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Full Length Research Paper

Effect of network hierarchy in a typical campus area network (CAN) of a university

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This paper presents the results of a practical implementation of the hierarchical network design. The aim of this paper is to briefly show the effect of hierarchy in a campus network by taking the case study of a University network that has no hierarchy implemented. We simulated the original network and subjected the network to run for a period of 30 min with all the deployed services fully running to obtain the values of our determining metric (HTTP page response time). We then implemented the hierarchy into the network and carried out the same test to get new values which were finally compared and we recorded a reduction in the HTTP page response time. We were able to show how the network hierarchy affects the download time and a simple way of integrating hierarchy into an already existing network.

Key words: Networking, local area network, campus area network, small campus design.

INTRODUCTION

Campus area networks (CANs) interconnect LANs with geographically dispersed users to create connectivity. Some of the technologies used for connecting LANs are T1 (William, 1998), T3 (Regis, 1992), ATM (Koichi et al., 1997), ISDN (Jonathan, 2004), ADSL (Michel, 2003), frame relay (Jim, 1997), radio links (Trevor, 1999), amongst others. All mentioned technologies are accompanied with their various topologies and model of deployment that best suit the technology. A lot of proposals have been put forward as regarding considerations and implementations that affect the performance of CANs. Designing a network for optimal performance and meeting the requirements for all the users in a Campus are very important. It is highly recommended that the proposed network is simulated quickly with ease and without much expense before purchasing and deploying the network equipment. The network might not function properly once this stage is bypassed. At this point, enhancing the network is the only option which at most times comes with its own cost implications. One of the factors that usually appear as a major hindrance at this point is the physical architecture and this is because of the nature of growth and expansion of networks in a CAN. This thus becomes a problem in that the expansion which is not planned for often introduces problems like load balancing and a drop in the overall performance of the CAN because an imperative ingredient of network architecture (that is network hierarchy) is missing. Every network has to be continuously monitored as it grows to ensure that optimal algorithms are abided by. This is to avoid the network being grounded after it has been performing excellently.

In this paper we have considered a case study of Nigerian university network where there was no hierarchy in its architecture. We have simulated the original network and applied the network to run for a period of 30 min and estimated HTTP page response time. A comparison to prove the worth of the work is also demonstrated.

The simulation tool

In the market there are two major options for networking

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and simulation software; Boson’s OPNET’s IT Guru and NetSim (network simulator). The former appears to be more widely adopted in academia while the latter seems to target the Cisco’s line of networking examination and prep markets and not necessarily networking in general. IT Guru also requires a lot of supporting software and more configurations before one can get the software ready for simulation. IT guru is comprehensive and technology neutral in its capabilities and versatility. It does not need much of setup configurations and it is more user-friendly. IT Guru enables one to create a ‘virtual’ network consisting of relevant hardware, protocols and application software. Virtual network is a purely software entity that can run on an individual workstation. Routers, switches, web servers - almost anything found in real networks - can be duplicated in an IT Guru virtual network. It can be scaled from just a network of two workstations to one representing tens of thousands running in a WAN. Once a virtual network is created it can be manipulated in various ways. For instance, routers can be added or subtracted, protocols switched around or altered, web servers added or discarded – any permutation imaginable. The effects of various alterations and diverse configurations can then be usefully and quantifiably examined and analyzed. Importantly, IT Guru allows one to study and gather useful statistics about a virtual network built from it. It permits not only the building of a virtual network in software but also provides tools for dynamically investigating the thus engendered network. Hence its choice for this work!

The paper is organised in the following way. The study is to introduce different networking techniques which are normally applied on LAN/CAN. Case study is described next. Then, it introduces the implementation. The results are demonstrated and finally the conclusion is drawn.

Background

Sood (2007) has showed the imperativeness of properly selecting equipments to be deployed after considering the requirements of the users. She also showed the usefulness of faster Ethernet cabling to get better performance when designing a network. In the same work, she analyzed and showed how the distribution of the services between multiple servers versus services handled by one server impacts the CPU utilization depending on the kind of services supported. Although he noted that when there was a balance between frequently used services and less frequently used services, it does not make sense to deploy more than one server to support different services. Kumar (2005) noted that by using different link media with varying speeds, the authors explained how the throughput of a network is affected by the network load, as well as by the size of the packets. In the same paper he examined the performance of different implementation schemes of local area networks connected by switches and hubs. He showed how the addition of a switch at strategic nodes makes a network perform better in terms of throughput and delay characteristics. Stallings (2004) studied the performance improvement through LAN hardware upgrade. He proved the benefits of upgrading switch hardware in a congested LAN environment by measuring the application performance on a 100 Mbps switched Ethernet network and a 1 Gbps switched Ethernet network after a switch hardware upgrade. In another work, Panko (2008b) evaluated the impact of TCP window size on application performance as against the choice of an increased bandwidth. He detailed how increasing the TCP window size from the initial 8 to 65 K was a good solution for a company which initially upgraded its WAN link from a T1 (1.544 Mbit/s) link to a T3 (44.736 Mbit/s).

While upgrading, a WAN link is expensive, optimizing configuration parameters such as window sizes is free. He also proved how LAN performance could be improved by configuring the network into a classified set of VLANs. Panko (2008) proposed the use of redundant links for large WANs. His proposal not only increases performance of the LAN but also implements load balancing.

He recorded significant improvement in both link utilizations (from 92 to 55%) and response times (59% reduction). Although his finding draws additional cost, it is a good trade-off to consider with respect to some WANs. A similar work is done by Joon and Seung-jae (2008). Many proposals have been forwarded as guidelines for campus LAN backbone design. Summarily, five different campus (Cisco, 1999) backbone designs are presented as follows:

Collapsed backbone—small campus design

This consists of two or more layer 3 switches as in the building network. This design lends itself well to the small- to medium-sized campus network or a large building network, but is not recommended for a larger campus network. Scalability is limited primarily by manageability concerns. It is also a consideration that the layer 3 switches in the backbone must maintain address resolution protocol (ARP) entries for every active networked device in the campus. Excessive ARP activity is CPU-intensive and can affect overall backbone performance. From a risk and performance point-of-view, it is desirable to break larger campus networks into several smaller collapsed modules and connect them with a core layer (Robert, 1998).

Full-mesh backbone—small campus design

A full-mesh backbone consists of up to three modules with layer 3 switches linked directly together forming a full-connectivity mesh. The full-mesh design is ideal for connecting two or three modules together. However, as more modules are added, the number of links required to maintain a full-mesh rises as the square of the number of modules. As the number of links increases, the number of subnets and routing peers also grows and the complexity rises. The full-mesh design also makes upgrading bandwidth more difficult. To upgrade one particular module from ‘fast Ethernet links’ to ‘gigabit Ethernet links’, all the other modules must be upgraded at the same time where they mesh together. Therefore, upgrades and changes are required everywhere. This approach is in contrast to using a dedicated layer 2 or 3 core to interconnect the distribution modules (Tony, 2002).

Partial mesh—small campus design

The partial-mesh backbone is similar to the full-mesh backbone with some of the trunks removed. The partial-mesh backbone is appropriate for a small campus where the traffic predominately goes into one centralized server farm module. Place high-capacity trunks from the layer 3 switches in each building directly into the layer 3 switches in the server farm. One minor consideration with the partial-mesh design is that traffic between client modules requires three logical hops through the backbone. In effect, the layer 3 switches at the server-farm side become a collapsed backbone for any client-to-client traffic (Graham, 2010).

Layer 2 switched backbone

The layer 2 switched backbones is appropriate for a larger campus with three or more buildings to be connected. Adding switches in the backbone reduces the number of connections and makes it easier to add additional modules. The backbone is actually a single layer 2 switched domains VLAN with a star topology. A single IP subnet is used in the backbone and each distribution switch routes traffic across the backbone subnet. Because there are no loops, spanning-tree protocol does not put any links in blocking mode and spanning-tree protocol convergence will not affect the backbone. To prevent spanning-tree protocol loops, the links into the backbone should be defined as routed interfaces not as VLAN trunks. It is easy to avoid spanning-tree protocol loops with just two layer 2 switches in the backbone. However, this restriction limits the ultimate scalability of the layer 2 backbone design. Another limitation is that all broadcasts and multicasts flood the backbone. Gigabit EtherChannel can be used to scale bandwidth between backbone switches without introducing a loop (Rich and James, 2008).

Layer 3 switched backbone

The most flexible and scalable campus backbone consists of layer 3 switches. The backbone switches are connected by routed Gigabit Ethernet or Gigabit EtherChannel links. Layer 3 switched backbones have several advantages:

i) Reduced router peering.
ii) Flexible topology with no spanning-tree loops.
iii) Multicast and broadcast control in the backbone.
iv) Scalability to arbitrarily large size.

The main advantage of this design is that each distribution-layer switch maintains two equal-cost paths to every destination network; so recovery from any link failure is fast. This design also provides double the trunking capacity into the backbone (Jerry and Alan, 2009). Taking into consideration the kind of users that are prevalent in this kind of network and the need for constant expansion, we have suggested the hierarchical mode (Cisco, 1999). Implementing a ‘hierarchical design’ in developing the network alone solves a lot of other issues like server centralization, issues of broadcast storms (Cisco, 1999) and load balancing. A 2007 Forrester report states that 51% of all firms consider server centralization a key priority (Jerry and Alan, 2009). However, the use of the fiber optic link as of now compensates for this, but the effect will become apparent when the network expands and when functional data centers and servers are deployed.

University campus network design

The campus network of our study is designed in a hierarchical manner which is a common practice of campus and enterprise networks (Cisco, 2003; Saha and Mukherjee, 1995; Sami et al, 2002). It provides a modular topology of building blocks that allow the network to evolve easily. A hierarchical design avoids the need for a fully-meshed network in which all network nodes are interconnected. The building block components are the access layer, the distribution layer and the core (backbone) layer as shown in Figure 1. The building blocks of modular networks are easy to replicate, redesign and expand. There is no need to redesign the whole network each time a module is added or removed. Distinct building blocks can be put in-service and taken out of-service with little impact on the rest of the network. This capability facilitates troubleshooting, problem isolation and network management (Damianos et al., 2002). In a hierarchical design (Saha et al., 1993), the capacity, features, and functionality of a specific device are optimized for its position in the network and the role that it plays. The number of flows and their associated bandwidth requirements increase as they traverse points

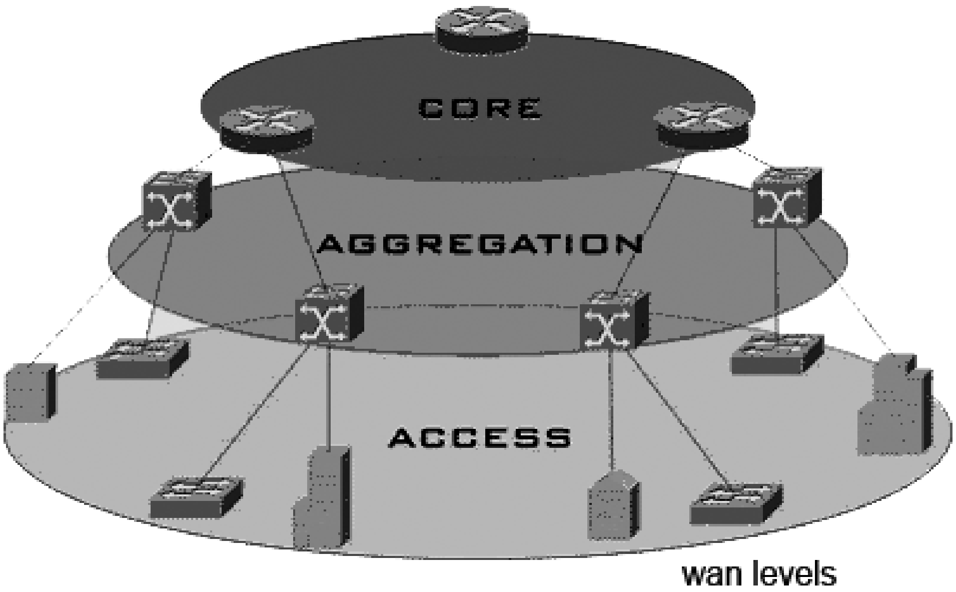


Figure 1. Hierarchical network design model (20).

of aggregation and move up the hierarchy from access to distribution and to core layer (Awerbuch et al., 2000). Functions are distributed at each layer. The core serves as a backbone for the network. The individual building blocks are interconnected using a core layer. The core devices are high capacity routers and expected to be very resilient as most of building blocks depend on it for connectivity.

There are only two routers in this layer for a minimal configuration so as to limit the possibility for operational error. The distribution layer aggregates nodes from the access layer, protecting the core from high-density peering. Additionally, the distribution layer creates a fault boundary providing a logical isolation point in the event of a failure originating in the access layer. Typically there is one distribution node per building and it is deployed as a pair of L3 switches, the distribution layer uses L3 switching for its connectivity to the core of the network and L2 services for its connectivity to the access layer. The access layer is the first point of entry into the network for edge devices and end stations.

THE CASE STUDY

Our case study is the Federal University of Technology Minna Gidan Kwano Campus Area Network, henceforth referred to as FUTGK network is basically a switched network that has for quite some time been faced with a lot of technical problems that have prevented the University community from gaining fully from its inherent benefits. Minimal performances during peak periods are often recorded. This can occur because of a number of reasons; a major one being the network architecture. This has also made some segments record frequent downtimes and thus higher operation costs. The layout of the FUTGK network features the server room and other 'departmental subnets' all connected via a fiber optic link. The overall topology can best be described as a bus topology. At the departmental level (that is blocks), a star topology is being deployed with the aid of a 3560G Cisco switch. The whole network features just a 2620 Cisco router at the server room that routes only to two switches, one at the ICT Center subnet (where the Server is located) and the other at the School of Environmental Technology Complex. Packets are then switched to all other connected subnets.

The CAN consists of six (6) blocks all switched together hosting a LAN of over fifty (50) users each running different application over the network (Figure 2). The core layer which is supposed to be a high-speed switching backbone and should be designed to switch packets as fast as possible should preferably consist of only routers. This layer of the network should not perform any packet manipulation such as access lists and filtering that would slow down the switching of packets.

IMPLEMENTING THE HIERARCHY

In the hierarchical design, we have formed our core layer out of two Cisco 2600 routers and three 3560G Cisco switches. The ports on the switches that connect to the other routers were specially configured only to route packets while other ports maintain their switching functions. By linking the configured port of the Agric Block switch to the Server room router, we have created a hybrid 'collapsed backbone'- small campus network having the main features of the layer 3 switched backbone network at the expense of introducing just one router at the 'engineering block' as shown in Figure 3a and b. The distribution layer which must not necessarily be distinct from all layers is implemented in our design in all local switches. At this layer, the deployed Cisco equipment (3560G) is able to implement all the services necessary at this layer.

Choosing the statistic

To test the performance of the network, it is relevant to collect

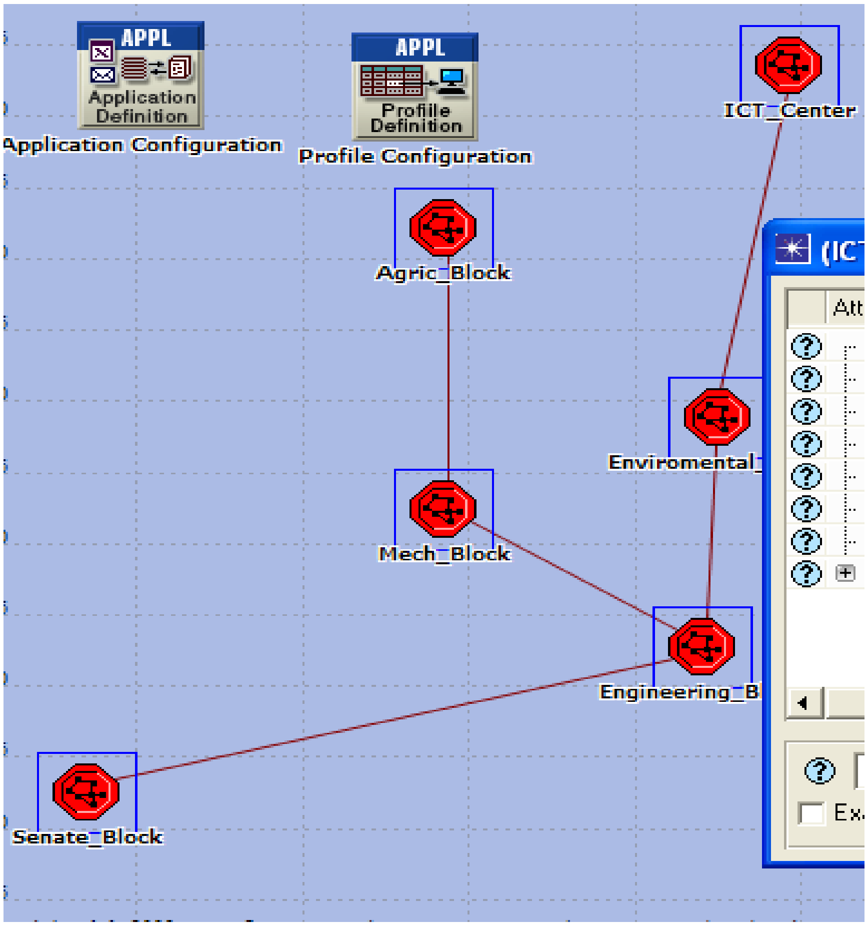


Figure 2. The network before implementing the hierarchy.

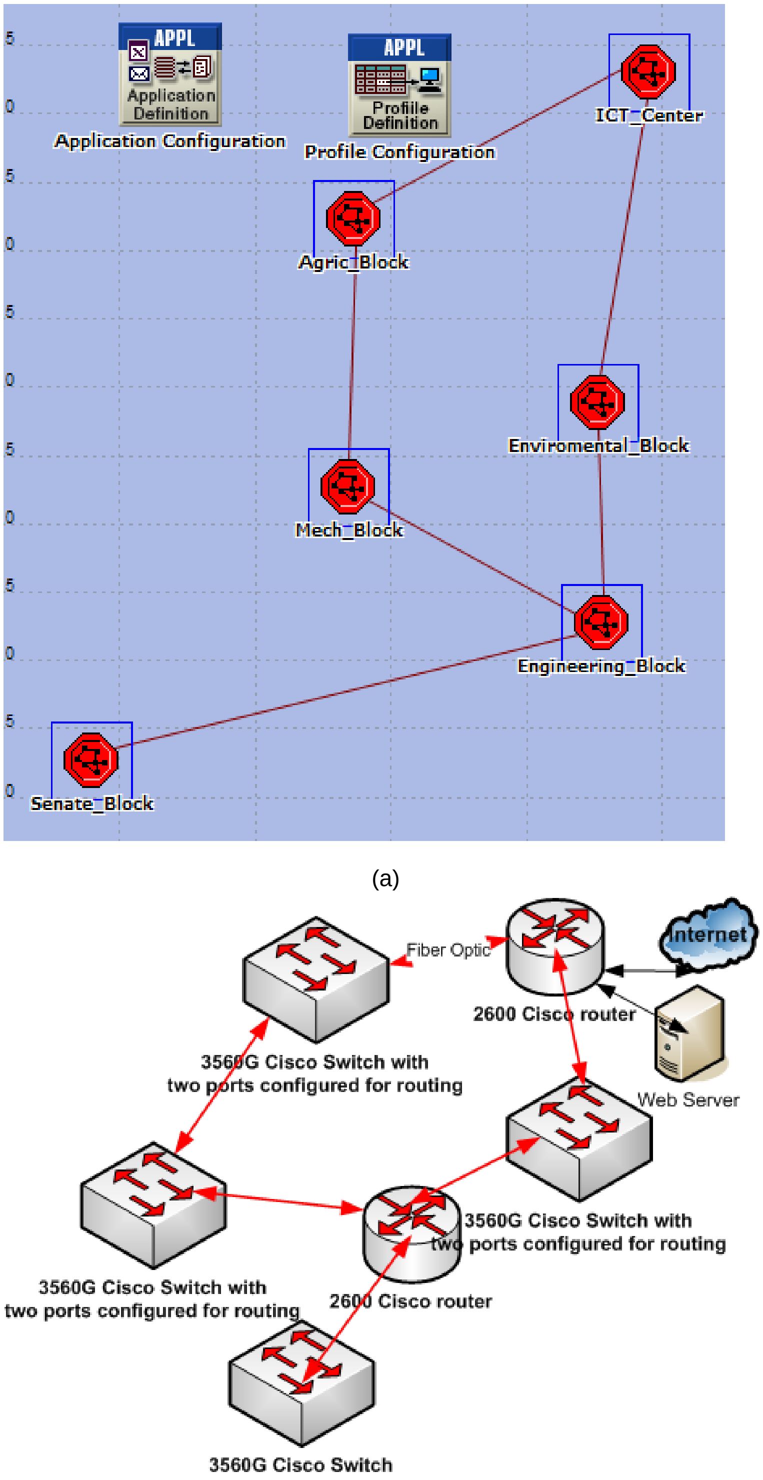
relevant data in particular the 'page response time' which is the time required to retrieve an entire web page that is being accessed over the internet as the benchmark parameter. This statistic was chosen for the following reasons:

i) The only server in the network is the web server and this statistic adequately describes the real performance of the network; and
ii) It is directly related to the network throughput.

The higher the network load and a proper load balancing not done, the higher the likelihood of experiencing an increase in the page response time. Likewise, when there is a frequent occurrence of broadcast storms, more collisions take place and the time it will take to resolve all such collisions directly increases the page response time. The page response time as defined earlier is also a direct reflection of the network throughput. The process of enhancing the network took the following procedure as illustrated in the flowchart (Figure 4).

RESULTS

The network as can be clearly seen comprises of subnets. Each subnet was loaded with 60 systems running full web applications as appropriate to the various departments. Although the actual loading capacity of each subnet at peak periods is estimated to be between 50 to 55. The values gotten for the HTTP page response is an average value taken from all the nodes. After the two simulations of the original network and the enhanced network were carried out, three more subnet with same loading capacity as the other subnets were randomly added to the network based on envisaged network expansion with time. This was done to test the load balancing characteristic of our design. In Figure 5, the blue line shows the graph of the average response time for the original 'network'. The graph presents a steady response of approximately 0.00425 s through the 30 min of the network, running all available service to all deployed clients. After the design was enhanced, the result of the average HTTP page response is reduced as shown by the green line. The response time for the optimized network rises gradually and becomes steady after about 10 min of initializing the 'network'. It becomes steady at a response time of about 0.0038 s. Usually, campus networks like the FUTGK network have the prosperity for expansion over the years. Thus, any optimal design should be able to accommodate such projected growth without a significant drop in its efficiency.



(a)

(b)

Figure 3. The network after implementing the hierarchy (a) and detail implementation of the hierarchy (b).

The red line shows the average HTTP page response for a projected expansion of the FUTGK network. Just as the green line, its time response increases steadily and approximately becomes constant at about 10 min of running the scenario. A slight gradual increase in the time is however still recorded throughout the period which

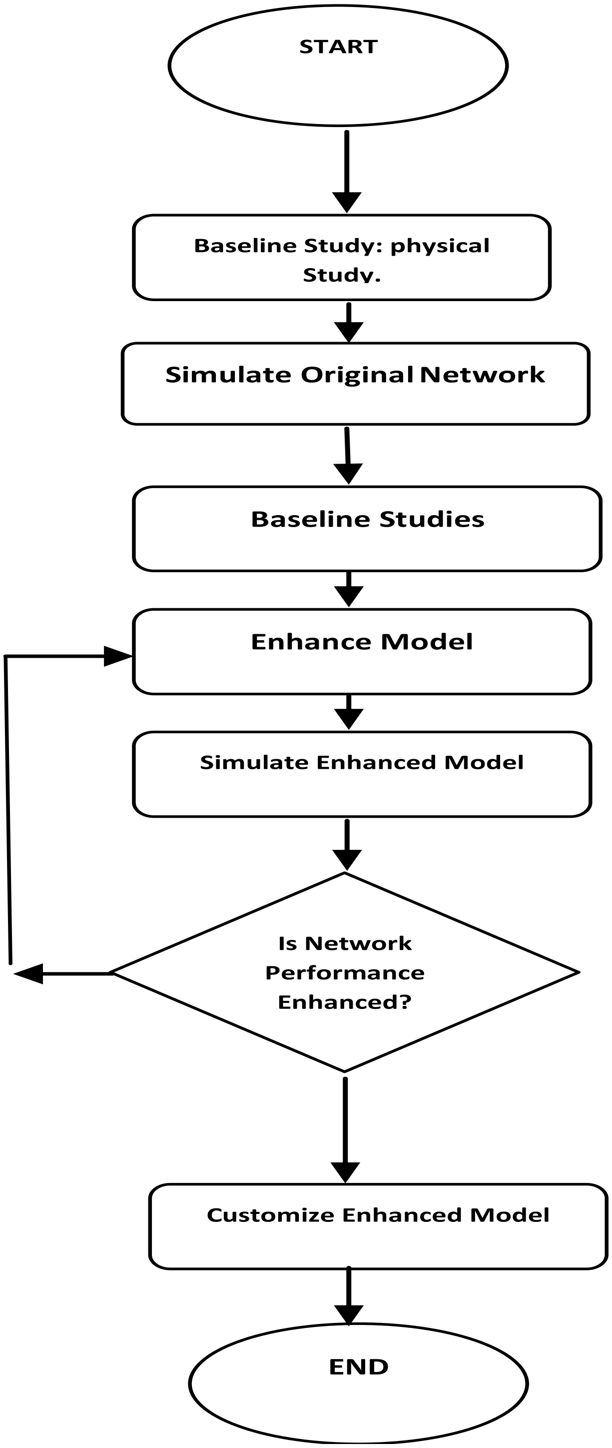


Figure 4. Flowchart of the enhancing process.

ends at about 0.0039 s.

The compared simulation results as shown represent the simulation results obtained after simulating the original FUTGK network, enhancing the design and then expanding the network to observe its effect on the optimized design. From there we derive (for the original network design) that the average time it ideally takes to download and properly view a web page is approximately 0.0042 s (as represented by the blue line). After incorporating 'hierarchy' into the network, thereby introducing load balancing and reducing the possibilities of broadcast storms, we get a page download time of

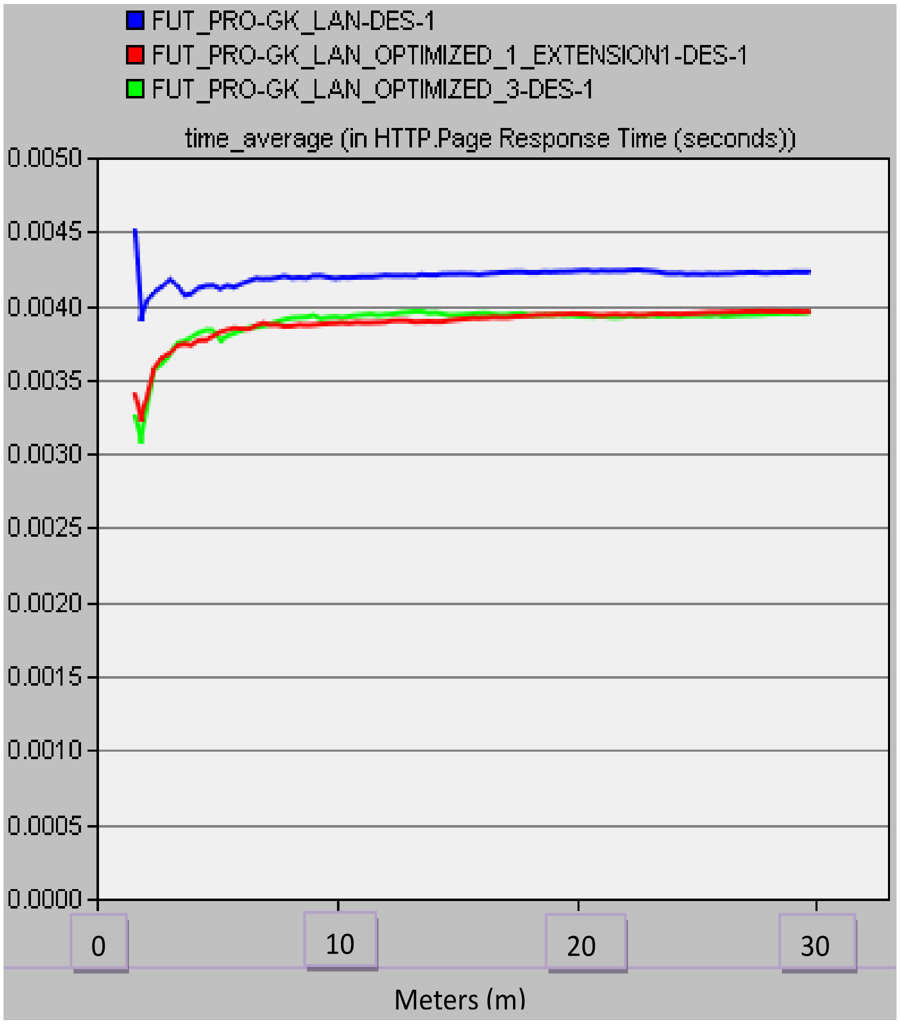


Figure 5. Average page response time of HTTP request. Original vs extension vs enhanced.

approximately 0.0038 s. This represents about 21% improvement in the general network performance. We can thus say that the network performance was enhanced. To test the ability of this design with time (that is expansion of the network with time) as represented in the figure, we get a result not too different from the first result; the difference being just a delay of approximately 0.0001 s over that of the optimized network design.

CONCLUSION

We have compared the download times of the two scenarios: the enhanced and the expanded scenarios. The enhanced scenario gives a download time of approximately 0.0038 s while the extended network gave a time of approximately 0.0039 s which is about 2.63% drop in the network throughput. Our result shows the summary of the aforementioned differences. The architecture deployed for any CAN surely has an effect in the final performance of the network.

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