et al. [4] specifies approximately 12.5 MB of buffer for Internet routers and switches; on the other hand, literature's tiny buffer's formula according to Enachescu et al. [6] specifies between 20 to 50 packets. Using the IP packet (the most common Protocol Data Unit – PDU, in the Internet), which is illustrated in Fig. 5, and is 65,536 bytes ≈ 0.066 MB in size, we see that, 12.5 MB = $\frac{12.5MB}{0.066MB}$ = 189

IP packets. The specified buffers tabulated in Table I are: 0.52 MB, 1.04 MB, 3.64 MB, and 7.28 MB. These buffers' capacities are equivalent to $\frac{0.52MB}{0.066MB}$ = 8 IP; packets; $\frac{1.04MB}{0.066MB}$ = 16 IP packets; $\frac{3.64MB}{0.066MB}$ = 55 IP packets, and $\frac{7.28MB}{0.066MB}$ = 110 IP packets respectively.

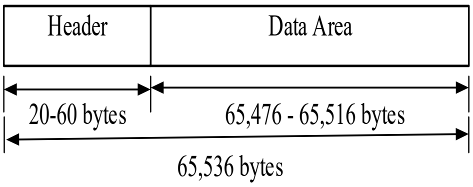

Fig. 5 Basic Structure of an IP Packet

IV CONCLUSION

The CAN (including, higher educational institutions' CANs) sluggishness problem has been a serious issue which has attracted the attention of researchers in the domain of computer and data communication networks, around the world; and has somehow defied solutions, partly, as a result of the fact that, the nature of the problem has really not been understood by researchers. Hence, the recommendations of various researches into the problem as reported in the literature have mainly been centered on bandwidth overprovisioning, bandwidth management, implementation of network and bandwidth access policies. Even with the implementation of these recommendations, the problem still persists; and bandwidth overprovisioning is not even a viable option, as bandwidth is a scarce and expensive resource that must have an upper limit for it to be economically viable for any given network installation. Moreover, OEMs of repute in the data and computer communication devices and equipment industry do not seem to understand the nature of the problem, and how to tackle it. In this paper, we have illustrated clearly, an aspect of the problem, using a practically (physically) installed subnetwork of a University's CAN, and which we believe, points out the solution that researchers have been searching for. In a sequel paper, we are going to report in detail, and empirically justify also, a methodology which we believe is the solution to this aspect of the communication networks' sluggishness problem as was previously pointed out in this paper

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BIOGRAPHIES OF AUTHORS

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