Effect of Backhaul Technologies on 3G Network Performance: A Case Study of Ado-Ekiti

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Abstract — In the past years, when wireless network improvement occurs from 1G/2G to third generation (3G), the rate in the use of real-time traffic oriented applications for voice, video and data increases. Consequently, the bandwidth to be backhauled from the cell site to the mobile switching center increases rapidly. 3G network is most prevalent in Nigeria with wide area of coverage. However, in recent times, poor subscribers' mobile broadband experience is still the major challenge faced by many GSM operators. One of the major causes of this challenge is the use of wrong backhaul for radio access network (RAN). This lead to poor traffic throughput, high packet loss or frame loss at the cell edge. To overcome this challenge, the use of appropriate backhaul technology is crucial. Third Generation Partnership Program (3GPP) recommends the use of either asynchronous transfer mode (ATM) or internet protocol (IP) as the backhaul technologies for its RAN. This paper presents the performance analysis and the comparison of the ATM RAN and IP RAN backhaul technologies using six different 3G sites (with 3G base stations) located at Ado local government area of Ekiti State, Nigeria. The performance of each base station with different backhaul technology was evaluated in term of average maximum throughput per day. The effect of frame loss (for ATM RAN network) and packet loss (for IP RAN network) on traffic throughput were also analyzed. The comparison of the overall result analysis shows that the 3G base stations with IP-based RAN backhaul has better performance than the base station with ATM-based RAN backhaul.

Index Terms — 3G; backhaul technology, base station; frame loss; throughput, packet loss.

I. INTRODUCTION

The number of mobile subscribers has increased drastically in the past years due to improvement in wireless technology for GSM (3G, LTE and LTE-A). This permits the use of real-time traffic oriented applications for voice, video and data to increase. Consequently, the demand for bandwidth has increased rapidly. Mobile operators face strong challenges in the transport of high capacity, high bit rate and increasingly dense data traffic over the internet. As a result of this, several mobile operators are keen to improving network

performance, availability and reliability by catering for congestion, traffic blockage, and traffic drop and improve traffic throughput. A way to achieve this is through the use of appropriate backhaul technology for their 3G networks [1]. Backhaul is a term commonly used to describe the connections between a base station (BS) and radio controller. Fig. 1 shows a backhaul for LTE network. As shown in Fig. 1, a backhaul system connects radio access network (RAN) air interface at the cell sites to the inner core network to ensure network connectivity of the end user (EU) with the mobile networks. The EU refers to the mobile phone users while the eNodeB represents the cell, cell cite or BSs. Each user data is added with other components of the backhaul traffic to estimate the single eNodeB transport provisioning and the aggregate with all other eNodeB's traffic before it connects with the core network.

Fig. 1. A mobile backhaul for LTE network [2].

In cellular network, the traffic from a base station to the base station controller and further to the mobile switching center is carried on the backhaul network. Thus, backhaul network constitutes a significant component of the operational expenses incurred by the cellular operator. The rapidly increase in the use of mobile data services has forced many mobile operators to invest in network infrastructure to meet subscriber's demand. The advent of 3G, broadband wireless technology and the introduction of new data intensive applications increases the traffic carried on the backhaul network [3]-[8]. Nowadays, data traffic requires more bandwidth than voice services on operator networks, which stresses the existing backhaul connection. This further increases the cost that backhaul network contribute to the

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overall operational expenses of a network [9]. More recently, with the introduction of 5G network [10], [11], increase data traffic and quality of service (QoS) based prioritization of traffic will form the key drivers behind the demand for better mobile backhaul network. For these reasons, amongst others, the need to assess and optimize mobile backhaul technologies [12]-[15] is crucial. Prior to this, assessing the performance of the existing backhaul technologies will be of great importance.

Obviously, the data traffic, and the number of subscribers with dynamically changing usage pattern will vary around the world depending on the country's population and access to network. In Nigeria, in spite of the wide area of coverage, poor subscribers' mobile broadband experience is still the major challenge faced by many GSM operators today. One of the major causes of this challenge is the use of wrong backhaul technology for the RAN which has led to poor traffic throughput, high packet loss or frame loss at the cell edge. Therefore, the use of appropriate backhaul technology is crucial. Nevertheless, the Third Generation Partnership Program (3GPP) which is an optimized mobile broadband service, adopts Asynchronous Transfer Mode (ATM) and Internet Protocol (IP), among others, as the two main types of backhaul technologies for its RAN [16]. It is then necessary to access the impact of the backhaul technologies on 3G network performance. The assessment will inform the choice of selection of an appropriate backhaul for 3G network. In this paper, this assessment was conducted for some selected 3G sites with ATM and IP backhaul technology, in Ado Local Government area of Ekiti State, Nigeria. The paper is organized as follows. The next section briefly introduces the mobile backhaul technologies. In Section 3, the research methods is presented while Section 4 presents the discussion and analysis of results. Section 5 concludes the paper.

II. MOBILE BACKHAUL: CONCEPT AND TECHNOLOGY

It has been acknowledged that the use of appropriate backhaul technology is crucial in mobile communication. The 3GPP adopts ATM and IP, among others, as the two main backhaul technologies for its RAN [16]. In this section, a brief discussion on these technologies is provided.

A. Mobile Backhaul

Radio base station is the subscribers' access point to the network. It transmits and receives signals from the mobile station (MS) or user equipment (UE). Backhaul is a way of transmitting signal, which may be voice and data traffic, from the radio base station cell site to a point of the mobile core network. It is a network access point that can be split into two sections: from the Node B (in 3G UMTS networks) or Base Transceiver Station (in 2G GSM/TDMA networks) to an aggregation point; and from the aggregation point to the Radio Network Controller (3G) or Base Station Controller (2G). A third section exist between Mobile Switching Centers (MSCs) and the core network, which is not part of the access network but, rather, the core network, where the fundamentals of backhaul still apply. Aggregation is vital part of the network transport design as it permits the utilization of the transport bandwidth efficiently, and ease network management. Conventionally, aggregation occurs when

traffic from several radio cell sites is concentrated in one location, usually at the controller sites and the MSC. However, as 3G gains momentum and new broadband wireless services increase, the quantity of backhaul links will improve rapidly. Consequently, the upstream aggregation at the front end of the transport network becomes appealing [17].

B. Backhaul Technologies

1. Asynchronous Transfer Mode

The asynchronous Transfer Mode (ATM) is an International Telecommunication Union standards section for cell relay in which information for multiple service types, such as voice, video, or data is transmitted in small, fixed size cells. ATM is connection oriented. It is a transmission protocol that uses a point-to-point network architecture to transports data over virtual channels using 53 bytes long packets, called cells [18]. In ATM, data blocks are broken down into smaller cells which are transmitted individually and possibly through different routes in a way similar to packet switching. It is regarded as one of the fast packet-switching classes called cell relay [19].

Conventionally, the ATM designed to use a statistical time-division multiplexed (TDM), to carry any form of traffic and permits the traffic to be sent asynchronously to the network. As illustrated in Fig. 2, when traffic in the form of cells arrives, these cells are mapped onto the network and are transported to their next destination. When traffic is inaccessible, the network carries empty or idle cells due to the synchronous nature of the network as illustrated in Fig. 3. For ATM, the transfer rate of 25, 155 and 622 Mbps respectively has been reported [18]. Thus, voice, video and data can be transmitted along the same network using the ATM.

Fig. 2. Traffic mapped onto the network as it arrives [19].

Fig. 3. When no cells arrive, idle cells are transported across the link [19].

2. Internet Protocol

The Internet Protocol (IP) is a packet switched protocol used to carry voice, data, video, and multimedia transmission. It permits the transmission of blocks of data (datagram) from the source to destination over an interconnected system of networks [20]. IP imposes few requirements on utilized network technologies. Therefore, IP can only guarantee an earnest attempt to deliver packet. It has been a moving center stage into carrier networking due to its capacity to reach the largest consumer markets [21]. This feature makes it the most preferred networking interface for advanced applications. By utilizing the IP as a network protocol, data is routed based on a network/sub network address. With the help of the routing tables, the location of the user can be tracked, and the datagram or packet routed to that sub network. When a mobile user logs on and seek a dial in to the network, the IP

address is checked against a routing table, thus given appropriate routing.

III. RESEARCH METHODS

A. Research Environment and Measurement Site Selection

As previously indicated, this study was carried out in Ado local government area of Ekiti Ado Ekiti town in Ekiti State, Nigeria. The base station considered are EK0028 (located at GRA), EK0030 (located at Adebayo area), EK0025 (at Ekiti state university Campus), EK0027 (at The Federal Polytechnic Ado Ekiti), EK0026 (at St Fidelis Church Ijigbo) and EK0027B (at Omisanjana area of Ado Ekiti). The location of the base station on the Airtel network transmission tree is shown in Fig. 4.

Fig. 4. Network transmission tree.

It is important to mention that the selected sites have the following features:

- all the sites selected have approximately the same utilization rate;
- all the sites have stable power sources;
- the sites are without any traffic affecting alarm; and
- all the sites have maximum terminal cell capacity.

B. Network Parameters: Hardware Equipment Used

The two major network equipment's at the terminal end of the 3G network from which data for this research are acquired are the node B and the access microwave radio shown in Fig. 5. The access microwave radio (Fig. 5(b)) is also known as mini-link traffic node.

Fig. 5. The network hardware equipment at the 3G terminal end (a) node B (b) mini-link traffic.

Node B is one of the 3G network elements which serves as the subscribers' access point to the network. It handles radio transmission and reception, mobility management and power control. It supports both ATM and IP transmission protocols with RJ-45 interface for E1/T1 (2.048 Mbps/1.55 Mbps channel) or Ethernet connection. The mini-link traffic node, on the other hand, is a complete hybrid microwave radio link with the capability of handling plesiochronous digital hierarchy, synchronous digital hierarchy, Ethernet and ATM in the same node [22]. It has full support for all-IP RAN and up to 600Mbps Ethernet per connection.

C. Network Parameters: Software Used

This section describes the software used for the research data collection. In this study, two software were utilized for data collection. These are business object (BO) and mini-link craft software. The former is used to access performance data from the 3G network database, present and analyse the information in the BO document. It can be used to run reports, view and modify reports, create report prototype for report developers and troubleshoot problematic situation case-by-case. BO was used to access and acquire the data used to evaluate the performance of the BSs under the different backhaul. Each performance management object to be

configuration of the node, transmission channel and accessing the performance data. Fig. 7 shows the packet link configuration interface for IP RAN based backhaul.

D. Performance Metrics

[23]. Maximum throughput is defined as the maximum supported user data throughput. The users' throughput per hour for ATM-based RAN Backhaul and IP-based RAN backhaul for the period of six months were obtained for the six selected Airtel 3G sites in Ado Ekiti town using Ericsson Business Object software. Since IP RAN varies in channel capacity, then the user's throughput per hour was obtained for different channel capacities.

1. Maximum Throughput

In transmission control protocol (TCP), traffic throughput T_t (Mbps) is estimated as:

$$T_i = \frac{1.22S}{R_{TT}\sqrt{g}} \quad (1)$$

where S is the maximum segment size, R_{TT} is the round-trip time, and q is the average packet loss probability. The hourly users throughput which was used to estimate the daily throughput was also obtained. Thus, the user's throughput UT , per day is estimated as:

$$UT = \sum_{i=0}^{24} HT_i \quad (2)$$

where HT is the hourly throughput.

2. Packet Loss Ratio

Packet loss is the difference between packets sent by the source node and received by the destination node. Thus, packet loss ratio is the rate by which packet is lost between the source node (Transmitter) and the destination node (Receiver) [23]. It is an index to determine the congestion rate of the transmission channel. High packet loss causes increased radio resource usage, decreased speech quality and decreased accessibility, thereby impacting the network quality [24]. The data used to evaluate the packet loss ratio in this research work was made available in form of performance managed object counter (Pm Counters) called Streaming control protocol. It is used to monitor the traffic on the transmission channel. The data was collected under two scenarios for IP RAN backhaul. Furthermore, due to variation in its channel capacity, the data was obtained for different channel capacities. The packet loss ratio is thereby estimated as

$$P_{lr} = \frac{100P_l}{P_l + P_r} \quad (3)$$

where P_{lr} denotes the packet loss ratio, P_l is used to represents the total packet dropped, and P_r is the total packet received.

3. Frame Loss Ratio

Frame loss ratio is the ratio of lost frames to total number of sent frame for either the committed or excess traffic streams. It is a performance metric for a specific Class of Services such as Circuit Switched network like ATM RAN. The frame loss ratio F_{lr} used in this research work is evaluated as

$$F_{lr} = \frac{100F_l}{F_l + F_r} \quad (4)$$

where F_l is the performance management object for high speed data lost between the two ends nodes and F_r is the high speed data received by the destination node.

Six 3G sites with different backhaul technologies shown in Fig. 8 is studied. Sites EK0025, EK0026 and EK0030 has the ATM RAN-based backhaul technology while sites EK0028A and EK0027A use the IP RAN-based backhaul. When the transmission channel capacity of the EK0028 and EK0027 was upgraded from 22.4 Mbps to 100.5 Mbps, the resulting 3G sites were EK0028B and EK0027B. Thus both EK0028B

and EK0027B sites use the IP RAN backhaul but with high channel capacity. The performance of the backhaul technology used in these sites was examined using users' average maximum throughput per day, the packet and frame loss ratio as well as the channel capacity. Within the network, the traffic throughput, packet loss ratio and frame loss ratio for the two backhaul technologies under two scenarios of standard channel capacity and upgraded channel capacity was analyzed. At the standard channel capacity, 22.5Mbps is used as minimum required for IP RAN based backhaul and 8.192Mbps as fixed channel capacity for ATM RAN-based backhaul.

Fig. 8. 3G sites under study with backhaul technology.

IV. RESULTS AND DISCUSSIONS

A. User's Maximum Throughput

Fig. 9 represents the users' maximum throughput (in Kbps) for 3G sites with IP RAN based backhaul with minimum channel capacity of 22.4Mbps each, while Figure 10 represents the users' maximum throughput (in Kbps) for 3G sites with ATM RAN based backhaul with maximum fixed channel capacity of 8.192Mbps (4E1's). The figure shows the variability of the user's maximum throughput for each 3G site. The maximum throughput for the sites (as shown in Fig. 9 and Fig. 10) does not have a definite pattern. For instance, site EK0028 has the highest throughput between Oct., 6 and 7 while that of the EK0027 occurs between Oct., 22 and 23. From Fig. 9, the users' average maximum throughput is 2.5Mbps (2500Kbps) for 3G sites with IP RAN based backhaul (Fig. 9) while that of the ATM RAN-based backhaul (Fig. 10) corresponds to 1.4Mbps (1400Kbps). This shows that the throughput offered by site with IP RAN-based backhaul is better than those offered by the ATM RAN-based backhaul.

When the channel capacity of the IP RAN-based backhaul is upgraded, the results of the user's maximum throughput due to the improved channel capacity is shown in Fig. 11 and Fig. 12. These figures show that the user's maximum throughput can be improved by enhancing the channel capacity. In these figures, an improved user's average maximum throughput of 3.817 Mbps is obtained for EK0028 (Fig. 11) and 3.729 Mbps for EK0027 (Fig. 12) respectively, after the channels' capacity is upgraded from 22.4 Mbps to 100.5 Mbps. These results are for the 3G site with IP RAN-based backhaul.

Fig. 9. Users' maximum throughput for 3G sites with IP RAN-based backhaul.

Fig. 10. Users' maximum throughput for 3G sites with ATM RAN-based backhaul.

Fig. 11. Users' maximum throughput for EK0028 after channel capacity upgrading (EK0028B).

Fig. 12. Users' maximum throughput for EK0027 after channel capacity upgrade (EK0027B).

Table I shows the 3G site under studied with their respective average users' throughput. The result shows that 3G sites with IP RAN based backhaul (EK2007, EK2008, EK0027B, and EK002B) has higher throughputs than those of the 3G sites with ATM RAN based backhaul (EK0025, EK0026 and EK0030). A system with higher throughput gives better performance, thus, the result presented clearly show that the 3G sites with IP RAN based backhaul has better performance than those with ATM RAN-based backhaul. It also shows that the performance of 3G sites with IP RAN-based backhaul can be improved by increasing the channel capacity. The graphs presented in subsection 4.1 are representative of the measurement results from the 3G operators in Ado Ekiti town.

TABLE I: 3G SITE UNDER STUDY WITH THEIR RESPECTIVE AVERAGE USERS' MAXIMUM THROUGHPUT

S/N	3G Site	Backhaul Used	User's Average Maximum Throughput (Mbps)
1	EK0025	ATM RAN	1.4
2	EK0026		1.4
3	EK0030		1.4
4	EK0027	IP RAN	2.5
5	EK0028		3.817
6	EK0027B	IP RAN with channel upgrade	2.59
7	EK0028B		3.835

B. Effect of Packet and Frame Loss Ratio on User's Throughput

In this section, the effects of packet loss ratio (PLR) and frame loss ratio (FLR) on the throughput performance of each

backhaul under study is presented. Fig. 13 shows the relationship between the FLR and user throughput for 3G site with ATM RAN-based backhaul while Fig. 14 represents the effect of PLR on the users' throughput for 3G site with IP RAN based backhaul. From Fig. 13, it can be observed that high speed frame loss on 1st, 2nd and 24th of the month causes the users' throughput to dip to as low as 0.48 Mbps, 0.45 Mbps, and 0.5 Mbps, respectively. Aside these few days, the frame loss ratio is lower for the period of observation, which makes the throughput to become higher. In Fig. 14, the impact of the PLR on the user's throughput is also noticed. Although, as compared to Fig. 13, the packet loss ratio is higher for most of the period of observation. In a similar manner to the results presented in Fig. 13, the effect of the PLR on the user's throughput is somewhat the same. The user throughput reduces as the PLR becomes higher. For the period of observation, the rate at which the reduction in the user's throughput takes place is not drastic when compare to Fig. 13. In both figures, it can be deduced that the lower the frame loss or packet loss ratio, the better the user's throughput. Furthermore, in Fig. 14, a large percentage of the days during the period of observation is affected by high packet loss ratio (which reduces the throughput) compare to Fig. 13 where most of the days experience better throughput due to lower FLR. The result shows that both FLR and PLR have impacts on the users' throughput. The result also shows that the throughput value at the peak PLR (1.796Mbps) for IP RAN sites is higher than the average maximum throughput value (1.4Mbps) for ATM RAN sites.

Fig. 13. The relationship between the frame loss ratio and user throughput for ATM RAN-based backhaul site.

Fig. 14. The relationship between the packet loss ratio and user throughput for IP RAN-based backhaul site.

C. Effect of Channel Capacity on Packet Loss Ratio

In a similar manner to the analysis presented on Fig. 11 and Fig. 12, when the transmission channel capacity of the 3G sites with IP RAN-based backhaul was upgraded from 22.4Mbps to 100.5Mbps, its impact on the PLR is shown in Fig. 15 for EK0028B and Fig. 16 for EK0027B. From these

figures, it can be deduced that the PLR was reduced to approximately zero after the channel capacity was increased. This shows that packet loss can be eliminated by providing 3G nodes with a transmission channel with high channel capacity. By this, the overall performance of the 3G network can be improved.

Fig. 15. The packet loss ratio for EK0028 (IP RAN site) after capacity upgrade.

Fig. 16. The packet loss ratio for EK0027B (IP RAN site) after capacity upgrade.

V. CONCLUSION

This paper presents a research study carried out on 3G network with IP RAN and ATM RAN backhaul in Ado Ekiti, South Western Nigeria. Within this network, the traffic throughput, packet loss ratio and frame loss ratio for the two backhaul technologies under two scenarios of standard channel capacity and upgraded channel capacity was analyzed. At the standard channel capacity (22.5 Mbps as minimum required for IP RAN-based backhaul and 8.192 Mbps as fixed channel capacity for ATM RAN-based backhaul), the result shows that IP RAN-based backhaul has a higher users' average maximum throughput (2.5 Mbps) than ATM RAN-based backhaul (1.4 Mbps). Under this scenario, the result also indicates that both PLR and FLR have effects on the users' average maximum throughput. The IP RAN-based backhaul technology exhibits a higher PLR while the ATM RAN-based backhaul technology exhibits a lower FLR. In the case of upgraded channel capacity for IP RAN-based backhaul, the 3G network shows a significant improvement in the user's average maximum throughput and

most importantly, the PLR was minimized to approximately zero level. The overall result shows that 3G sites with IP RAN-based backhaul technology has a better network performance than 3G sites with ATM RAN-based backhaul technology especially when enough channel capacity is provided for its transport network. The authors are optimistic that the results will assist the network operators in selecting appropriate backhaul technology for their networks.

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