

## Comparative analysis of LTE backbone transport techniques for efficient broadband penetration in a heterogeneous network morphology

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### Abstract

*In the bid to bring about a solution to the nagging problem associated with the provision of ubiquitous broadband access, Next Generation Network (NGN) popularly referred to as Long Term Evolution (LTE) network with appropriate network integration technique is recommended as solution. Currently, Internet Protocol/Multi-Protocol Label Switching (IP/MPLS) is the transport technique in LTE backbone infrastructure. This technique, however, suffers significantly in the event of failure of IP path resulting in delay and packet loss budgets across the network. The resultant effect is degradation in users quality of service (QoS) experience with real-time services. A competitive alternative is the Internet Protocol/Asynchronous Transfer Mode (IP/ATM). This transport technique provides great dynamism in the allocation of bandwidth and supports varying requests of multimedia connections with diverse QoS requirements. This paper, therefore, seeks to evaluate the performance of these two transport techniques in a bid to establish the extent to which the latter technique ameliorates the aforementioned challenges suffered by the previous technique. Results from the simulation show that the IP/ATM transport scheme is superior to the IP/MPLS scheme in terms of average bandwidth utilization, mean traffic drop and mean traffic delay in the ratio of 9.8, 8.7 and 1.0% respectively.*

**Keywords:** ATM, IoTs, LTE, MBB, MPLS, QoS

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### 1. Introduction

The past decade has been an extraordinary time for the development of information and communication technologies (ICTs). With the advent of the 'mobile miracle', the benefits of ICTs have been brought to the reach of everyone globally. Currently, efforts in research are geared toward ensuring efficient ubiquitous broadband experience [1-3]. Many developed nations have explored the services of mobile broadband services (MBBS) in realizing their current economic growth [4-8]. Nigeria is still at an infant stage in harnessing MBBS for economic development [2, 9]. The benefits of broadband services are enormous they include improved welfare for people through better access to economic opportunities and social welfare. It also has the potential to drive financial institutions through provision of support for mobile banking and mobile money. Broadband internet access has also supported new ways of delivering better healthcare services. It has also improved the productivity level of many of businesses, as it has supported the invention of recent products and services, and has brought about accelerated changes. Broadband penetration has directly impacted on the economy of many developed nations as it has herald the new jobs opportunities either directly or indirectly [10, 11].

In many developing nations, there is a growing demand for mobile broadband internet supported smart-phones. This has also been the major reason for a heightened quest for adequate and efficient broadband access [12, 13]. However, report by the International Telecommunication Union (ITU) in May 2014, on the extent of MBB spread in developing countries has it at 6%. The Nigerian Communications Commission (NCC) has, however, admitted the low penetration and declared in August 2014 strategies it is putting in place to expand MBB penetration rate from the current 6% to about 30% in 2018. According to current findings on the activities of telecom operators, while there are about 45,000 Base stations (BSs) in the country, only 7,000 of them are 4G-enabled (broadband enabled) to provide high-speed Internet to consumers. Analysts consider these 7,000 4G sites grossly inadequate to provide

ubiquitous top-notch Internet services in a country targeting 30% broadband penetration by 2018 [14, 15]. This thus raises the big question “How will a developing country like Nigeria realize the projected 30% MBB penetration rate by 2018 side by side the grossly inadequate LTE enabled BSs”. In literature, many researchers have suggested that an efficient network integration system would help ameliorate this challenge [15].

Next Generation Network (NGN) comes as a remedy to this challenge. The NGN aims at completely reshaping the current model of communication systems and ingress to the Internet. It intend to transform the existing structure of vertically independent, but integrated networks into a horizontal form of networks established on IP. This central platform architecture brings existing networks with varying transport and control technologies into a distinct, coalesce and multi-service structure formed on IP. The implementation of LTE networks gears toward NGNs since it was built toward an all IP core. As such, current LTE backbone infrastructure uses IP/MPLS as its transport techniques [16]. This technique, however, suffers significantly in the event of failure IP path. Thus, resulting in delay and packet loss budgets across the network and resultant degradation in users' quality of service (QoS) experience with services, such as voice, real-time services, and video [1, 9]. This paper, therefore, seeks to carry out a comparative analysis of the performance of IP/MPLS and ATM as LTE backbone transport techniques for the provision of MBBS.

To achieve the specific intent of this work, the rest of this work is ordered as thus: section 2 provides an overview of the current transport techniques in LTE backbone NGN architecture. Section 3 discusses the IP/MPLS and ATM transport algorithms for the adopted converged LTE backbone network architecture. Furthermore, in section 4 we carry out the simulation of the adopted network architecture and transport schemes, and also investigate their performance by subjecting them to voice video, and real-time services. The results obtained from the simulation are analyzed and discussed. Finally, section 5 concludes and makes recommendations for future work.

## 2. Network Convergence for Mobile Broadband Services Experience

The Internet which has evolved over the last few decades from a miniature network connecting a few research center to an enormous global network. Its capacity to carter for a number of useful services to numerous users, has been aided by advances in mobile communication system [1, 3, 17, 18]. Similarly, the capacity, access techniques and also kind of services supported by mobile networks have also evolved as shown in Table 1. Pertinent to point out is that not all mobile networks can provide users with broadband support standing alone, hence, the reason for convergence of networks. Network integration as envisioned for NGN, would cater for the limitation of standalone heterogeneous networks, by providing them with ubiquitous MBB experience [1].

Table 1. Mobile Networks Capacity, Access Techniques and Services

Network	Standard	Core network	Multiple Access Techniques	Carrier Frequency	Maximum Data rate	Maximum throughput per channel (bps/Hz)	Applications Supported
1G	NMT, MPS, Hicap, CDPD, TACS, ETACS	PSTN	FDMA	30KHz	2.4Kbps	0.08	Analog voice
2G	GSM, iDEN, D-MPS	PSTN, packet network	TDMA, CDMA	200KHz	64Kbps	0.32	Digital voice Higher capacity, packetized data
2.5G	EDGE, GPRS	PSTN, packet network	TDMA, CDMA	200KHz	384Kbps	1.9	Integrated high-quality audio, video and data.
3G	WCDMA, CDMA	Packet network	CDMA	1.25MHz	144kbps-2Mbps	1.6	Video conferencing, mobile TV, GPS
4G	LTE, WiMAX	Internet	SC-FDMA, OFDMA,	15MHz	100Mbps - 1Gbps	66.7	Dynamic access to information, HD video streaming, wearable gadget, ubiquitous roaming.

NGN, which is envisioned to transform the present vertically independent, although interconnected networks to a horizontal structure of networks based on IP, would proffer a central structure through the interconnection of several networks with different transport and control technologies. It promises to uniquely, unify multi-service platform [19-21]. It aims at providing ubiquitous next-generation broadband services experience to users not minding their host network. LTE fits in as a backbone network for this future network as it can provide high capacity support for this overlay of networks. It also has the capability to provide broadband capacity with high efficiency, reduced latency improved capacity and seamless mobility management and resource provisioning [9, 19, 22]. IP/MPLS currently serves as backhaul and backbone transport techniques for connecting several end-points in an LTE network. With IP/MPLS, the paths between evolved packet core (EPC) terminal-points are evolving and immensely resistive to failures as they tend to locate a regardless of degree and places where failure have occurred in the network [1, 18, 23].

### 3. IP/MPLS and ATM Transport Networks for LTE Core

The backbone of every communication network is usually a central node (Core) furnished with high capacity to provide communication paths between applications and different sub-networks as shown in Figure 1. The Core, which has a mesh topology and provides any-to-any connectivity as shown in Figure 2, has the ability to handle very high volumes of data at very high speeds from any source to any destination. However, with the coming of the internet, increased demand for bandwidth for most new networks, and the demand for connectivity for all things i.e. Internet of Things (IoT), there has been a great need for improved capacity for the core in terms of efficiency. This is as a result of demand for ubiquitous high-speed connectivity by subscribers. Over time, Internet Protocol (IP) routing, which was software-defined routing and connection-less oriented has sufficed as the transport techniques for core networks. However, it has over time shown unpredictable behavior for large networks with high data volumes. As such IP/MPLS was introduced in addition to IP Routing. IP/MPLS which is connection-oriented made for the classification of incoming packets, their labeling and forwarded.

Today, IP/MPLS is a widely used technology in Core Networks [3, 17]. Similarly, ATM which is a connection-oriented transport technique is also used at the backbones of some public networks. Its ability to dynamically allocate bandwidth, support a variety of traffic classes with changing flow characteristics and scalability in speed make it also an admirable transport technique to adopt for the future core network. This is due to the fact that this core network, would be required to support several other networks, traffics of varying class and the current traffic burden associated with IoT [20, 21]. Hence, there is a need to enhance the overall utilization of network resources in the future backbone network. Also, there is need to furnish Network Engineers with information's on the performance of various transport techniques in different traffic scenario, as this will go a long way in guiding their choice of transport technique to deploy in any point in time. Thus we seek to evaluate the performance of the aforementioned transport techniques. We first develop analytical models for IP/MPLS and IP/ATM and run the simulation to evaluate the performance of these models.

#### 3.1. IP/MPLS Transport Model

The availability base routing algorithm in an IP/MPLS based network as proposed by [24, 25] is thus reviewed. In this model, packet loss and retransmission due to link overload are managed using load balancing. Here, the weight of a given path is normalized using (1):

$$W_k = \frac{P_k}{\sum_{i=1}^n P_i} \quad (1)$$

where

$$P_k = \left( \frac{AHP\_cost(path\ k)}{\sum_{i=1}^n AHP\_cost(path\ i)} \right) \quad (2)$$

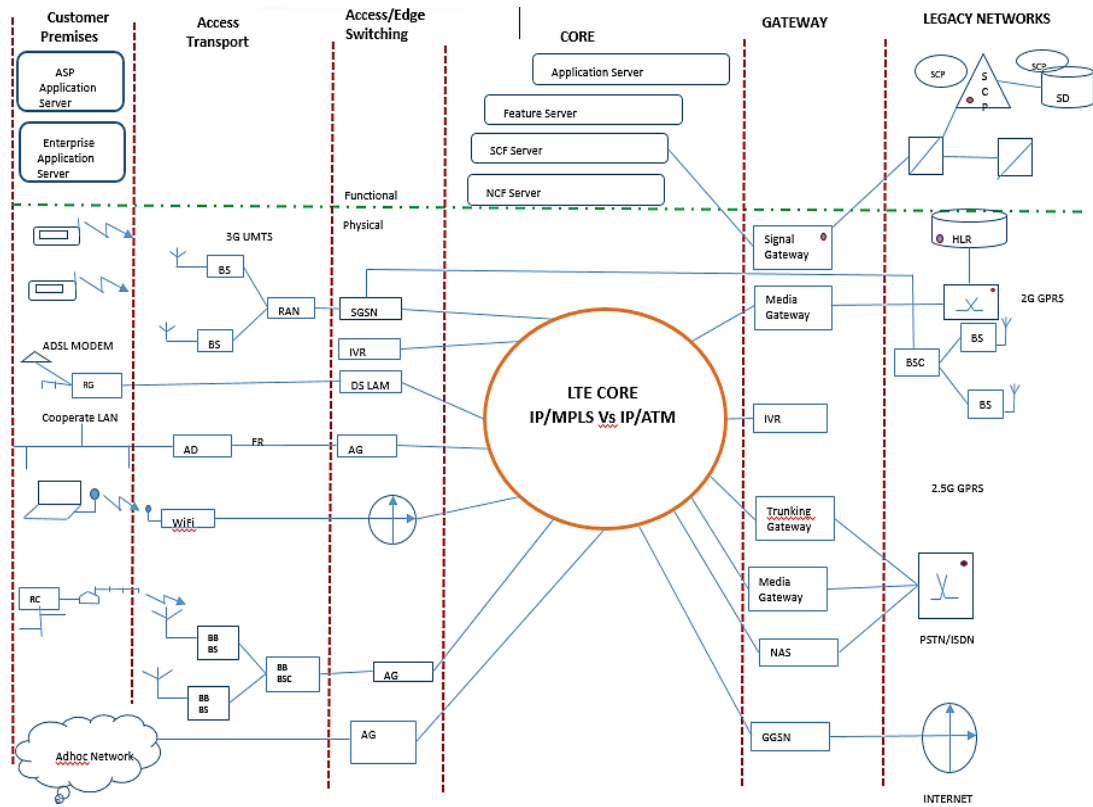


Figure 1. Convergence scenario for a typical LTE as core backbone network [21]

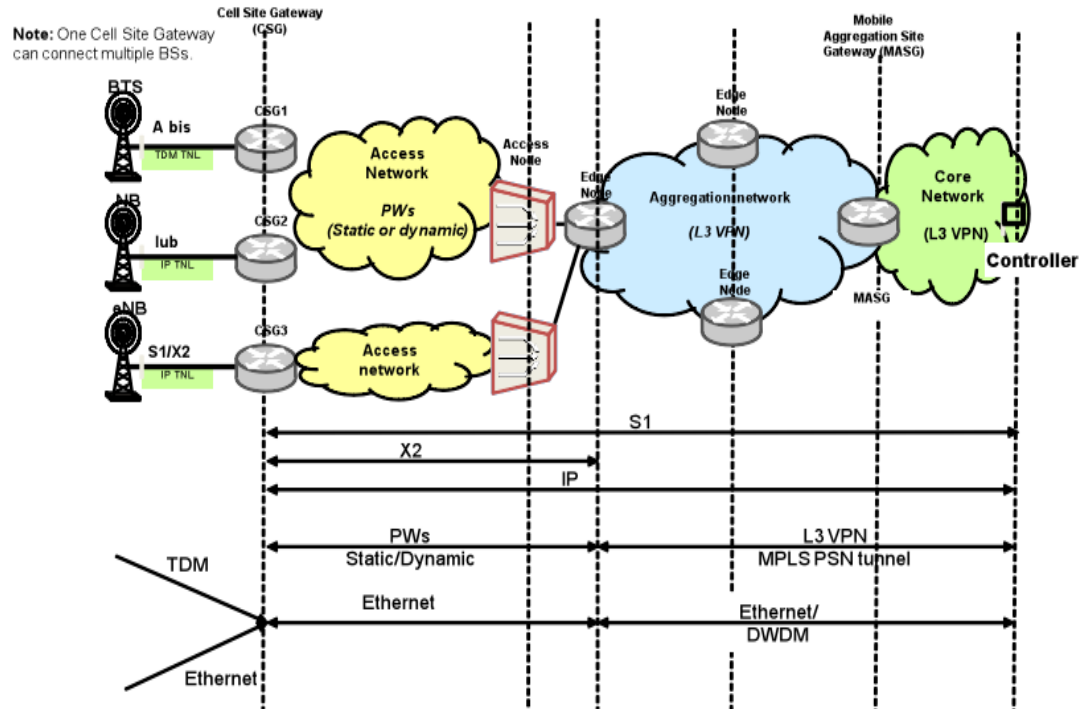


Figure 2. L3VPN backhaul and backbone transport [23]

We define the initialized traffic to each path using (3) where  $T_a$  is the allocated traffic to path  $k$  and is a fraction  $T_g$ , which is the generated traffic by the source.

$$T_a(\text{path } k) = W_k T_g \quad (3)$$

After allocating traffic to selected paths in the network, periodical monitoring is assumed. If the observed difference between chosen paths say:  $W_i$  and  $W_k$  gets greater than set threshold  $d_{wth}$ , the path  $k$  relinquishes some of its traffic  $T_r$  as in (4).

$$T_r(\text{path } k) = \frac{(\text{Avg}(W_i) - (W_k) * T_a(\text{path } k))}{\text{Avg}(W_i)} \quad (4)$$

where

$$\text{Avg}(W_i) = \sum_{i=1}^n \frac{W_i}{n} \text{ and } \text{Avg}(W_i) - (W_k) > d_{wth}$$

This released traffic is shared amongst other paths in the network. If, from each path  $i$  among the set of selected paths, the difference between  $W_j$  and  $\text{Avg}(W_i)$  is greater than zero, then, such paths can get part of  $T_r(\text{path } k)$ . Paths with higher weight gets more of the relinquished traffic. Also, the optimum bandwidth of a path is usually taken into consideration before resource are released, and paths with greater weight receive more from the released traffic.

$$T_i(\text{path } j) = \frac{W_j}{\sum_{i=1}^n W_i} * T_r(\text{path } k) \quad (5)$$

### 3.2. IP/ATM Transport Model

The fluid-flow approximation approach proposed in [12] typically model busy multimedia traffic in an ATM network. This model assumes a constant and continuous arrival and departure process for traffic. The traffic source in this model produces packets at the rate of  $\pi$  per unit time during burst period as expressed by (6):

$$\pi = \frac{1}{\delta} \quad (6)$$

where  $\delta$  is the packet production-time. Similarly, the mean rate of packet generation  $\lambda$ , for a period  $T_s + \tau$  is given as (7).

$$\lambda = \frac{\text{mean packets in a burst}}{T_s + \tau} \quad (7)$$

Similarly, (8) represents the packet generation rate for a busy source:

$$T = \tau * \left( \frac{1}{\rho - 1} \right) \quad (8)$$

where  $\rho$  is known as the burstiness and is expressed as (9).

$$\rho = \left( \frac{\tau}{T_s + \tau} \right) \quad (9)$$

Also, the packet loss rate in the network is given as (10).

$$\text{packet loss rate} = \left( \frac{\text{Number of packets rejected}}{\text{Number of packets through queue} + \text{Number of packets rejected}} \right) \quad (10)$$

The probability of packet loss for a single node  $P_r$  is given as (11):

$$P_r = \psi \exp - (\varphi) \quad (11)$$

where  $\psi$  is usually unity

$$\varphi = \frac{\pi(\mu - \lambda)k}{\tau(\pi - \lambda)(\lambda - \mu)} \quad (12)$$

However, for multiple independent sources  $N$ , the probability of loss  $P_r(N)$  is given as

$$P_r(N) = \Phi * \theta \exp(Z_o * \varepsilon) \tag{13}$$

where

$$\varepsilon = \frac{k}{\tau * \pi}; \Phi = \left[ \frac{N\lambda}{\mu} \right]^N; \theta = \prod_i^{N - \left[ \frac{N}{\pi} \right] - 1} \frac{Z_i}{(Z_i - Z_o)}$$

where  $Z_o$  and  $Z_i$  are eigenvalues with  $Z_o$  being the largest and is expressed as (14).

$$Z_o = \frac{N(\mu - N\lambda)\pi^2}{\mu(\pi - \lambda)(N\pi - \mu)} \tag{14}$$

Similarly,  $Z_i \neq 0$  determined by evaluating the roots of the quadratic expression in (15), with constants:  $A(i)$ ,  $B(i)$ ,  $C(i)$  as in (16)-(18) respectively:

$$A(i)Z^2 + B(i)Z + C(i) = 0 \tag{15}$$

for  $i: 1, 2, 3, \dots, N$ .

$$A(i) \cong \left( \frac{N}{2} - i \right)^2 - \left( \frac{N\pi - 2\mu}{2\pi} \right)^2 \tag{16}$$

$$B(i) \cong 2 \left( \frac{\pi - 2\lambda}{\pi - \lambda} \right)^2 \left( \frac{N}{2} - i \right) - N \left( \frac{\pi}{\pi - \lambda} \right) \left( \frac{N\pi - 2\mu}{2\pi} \right) \tag{17}$$

$$C(i) \cong \left( \frac{\pi}{\pi - \lambda} \right)^2 \left\{ \left( \frac{N}{2} \right)^2 - \left( \frac{N}{2} - 1 \right)^2 \right\} \tag{18}$$

**4. Simulation and Result Analysis**

Typical network work convergence architecture for this analysis is shown in Figure 1. In this architecture, several heterogeneous networks integrated into LTE core as support for broadband services and as their backbone network. An unvarying arrival and continuous service process flow was adopted for the models. Traffics were modeled as Markov Modulated Poisson Process (MMPP) in MATLAB/Simulink environment with set parameters for supported class of traffic as captured in Table 2. This is to account for bustiness of the envisioned future multimedia services to be supported in the networks.

Table 2. Table of simulation Parameters

Parameters	Values for IP/ATM model	Values for IP/MPSL model
Number of MS	20	20
Simulation Time	1000	1000
Link Bandwidth	2Mbps	0.3Mbps 0.7Mbps 1Mbps
Voice source		16 Kbps
VBR video source		16 to 384 Kbps
Data source		256 Kbps
Voice active factor		0.4
Packet arrival		Poisson
Packet generation type		Exponential
Queue type		FIFO

**4.1. Bandwidth Utilization against Traffic Intensity for MPLS and ATM Transport Schemes**

Figure 3 shows the behavior of the network when MPLS and ATM transport schemes were both deployed at the core of the network under the same traffic condition. It is observed from the plot that the ATM transport technique outperforms the MPLS scheme in terms of network bandwidth utilization by an estimated average of 0.098%. This could be attributable to the fact

that the ATM techniques use statistical multiplexing and the size of the cells are fixed as such they tend to use the network resource more than the MPLS based core. Though it is designed to provide efficient service formed on best effort delivery and varying path formation, under high traffic scenario, this network technique suffers causing underutilization of network resource.

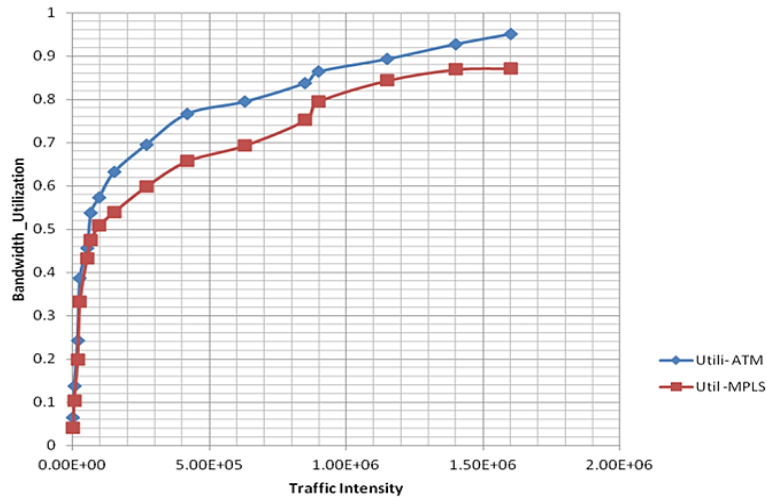


Figure 3. Bandwidth utilization against traffic intensity for MPLS and ATM transport schemes

**4.2. Traffic drop against Traffic Intensity for MPLS and ATM Transport Schemes**

The plot in Figure 4 shows the mean variation in traffic drop experienced in the network when the schemes under investigation were subjected to varying traffic intensity. It is observed from the chat that there is a linear relationship between the traffic intensity and the degree of traffic drop for both transport techniques. However, it is observed that the ATM technique surpasses that of the MPLS by an average of 0.0875%. It is seen that ATM experiences reduced traffic drop when compared to MPLS when both are subjected to same traffic intensity. This could be attributed to the fact that ATM core uses statistical multiplexing techniques in allotting network resource, experiences reduced congestion as such the probability of traffic drop is reduced. However, MPLS even though it uses dynamic path establishment in routing traffic, its core still experiences more congestion relative to the ATM as such it suffers more traffic drop.

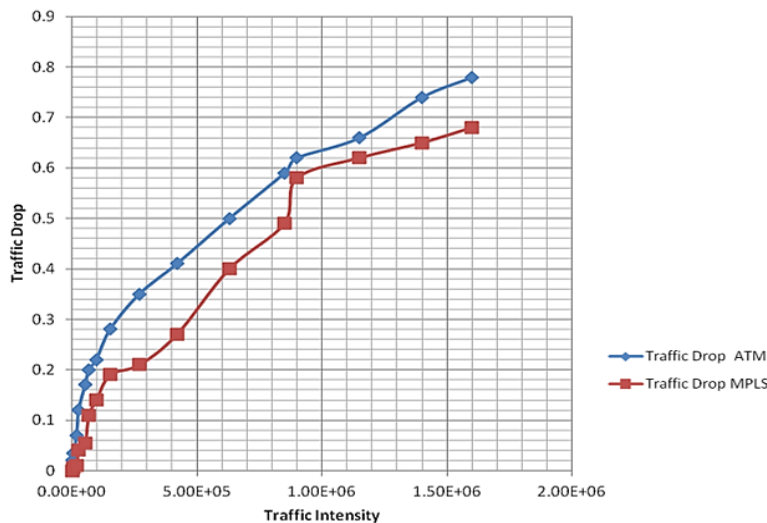


Figure 4. Traffic drop against traffic intensity for MPLS and ATM transport schemes

### 4.3. Average Traffic Delay against Traffic Intensity for MPLS and ATM Transport Schemes

It is observed from the plot in Figure 5, that both techniques have an almost uniform delay pattern for traffic in the network. However, it is seen that the mean delay experienced by traffic in the network when the MPLS transport scheme is deployed at the core is more in the range of  $2.35E-12$ . While that network deploying ATM at the core is in the mean range of  $1.01E-12$ . The abrupt difference in traffic delay for the two schemes could be attributable to the degree of congestion usually associated with the techniques. Haven established that the MPLS scheme experiences more congestion relative to the ATM techniques when both are subjected to traffic intensity of similar magnitude.

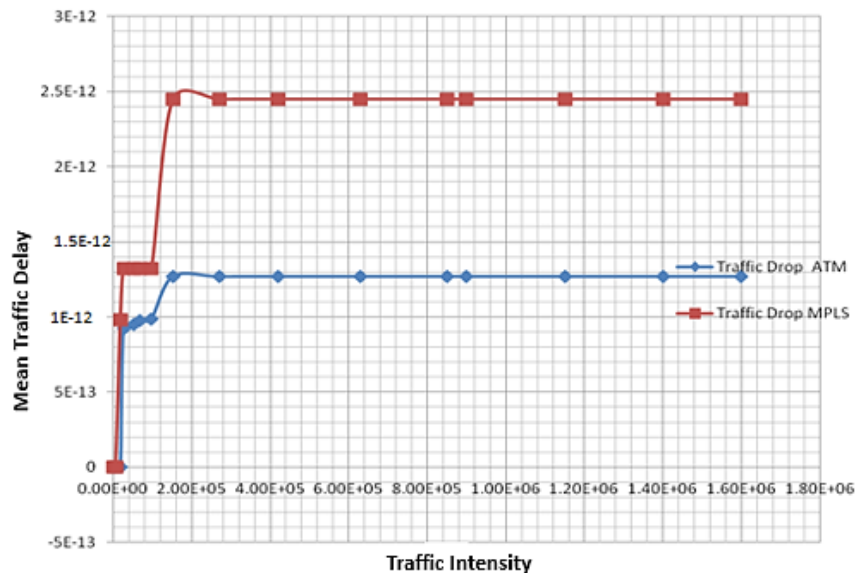


Figure 5. Average Traffic Delay experienced by packets across the network for MPLS and ATM transport schemes

## 5. Conclusion

We have been able to establish in this work that even though IP/MPLS is the current transport technique for core network, ATM offers a highly competitive advantage based on the evaluated metrics. This could be attributable to its ability to dynamically allocate bandwidth, support a broad group of traffic classes with dynamic flow characteristics and scalability in speed. Since the current transport technique deployed at the core is faced challenge of being able to efficiently support several other networks with their heterogeneous traffics class requirement and the current traffic burden associated with IoTs where devices place demand on the network based on the sensitivity of the traffic they generate. Therefore, there is a need to enhance the overall utilization of network resources in the core of future backbone network. Findings from the simulation carried out show that the IP/ATM transport scheme outperforms the IP/MPLS scheme in terms of average bandwidth utilization of the core, mean traffic drop in the network and mean traffic delay experienced by traffic in the network. These were in the in the ratio: 9.8, 8.7 and 1.0% respectively. However, this work fails to consider delay variation (jitter) of different class of traffic across the network. It also did not establish the degree to which each of the techniques under consideration outperform themselves taking into cognizance the individual requirement of packets (sensitivity) in the network. Finally, it is pertinent to note that the need for performance improvement of transport techniques deployed at the core with regards to the characteristic of the traffic they supported by networks, is a key area in recent research.

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