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Evaluation of SDCCH and TCCH congestions for Mobile networks in Yenagoa-Southern Nigeria

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Abstract

This work attempts to effectively compare standalone dedicated control channel and traffic control channel congestion rates against industry benchmarks and competitor networks to identify areas for improvement, sets performance targets and establish a relationship between them. Four mobile telecommunication networks operational in Yenagoa – Southern Nigeria were considered. Results obtained shows that 9mobile, Airtel and MTN performed within the regulator's benchmark in most cases, while noting many instances where their performance fell outside the benchmark. The maximum value obtained within the period in view for SDCCH was 3.09% and it was gotten from 9mobile while the minimum value was 0.00% and it was also from 9mobile; conversely for HTTC, The maximum value obtained within the period in view was 2.49% and it was gotten from Globacom while the minimum value obtained was 0.00% and it was from 9mobile and Airtel. For Airtel, 9mobile, Globacom, and MTN, the correlation coefficients between SDCCH and TCCH were 0.13, 0.07, 0.37, and 0.62, respectively. The four networks' positive correlation coefficient values show that, in every scenario, a rise in SDCCH congestion does not result in a corresponding drop in TCCH congestion, and vice versa. As a result, the causes of the different congestions are independent of one another.

Keywords: Standalone Dedicated Channel; Traffic Control Channel; Data; Erlang Formula; Handover Failure Rate; Key Performance Indicator; Mobile Network; Signaling

1. Introduction

Channel congestions is a critical issue in mobile telecommunication networks, particularly in Long-Term Evolution (LTE) networks. Standalone Dedicated Channel (SDCCH) serves as a dedicated control channel for signaling purposes, facilitating various essential functions such as call setup, location updates, SMS delivery, and authentication [1]. The SDCCH is a dedicated signaling channel used primarily for the exchange of control messages between mobile devices (MS) and the Base Transceiver Station (BTS) in Telecommunication networks. It is "standalone" because it is not combined with a traffic channel, allowing it to handle signaling traffic independently [2]. When this channel experiences congestion, it directly impacts the network's ability to handle signaling traffic efficiently, leading to service degradation, call drops, and poor user experience [3].

On the other hand, Traffic Control Channel Congestion Rate (TCCCR) in mobile telecommunication networks refers to the percentage of time during which the control channels within the network experience congestion. Control channels play a crucial role in managing the signaling traffic between mobile devices and the network infrastructure. These channels facilitate tasks such as call setup, handovers, paging, and various other network management functions [4,5]. When the traffic load on these control channels exceeds their capacity, congestion occurs. This congestion can lead to call setup failures, increased call setup times, degraded call quality, and poor overall network performance. TCCCR is an essential metric for assessing the efficiency and effectiveness of the control channel resources within a mobile network [2,6].

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To calculate Standalone Dedicated Control Channel (SDCCH) congestion in mobile telecommunication networks one must understand the utilization of SDCCH channels and determine when the system is overloaded [7]. The simplest approach to calculate congestion is by examining the ratio of the number of busy SDCCH channels to the total number of available SDCCH channels [8,9]. The congestion ratio represents the utilization of SDCCH relative to the total available channels. It is calculated as the ratio of busy channels to total channels:

$$CR = \frac{B}{N} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

B = Number of busy SDCCH channels
N = Total number of SDCCH channels
CR = SDCCH Congestion Ratio (expressed as a percentage)

If the CR value is close to 100%, it indicates that a high proportion of SDCCH are in use which suggests a potential congestion issues. On the other hand, If the CR value consistently exceeds a predefined threshold (e.g., 80-90%), it suggests that the system is overloaded, and measures should be taken to alleviate congestion [6].

Calculating TCCCR involves quantifying the amount of time during which control channels experience congestion relative to the total observation period [3]. The mathematical calculation typically follows a straightforward formula based on the duration of congestion events and the total observation time.

$$TCCCR = \left(\frac{CD}{TOT}\right) \times 100\% \ \ldots\ldots\ldots\ldots\ldots(2)$$

Where :

TCCCR is the Traffic Control Channel Congestion Rate expressed in percentage
CD is the Congestion Duration in the observation period
TOT is the Total Observation Time
High TCCCR values indicate that the control channels within a mobile telecommunication network are experiencing significant congestion [6]. This congestion occurs when the demand for signaling resources exceeds their available capacity, leading to various operational challenges and potential degradation of network performance

2. Causes of Channel Congestion

There are several reasons why telecommunication networks may experience channel congestion, which can result in poorer performance, higher latency, and even possible service interruptions. The following are a few potential reasons:

- High Traffic Volume: Congestion can arise from a network that is overloaded with too many users or data packets being transmitted at once [10]. This often occurs at periods of high usage or during special occasions.
- Insufficient Bandwidth: Congestion may result if the bandwidth allotted is insufficient to manage the data load. Inadequate network planning or unforeseen spikes in data demand could be the cause of this.
- Network Topology and Design Issues: Bottlenecks can be brought about by ineffective network design, which includes things like incorrect routing paths or insufficient node interconnects. Congestion may worsen if network resources are not positioned optimally [11].
- Hardware Restrictions: Base stations, switches, and routers are examples of network equipment with limited processing power. Congestion may arise if these devices are used excessively.
- Software Limitations: Network management protocols and software may not be able to handle high traffic volumes or effectively manage network resources, which can cause congestion.
- Propagation Delays: When buffers fill up, delays in signal transmission caused by distance, especially in satellite communications or long-haul links, can result in brief congestion [12].
- Interference and Noise: Retransmissions and an increase in traffic load are caused by electromagnetic interference and noise, which deteriorates signal quality and adds to congestion.
- Network Attacks: Malicious activities, such as denial-of-service (DoS) attacks, have the ability to overwhelm networks with erroneous traffic, leading to congestion and a decline in the quality of services provided [13].

- Natural Disasters and Hardware Failures: Situations like these can cause traffic patterns to be disrupted, which can cause sudden spikes in network load as traffic is rerouted through links that are still operational[14] .
- Content Popularity and Viral Events: Unexpected increases in data demand, brought on by the release of viral content or other popular content, can suddenly overwhelm network resources.
- Misconfigured Network Settings: Improper protocol execution or incorrect network device settings can result in ineffective traffic management and congestion.
- Overlapping Cells in Wireless Networks: In certain cell towers, overlapping coverage areas in mobile networks can result in interference and handoff problems [15].
- Improper management of Quality of Service (QoS): Inadequate QoS regulations may result in an unequal allocation of network resources, whereby high-priority traffic might not receive the required bandwidth, thereby creating congestion for both high-priority and regular traffic.
- User Behavior: Modifications in user behavior can greatly raise data traffic and cause congestion, such as an increase in the streaming of videos or the downloading of large files.

3. Previous Related Studies

Due to the extensive array of services available to consumers, mobile phones have become increasingly important. This has resulted to a situation where users have multiple lines with one or more network providers, which has added to the congestion problem [16]. Fast, dependable, and readily available infrastructure is correspondingly needed given the exponential growth in the number of user devices [7, 17]. Still, there are a lot of technical issues that need to be resolved before the various parts of this infrastructure can function as intended. While satisfying subscribers is the primary objective of Mobile Network Operators (MNOs), as stated by [18], the telephone system is not designed to support simultaneous connections from all subscribers. It would be extremely costly to provide enough resources in a telecommunications system to handle all of the traffic that could be offered [19]. The exchanges' expensive equipment forces subscribers to share resources. This means that there may occasionally be issues with telecommunications systems. According to [10] increased Handover Failure Rate (HOFR) and inadequate network availability both within the communities and even when relocating were the main causes of the poor QoS. [11] in their studies stated that the Call Setup Success Rate, Call Setup Failure Rate (CSFR), Handover Failure Rate and Standalone Dedicated Control Channel (SDCCH) congestion and Traffic Control Channel congestion were the most important Key Performance Indicators (KPIs) used in ascertaining the efficiency of GSM network in terms of the quality of services rendered. The two most significant channel congestions are the Standalone Dedicated Control Channel (SDCCH) congestion rate and Traffic Control Channel congestion; however, since there is no standard way to measure these parameter, different operators may use different approaches. The real challenge lies in successfully optimizing the BTS coverage area in addition to providing better service [12,13]. According to [20] most networks issues arise from growing subscriber numbers and changing environmental conditions because of subscriber mobility and the intricacy of radio wave propagation. With the evolution of the network, RF optimization is an ongoing process that is necessary. Using the resources that are currently available, RF optimization is done to increase network performance. SDCCH channels can experience congestion, just like any other resource in a network, when demand for them surpasses capacity [21]. Channel congestion is determined by keeping an eye on and examining a number of technical network parameters. To maximize resource use and reduce congestion, dynamic channel allocation based on traffic demand is necessary. Based on current traffic conditions, network components like Base Station Controllers (BSCs) and Mobile Switching Centers (MSCs) dynamically modify the number of channels allotted to various cells [16]. The purpose of load balancing techniques is to reduce congestion on certain channels by redistributing traffic among nearby cells or sectors [17]. To more evenly distribute signaling load throughout the network, this may entail modifying traffic routing policies, handover thresholds, or cell parameters [22]. Expanding capacity might be required in situations where congestion occurs as a result of an increase in signal traffic. To boost signaling capacity, this can entail expanding the number of channels, improving network hardware, or improving cell configurations. Based on traffic patterns and service demands, sophisticated optimization algorithms like Erlang-B and Erlang-C are used to forecast SDCCH requirements [23]. These algorithms assist in figuring out the ideal number of SDCCH required to minimize congestion and meet service quality goals.

4. Mathematical Techniques Used in Resolving Standalone Dedicated Control Channel (Sdcch) Congestion

Many mathematical ideas and methods are used to resolve standalone dedicated control channel (SDCCH) congestion in mobile telecommunications networks. These methods are divided into five sections, which are as follows:

- Traffic Modeling: This plays a crucial role in resolving standalone dedicated control channel (SDCCH) congestion in mobile telecommunications networks. By accurately modeling the traffic behavior, network operators can anticipate demand, dimension the network appropriately, and implement effective congestion management strategies [6]. Traffic modeling involves the use of

a. Erlang B Formula: The formula is commonly used to calculate the probability of blocking in a system with a fixed number of channels and a Poisson arrival process. It can be expressed mathematically as:

$$P_b = \frac{\frac{A^N}{N!}}{\sum_{n=0}^{N} \frac{A^n}{n!}} \quad \text{.....................(3)}$$

Where P_b is the probability of blocking

A is the offered traffic (measured in Erlangs)

N is the number of channels

b. Erlang C Formula: The formula is used to calculate the probability of delay (queueing) in a system where blocked calls are queued and wait for service. It's particularly useful for modeling situations where blocked calls may retry after a certain period. The formula is more complex than Erlang B but takes into account queuing delay, it is expressed mathematically as:

$$P_w = \frac{\frac{A^N}{N!}\frac{N}{N-A}}{\left(\sum_{i=0}^{N-1}\frac{A^i}{i!}\right)+\frac{A^N}{N!}\frac{N}{N-A}} \text{........ (4)}$$

Where

P_w is probability of delay when the customer waits to connect with a support agent, P>0
A is total traffic (traffic intensity)of the call center in Erlangs
N is the number of available call center resources/agents.
According to [24], Several assumptions are made by the Erlang C formula, including: A Poisson arrival process (number of events over a specified period of time) is followed by the customer requests. There are a lot of clients, The performance of the system as a whole is hardly affected by the actions of a single customer. Every client uses the system on their own, apart from one another. There is an exponential distribution in service times. Clients never give up on a support request while it's being handled by an agent, All missed calls are just postponed rather than abandoned. A support representative works solely with one client for the allotted time. There are fewer support resources overall than there are clients. Customers exceeds the number of agents by at least ten times.

Customer requests that are not independent or that are prompted by a common event—such as phoning a help line after a natural disaster—do not function with the Erlang C formula [24]. Furthermore, the formula typically yields satisfactory outcomes only when the customer base exceeds the agent count by a factor of ten.

- Dimensioning and Capacity Planning: These are critical techniques in resolving standalone dedicated control channel (SDCCH) congestion in mobile telecommunications networks. These processes involve determining the appropriate number of resources needed to handle the expected traffic load efficiently while meeting quality of service (QoS) requirements [25]. Basically two methods used which are:
    - Erlang Capacity Tables: These tables enable quick estimation of needed resources based on anticipated traffic loads by providing pre-calculated values for various combinations of offered traffic and number of channels.
    - Traffic Engineering Algorithms: Different algorithms, like the aforementioned Erlang-B or Erlang-C formulas, or more advanced optimization methods, can be employed to dimension the network.
- Call Admission Control (CAC): This is the technique or procedure used to control voice traffic, particularly in Voice over Internet Protocol (VoIP) and wireless mobile networks. In voice communications networks, call admission control can also be used to guarantee or maintain a specific level of audio quality, or to maintain a specific level of performance in Internet nodes and servers that handle VoIP traffic. The majority of CAC algorithms regulate the total amount of bandwidth that is used, the total number of calls, or the total number of packets or data bits that pass a given point in a given amount of time [26]. A new call may be prevented from joining the network until at least one existing call ends if a predetermined limit is reached or exceeded. Another

approach is to control calls based on predetermined parameters, like priority descriptors. This technique blocks new calls from joining the network only when they would overwhelm the Central Processing Unit's (CPU) capabilities on a specific computer or server [27].

- Load Balancing: The process of dividing network traffic evenly among a pool of resources to support an application is known as load balancing. Millions of users must be processed concurrently by modern applications, and each user must receive accurate text, videos, images, and other data quickly and reliably [28]. It is basically divided into two segments:
    - Traffic Distribution Algorithms: In order to balance the load on SDCCH channels, mathematical algorithms can analyze traffic patterns across various cells or sectors and dynamically redistribute traffic.
    - Cell Breathing: This is a technique that dynamically expands or contracts a cell's coverage area in response to traffic load. This effectively reroutes traffic among nearby cells to relieve congestion.
- Optimization Techniques: These are techniques or algorithms that are used to find the solution to specific problem. The procedure consists of finding the combination of design variable values that results in the best objective function value, while satisfying all the equality, inequality and side constraints. Here it is basically of two segments:
    - Integer Linear Programming (ILP): This models can be formulated to optimize the allocation of SDCCHs while satisfying constraints such as capacity limits and QoS requirements
    - Gradient Descent Algorithms: These algorithms can iteratively adjust parameters such as channel allocation or admission thresholds to minimize congestion based on feedback from network performance metrics [29].

5. Mathematical Techniques Used In Resolving Traffic Control Channel (Tcch) Congestion

Resolving Traffic Control Channel Congestion in mobile networks often involves the application of various mathematical techniques to analyze network behavior, optimize resource allocation, and mitigate congestion. These methods are as follows:

- Queuing Theory: This is a mathematical framework used to model the behavior of queues or waiting lines in systems where entities arrive, wait for service, and then depart. In the context of mobile networks, queuing theory can be applied to model the behavior of signaling message queues at various network elements, such as base stations, mobile switching centers, and signaling gateways [12]. By analyzing queuing models, network operators can identify congestion hotspots, predict performance metrics such as call setup times and queuing delays, and optimize network parameters to minimize congestion [28]. The queuing theory equation, also known as Little's Law, relates the average number of items in a queue (L), the average rate at which items arrive (λ), and the average time spent in the system (W). It is expressed as

$$L = \lambda \times W \qquad \text{.................} (5)$$

- Optimization Theory: This theory involves the formulation and solution of mathematical optimization problems to find the best possible solution given certain constraints and objectives. In the context of congestion management, optimization techniques can be used to allocate network resources, such as radio spectrum, bandwidth, and processing capacity, in an optimal manner to minimize congestion and maximize network performance [30]. Techniques such as linear programming, integer programming, and convex optimization can be applied to optimize resource allocation, routing, and scheduling in mobile networks.
- Network Flow Analysis: This involves studying the flow of entities, such as data packets or signaling messages, through a network topology to analyze performance metrics such as throughput, delay, and congestion [30]. Mathematical techniques such as network flow algorithms (e.g., Ford-Fulkerson algorithm, shortest path algorithms) and network equilibrium models (e.g., Wardrop equilibrium) can be applied to analyze traffic flow patterns, identify bottlenecks, and optimize routing strategies to alleviate congestion in mobile networks.
- Stochastic Modeling: This involves the use of probabilistic models to represent uncertain or random phenomena in systems. In the context of mobile networks, stochastic models can be used to capture the random nature of user behavior, traffic arrivals, and channel conditions [31]. Techniques such as Markov chains, stochastic processes, and queuing networks can be applied to model and analyze the dynamic behavior of signaling traffic, predict congestion events, and design congestion control mechanisms that adapt to changing network conditions.
- Game Theory: This theory provides a mathematical framework for analyzing strategic interactions between multiple decision-makers or players in a system. In the context of congestion management, game theory can be applied to model the interactions between competing users or network operators vying for limited network

resources. Techniques such as non-cooperative game theory, evolutionary game theory, and mechanism design can be used to study congestion pricing mechanisms, resource allocation strategies, and incentive mechanisms that encourage cooperation and discourage selfish behavior to mitigate congestion in mobile networks [32].

- Machine Learning and Data Analytics: This technique can be used to analyze large volumes of network data, identify congestion patterns, and predict congestion events in real-time. Techniques such as supervised learning, unsupervised learning, and reinforcement learning can be applied to develop predictive models, anomaly detection algorithms, and congestion management strategies that adapt to changing network conditions and user behavior

6. Material and methods

This study examines the SDCCH and TCCH congestion of four mobile network providers in Yenagoa, Bayelsa State - Nigeria and conducts comparative assessments to determine which network has the best SDCCH and TCCH congestion rates. A correlation analysis is also done to ascertain how SDCCH relates with TCCH. Cellular networks analyzed include MTN, Airtel, Globacom, and 9mobile. Materials used are

- Manager M2000 File Transfer Protocol (FTP): This distributed network file system standardizes file access and management through the use of an OSI application Layer 7 protocol. It defines and unifies, into a single protocol, standards for both file transfer and remote file access. It served as a tool for network data collection.
- Microsoft (MS) Excel tool box: This was use to perform the correlation analysis and to plot the data values to make the investigation's findings easier to comprehend and interpret.

This study employs a methodology that entails a systematic approach to gather data from the Management Centers of the four operational mobile networks. The steps are as follows:

- Data Analysis: Primary data from all the Base Station Controllers (BSCs) in the State served as the basis for the analysis. Following that, a data set analysis was done to look into the QoS performance for every place under study. The Manager M2000 File Transfer Protocol was deployed at the Network Management Switching (NMS) to pull data from the network.
- Determination of Average SDCCH and TCCH Congestion Rate: The average variable used in this study was previously assessed using the unprocessed data set that was acquired from the NMS. Using the MS-Excel toolbox, the monthly total average of SDCCH and TCCH congestion was determined on a daily basis for a month.
- Evaluation of Data Values: The QoS results from this paper's study were evaluated through performance analysis, with SDCCH and TCCH congestion serving as an index. For every one of the four network operators under examination, the performance index values were plotted on graphs from January, 2015 through December, 2021. The benchmark set by the Nigerian Communication Commission (NCC) was used to compare these measured values.

Table 1 SDCCH and TCCH Congestion Rate Benchmarks in Nigeria

KPI	Benchmark Value
SDCCH	$\leq 0.2\%$
TCCH	$\leq 2\%$

7. Result Analysis

SDCCH's effects on TCCR were investigated. Plotting of graphs and statistical analysis (regression and correlation) were done. Regression analysis was utilized to create a prediction model between the parameters, and the correlation between CSSR and DCR was carried out to establish a relationship between both parameters. As shown in Figures 1 through 4, the TCCH were the dependent variables and the SDCCH were the independent variables in each plotted graph. As indicated in Tables 2 through 8, the SDCCH and TCCH data used in this study cover the period of 84 months, from January 2015 to December 2021.

Table 2 2015 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	9mobile	Globacom	MTN	Airtel	9mobile	Globacom	MTN
Jan'15	0.03	0.98	0.08	0.04	0.03	0.28	1.52	0.21
Feb'15	0.04	0	0.07	0.1	0.08	0.38	1.76	0.27
Mar'15	0.1	0.01	0.17	0.13	0.1	0.26	1.5	0.32
Apr'15	0.06	0.02	0.15	0.12	0.1	0.17	1.92	0.27
May'15	0.03	0.98	0.05	0.1	0.04	0.17	0.29	0.27
Jun'15	0.03	0.07	0.01	0.11	0.05	0.2	0.33	0.29
Jul'15	0.04	0.05	0.02	0.14	0.07	0.27	0.29	0.24
Aug'15	0.02	0.04	0.01	0.07	0.07	0.21	0.24	0.29
Sep'15	0.03	0.01	0.01	0.04	0.07	0.06	0.22	0.26
Oct'15	0.04	0	0.58	0.07	0.04	0.05	0.26	0.29
Nov'15	0.04	0.03	0.79	0.15	0.04	0.12	0.24	0.33
Dec'15	0.15	0.07	1.19	0.16	0.05	0.12	1.62	0.37

Table 3 2016 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	9mobile	Globacom	MTN	Airtel	9mobile	Globacom	MTN
Jan'16	0.04	0.04	1.8	0.16	0.08	0.07	1.04	0.28
Feb'16	0.03	0.12	1.71	0.26	0.07	0.3	1.02	0.5
Mar'16	0.07	0	0.07	0.23	0.03	0.01	0.91	0.45
Apr'16	0.07	0.02	0.53	0.29	0.03	0.04	1.05	0.51
May'16	0.05	0.02	0.52	0.1	0.02	0.02	0.86	0.43
Jun'16	0.07	0	0.19	0.1	0.01	0.08	1.5	0.59
Jul'16	0.08	0.01	0.1	0.13	0.03	0.09	0.47	0.54
Aug'16	0.3	0.01	0.08	0.06	0.1	0.1	0.2	0.15
Sep'16	0.06	0.01	0.03	0.12	0.03	0.01	0.02	0.46
Oct'16	0.05	0.01	0.12	0.13	0.02	0.01	0.03	0.42
Nov'16	0.02	0.01	0.04	0.05	0.02	0.02	0.01	0.45
Dec'16	0.04	0.02	0.07	0.09	0.02	0	0.02	0.45

Table 4 2017 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	9mobile	Globacom	MTN	Airtel	9mobile	Globacom	MTN
Jan'17	0.03	0.01	0.09	0.1	0.03	0	0.03	0.31
Feb'17	0.04	0.03	0.14	0.13	0.04	0.01	0.06	0.33
Mar'17	0.04	0.02	0.1	0.13	0.03	0.01	0.08	0.33
Apr'17	0.03	0.01	0.14	0.14	0.05	0	0.07	0.42
May'17	0.03	0.04	0.15	0.23	0.04	0	0.12	0.35
Jun'17	0.05	0.02	0.05	0.12	0.05	0.02	0.1	0.33
Jul'17	0.04	0.01	0.02	0.12	0.03	0.01	0.06	0.51
Aug'17	0.05	0	0.04	0.11	0.04	0.01	0.06	0.13
Sep'17	0.09	0.01	0.02	0.04	0.03	0	0.06	0.1
Oct'17	0.04	0.01	0.07	0.08	0.02	0	0.05	0.2
Nov'17	0.06	0.02	0.1	0.14	0.03	0.01	0.15	0.16
Dec'17	0.09	0.03	0.1	0.11	0.03	0	0.15	0.17

Table 5 2018 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	9mobile	Globacom	MTN	Airtel	9mobile	Globacom	MTN
Jan'18	0.16	0.02	0.25	0.12	0.04	0.05	0.25	0.17
Feb'18	0.03	0.02	0.48	0.07	0.02	0.01	0.18	0.23
Mar'18	0.04	0.02	1.02	0.21	0.02	0.02	0.1	0.31
Apr'18	0.05	0.01	0.1	0.21	0.06	0	0.2	0.37
May'18	0.03	0.03	0.13	0.12	0.04	0.01	0.14	0.33
Jun'18	0.02	0.04	0.13	0.2	0.02	0	0.22	0.35
Jul'18	0.09	0.02	0.09	0.1	0.02	0	0.11	0.3
Aug'18	0.1	0.01	0.06	0.24	0.03	0	0.58	0.11
Sep'18	0.1	0	0.21	0.13	0.03	0	2.49	0.32
Oct'18	0.04	0.02	0.14	0.16	0.32	0	0.45	0.22
Nov'18	0.05	0.01	0.32	0.09	0.04	0	0.49	0.15
Dec'18	0.08	0.08	0.52	0.16	0.04	0	0.5	0.18

Table 6 2019 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	**9mobile**	**Globacom**	**MTN**	**Airtel**	**9mobile**	**Globacom**	**MTN**
Jan'19	0.09	0.05	0.4	0.12	0.03	0	0.48	0.08
Feb'19	0.04	0.06	0.18	0.05	0.04	0	0.16	0.11
Mar'19	0.08	0.02	0.06	0.03	0.04	0	0.14	0.13
Apr'19	0.14	0	0.03	0.05	0.01	0	0.16	0.14
May'19	0.41	0.01	0.12	0.09	0.03	0	0.18	0.74
Jun'19	0.27	0.01	0.12	0.02	0.04	0	0.16	0.11
Jul'19	0.15	0.01	0.03	0.04	0.17	0	0.14	0.26
Aug'19	0.04	0.01	0.05	0.04	0.04	0	0.15	0.16
Sep'19	0.06	0.02	0.2	0.02	0.04	0	0.23	0.16
Oct'19	0.04	0.01	0.09	0.02	0.01	0	0.16	0.07
Nov'19	0.04	0.04	0.12	0.03	0.1	0	0.17	0.07
Dec'19	0.03	0.05	0.12	0.02	0.05	0	0.15	0.05

Table 7 2020 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	**9mobile**	**Globacom**	**MTN**	**Airtel**	**9mobile**	**Globacom**	**MTN**
Jan'20	0.11	0.15	0.18	0.12	0.39	0.17	0.49	0.23
Feb'20	0.09	0.16	0.18	0.11	1.25	0.13	0.47	0.23
Mar'20	0.1	0.13	0.18	0.12	0.61	0.11	0.48	0.24
Apr'20	0.09	0.12	0.17	0.11	0.52	0.14	0.39	0.18
May'20	0.09	0.13	0.18	0.09	0.35	0.12	0.42	0.19
Jun'20	0.01	0.01	0.06	0.02	0.07	0	0.08	0.05
Jul'20	0.02	0.02	0.02	0.01	0.03	0.01	0.05	0.05
Aug'20	0.01	0.02	0.01	0.02	0.03	0	0.04	0.05
Sep'20	0.04	0.05	0.01	0.01	0.02	0	0.03	0.03
Oct'20	0.08	0.03	0.01	0.03	0.01	0	0.06	0.09
Nov'20	0.09	0	0.02	0.03	0.02	0	0.06	0.08
Dec'20	0.06	0.05	0.05	0.02	0.02	0	0.06	0.08

Table 8 2021 SDCCH and TCCH Congestion Rates

MONTH	SDCCH				TCCH			
	Airtel	**9mobile**	**Globacom**	**MTN**	**Airtel**	**9mobile**	**Globacom**	**MTN**
Jan'21	0.04	0.03	0.03	0.04	0	0	0.05	0.07
Feb'21	0.06	0.07	0.09	0.02	0.01	0.01	0.12	0.04
Mar'21	0.01	0.4	0.03	0.04	0.01	0.01	0.05	0.05
Apr'21	0.02	0.14	0.03	0.05	0.01	0	0.05	0.06
May'21	0.02	0.14	0.03	0.05	0.01	0	0.05	0.06
Jun'21	0.05	0.19	0.05	0.02	0.01	0.01	0.06	0.03
Jul'21	0.01	0.16	0.01	0.01	0.01	0.02	0.04	0.02
Aug'21	0.01	0.07	0.05	0.02	0.01	0.01	0.05	0.05
Sep'21	0.15	3.09	0.03	0.02	0.02	0	0.09	0.04
Oct'21	0.02	0.44	0.1	0.02	0	0	0.07	0.04
Nov'21	0.02	0.27	0.14	0.03	0	0.04	0.15	0.07
Dec'21	0.01	1.16	0.14	0.1	0	0.03	0.16	0.07

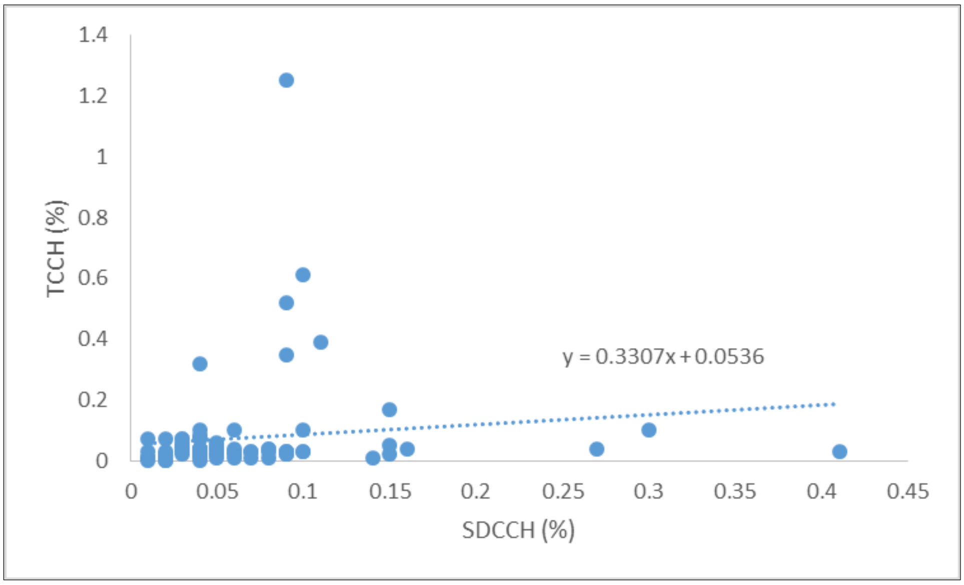

Figure 1 Graph of TCCH against SDCCH for Airtel network

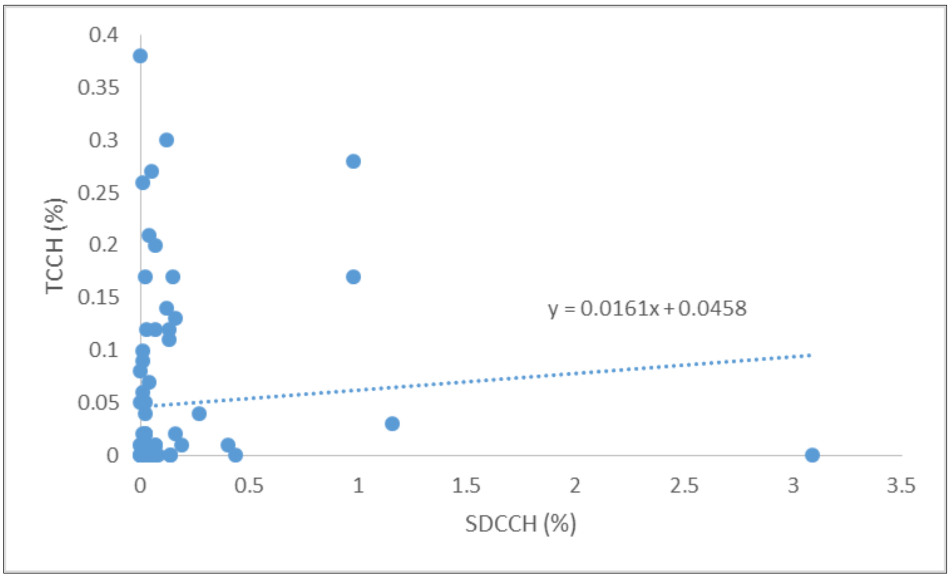

Figure 2 Graph of TCCH against SDCCH for 9mobile network

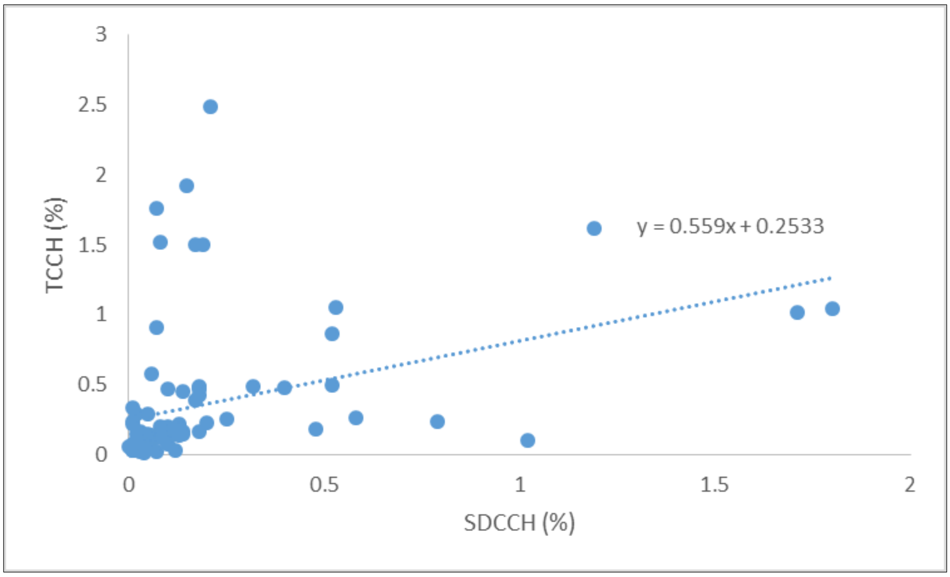

Figure 3 Graph of TCCH against SDCCH for Globacom network

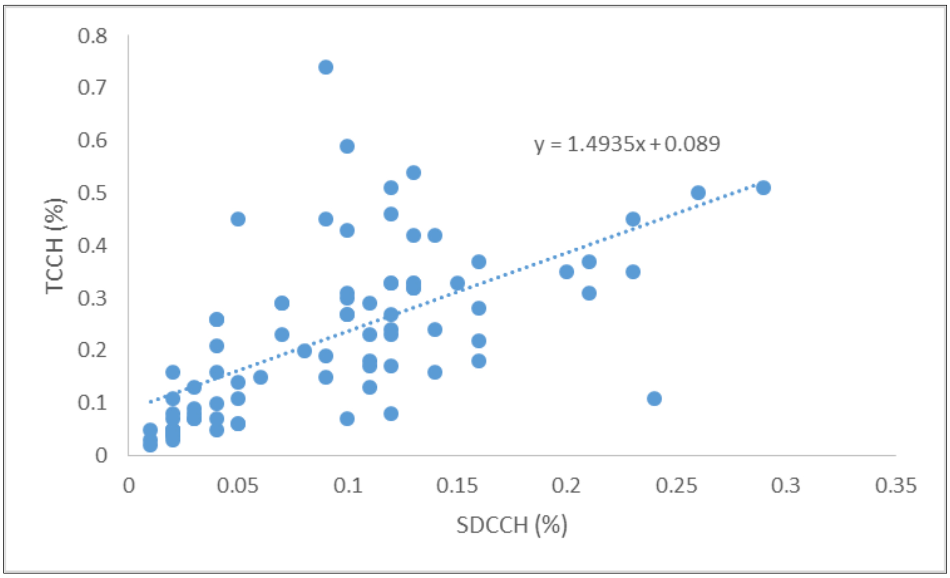

Figure 4 Graph of TCCH against SDCCH for MTN network

8. Conclusion

This investigation addresses In addition to determining performance targets and areas for improvement, the analysis compares SDCCH and TCCH congestion rates to industry benchmarks and competitor networks. It also establishes the relationship between SDCCH and TCCH for the four mobile networks that operate in Yenagoa, Southern Nigeria. The Nigeria Communication Commission's benchmark values were met by the four networks according to the data collected, but there is still opportunity for improvement as some of the networks experienced periods when their performance fell short of the benchmark. Throughout the study period (2015–2021), 9mobile's data outperformed that of the other four networks for SDCCH. Throughout the review period, MTN and Airtel's data exhibited minimal variations and were consistently well within the benchmark. Globacom's data was highly variable and occasionally deviated from the benchmark; these inconsistencies necessitate improvement if high standards of quality of service and customer satisfaction are to be maintained. During the seven-year period under review, 9mobile recorded the highest SDCCH Congestion Rate of 3.09% in September 2021. Conversely, the lowest recorded value of 0.00% occurred seven times during the same period: in February and October 2015, July 2016, August 2017, September 2018, April 2019, and November 2020. Conversely, during the study period (2015–2021), data from 9mobile outperformed data from the other four networks for TCCH. Airtel's data varied very little during the review period and were consistently well within the benchmark. Wide variations and instances of data falling short of the benchmark were present in the Globacom and MTN data, indicating the need for improvement to sustain high customer satisfaction and good quality of service. The lowest recorded value of TCCCR was 0.00%, which happened multiple times during the review period of seven years. The highest recorded value of TCCCR was 2.49%, which occurred in September 2018 for Globacom. For Airtel, 9mobile, Globacom, and MTN, the correlation coefficients between SDCCH and TCCH were 0.13, 0.07, 0.37, and 0.62, respectively. The four networks' positive correlation coefficient values show that, in every scenario, a rise in SDCCH congestion does not result in a corresponding drop in TCCH congestion, and vice versa. As a result, the causes of the different congestions are independent of one another.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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