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Congestion Control Mechanism on Transport Layer Protocol: The Application of Terahertz Frequency

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ABSTRACT

Due to the increasing population, there is a demand for new technologies that require nanotechnology. As a result, rapid increase in congestion will be experienced in the transport layer protocol. The transport layer protocol serves as a vehicle to transmit data from one layer to the next. Nanotechnology uses extremely small components in the region of 1×10^{-9} or smaller. Moreover, with the new viruses or pandemics already detected like Ibola, Coronavirus, Monkeypox, etc. new technologies that will transmit data from the body of a patient to healthcare practitioners will be required and during this period, there will be a large amount of data transferred from one device to the other, and this will increase congestion in the network. The usage of social media, i.e., WhatsApp, Facebook, Twitter, Instagram, TikTok, etc., has also increased significantly, contributing to congestion in the wireless network. The use of wires to connect two or more devices is becoming obsolete as the world is moving towards the next industrial revolution. One of the Modelers that are used in wireless systems in local area networks is known as Optimized Network Engineering Tool (OPNET) 14.5. This simulation method is used in this paper to conclude. This paper also suggests further research that needs to be undertaken.

1. INTRODUCTION

Significant potential development has increased in the data communication, high-resolution imaging, etc. Data short transmission distance due to absorption by the atmosphere and free space path loss is still an issue [1]. This is overcome by improving the gain of the antenna to cater for the losses. The one solution is to shape terahertz wavefront thereby controlling the direction of the beam and characteristics of the wavefront to meet the application requirements of the terahertz system [1]. Nanotechnology controls materials at a very small scale and the approach has transformed the way the society live unnoticed. Nanotechnology materials are used to fields such as construction, healthcare systems and agriculture. There are currently many research studies that are being undertaken on the subject, i.e., nanotechnology [2]. The two main transport layer protocols of the Open System Interconnection (OSI) are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). The transport layer protocol provides an end-to-end connection between two layers, which serves as a communication link. TCP is more reliable than UDP due to its flow and congestion control mechanisms [3]. These flow control and congestion mechanisms function according to end-to-end information obtainable from Acknowledgement (ACK) packets as received from sender [3]. Various applications migrate to wireless networks as opposed to wired networks. Therefore, focus should be on the design of a congestion control algorithm that will be suitable for wireless networks, which will overcome unfavourable conditions like atmospheric conditions, thick walls, mobility, etc. [3]. The study reveals that mechanisms like link level approach, TCP protocol boosters, split connection approach, and many more as applied in wireless networks have been studied but the disadvantage is that these mechanisms require additional functionalities in their intermediate nodes [3]. This paper focuses on the TCP congestion control mechanism in the transport layer protocol by varying frequencies from lower frequencies to higher frequencies in the terahertz band. The rest of this paper covers the literature survey, methodology used, experiments demonstrated through OPNET simulation method, findings and conclusions.

The articles [4-6] suggest that the terahertz band should be considered as a band that enables the transmission of very high data rates. This terahertz band transmission of data rates happens in the sixth-generation networks between 0.1 and 10 THz bandwidth for communications and sensing features. The research reveals that sources of THz above 1 THz have recently been developed. However, they cannot utilize wireless communication and also cannot be directly connected. In such a frequency, optical photo mixing is used to develop THz wave, thereby mixing two offset laser frequencies [7]. The bandwidth of a communication system should be improved to provide 40-100 Gigabits per second (Gbps) data rate for the indoor and 100 Gbps data rate for outdoor communication [7]. In this survey [8] the two ways of improving data rate are as follow: (a) increase the communication system's bandwidth, and (b) increase the operating frequency such that communication systems collect high data rate to the target customers, with the narrow bandwidth.

The wireless communication system gets highly congested as the growth in data traffic occurs. The study reveals that terahertz frequency band is seen as a future to overcome the congestion in the communication network to beyond fifth generation (5G). Research studies indicate that the frequencies below terahertz have been fully utilized and there is no space to accommodate the increasing usage of data that causes too much congestion in the transport layer protocol. This congestion continues to grow due to an increase in population and new technology usage that makes use of network systems. A need to pursue research studies to come up with solutions to overcome congestion in the transport layer protocol has increased. This paper provides a detailed literature survey on the importance of THz band in wireless communication in trying to overcome congestion. It is predicted that technology network that currently exists will be inadequate in the near future (10 to 20 years to come) since this network was designed to cater for gradual future increase of population. The pandemic outbreak called Covid 19 (also known as Coronavirus) has resulted in an increase in the usage of nanotechnology. In South Africa alone, the total number of corona virus cases was sitting at 26,976 as of the 15th of December 2021 [9]. This increases the total number of patients admitted to various hospitals. Furthermore, there is an extreme increase of data traffic in wireless communication due to the shift in the manner in which organizations, individuals, etc. share and consume the information. Due to this increase, wireless communication of very high speed is a necessity to overcome the current and future demand [10]. This has led to a drastic increased data traffic due to different increase in nanotechnology in the healthcare centers. A bottom-up perspective suggests that it is necessary to develop a new transport layer solution to overcome congestion of the network [10].

2. LITERATURE REVIEW

2.1 Terahertz (THz) nano-communication

The paper [10] mentions different nano communication paradigms i.e., electromagnetic, acoustic, mechanical, and molecular communication. The same paper [10] also defines each nano communication as follow: molecular nano communication is responsible releasing molecules into a propagation medium through a transmission device; acoustic nano communication transmits information from the transmitter to the receiver by making use of variations of pressure in the solid medium as well as fluid medium. The authors reveal that mechanical nano communication makes use of nanorobots for information carrier exchange; and electromagnetic nano communication makes use of electromagnetic waves as information carriers. It further states that electromagnetic nano communication is suitable for several propagation media like in-body nano communication, free-space nano communication and on-chip nano communication [10]. Graphene propagation of Surface Plasmon Polariton (SPP) in the terahertz frequency band and electromagnetic nano communication is in the position to provide miniaturization in the THz band frequencies as required by nano communication. Antenna can be integrated directly in nano communication devices through graphene due to its compatibility with complementary metal oxide semiconductor field effect (CMOS) manufacturing process [10].

2.2 Nano-material

The article [11] indicates that nanomaterial have extremely small size and therefore wiring number of nanomaterials is impossible and also the transceiver existing in the market cannot be used in these nanodevices. The paper [12], defines the nanomaterials as those materials with magnitudes of nanoscale, while nanotechnology is the nanoscience application. There are different uses of nanotechnology, and they include sectors such as manufacturing, healthcare systems, agri-food and information and communication technologies [12]. Carbon Nanotubes (CNT) and Graphene Nanoribbon (GNR) are the two derivatives of graphene that are suitable for the purpose [11].

Nano-machines are devices that are embedded in communication systems. The sizes of these nano-machines range from 10 to 100 μm^2. They are meant for communication, sensing, local actuation and plain computation purposes. When nano-machines are connected together, they form nano-networks. These nano-networks deliver drugs in the healthcare environment, monitor health of a patient, and detect biological or chemical attacks in the environment of nanoscale and nano-machines. Through nano-machines networking, these can execute macro-scale objectives and can function over a wider area. Nano-networks enable the broadcasting of information between nano-machines in the wide area and also enables collaboration amongst nano-nodes like data receiving, activation, etc. [11]. As mentioned, and defined under THz nano-communication, the four methods used in nanoscale are acoustic, electromagnetic, chemical or molecular and nanomechanical communications [11]. The article [11] reveals that molecular and electromagnetic communications are the most popular methods used for nano-networking. Biological systems like cells and nano-materials form part of the materials that is used to form nano-machines. The production of the nano-machines is based on the three methods, namely, bio-inspired, bottom-up and top-down methods. Bio-inspired method covers the integration of nano-machines into a complex system and is mainly applicable in a living cell. Some of the biological nano-machines found in the living cells are nano-actuators, control units, nano-biosensors and biological data storing components. Bio-inspired method pertains to the application in molecular signalling, which looks into the communication between the living cells to achieve mutual goal. In the case of bottom-up method, molecules are organised as molecular building blocks to form nano-machines, whereas in the case of top-down method, electron beam like lithography are employed [11]. The nanomaterials are of a very small size with one side being equal to 100 nm or even smaller. These materials can take a variety of dimensions, i.e., one, two, or three dimensions [13]. These dimensions are available in single or fused or agglomerated forms with different types of shapes such as tubular, spherical and irregular shapes.

2.3 Nano-sensors

In the paper [11], the nano-sensors are small in size, responsible for sensing, and actuation and they consist of the following components:

- **Sensing unit** – made of graphene, CNTs and GNRs derivatives for sensing purposes.
- **Actuation unit** – the two types of actuators are physical and chemical where physical nanoactuators are responsible for creating a change in the electrical properties, while chemical nanoactuators are responsible for interacting with the nanoparticles, electromagnetic fields and heat.
- **Power unit** – built in power nanobatteries are used as power supply in case where nano sensors are placed in an inaccessible location, which makes it impossible to charge. Those self-power devices are used for conversion of one form of energy into electrical energy.
- **Processing unit** – these are nano processors made from graphene transistors where graphene promotes free and easy flow of electron to cater for fast switching devices. Since the nano sensors are very small, the number of transistors embedded in the nano processor are restricted.
- **Storage unit** – each bit on a single atom gets stored in nano memories by nanomaterial and new technologies.
- **Communication unit** – the usage of a reduced sized (a few hundreds of nanometres) antenna requires extremely high frequency in THz band, which is an issue with electromagnetic communication that will cause high attenuation. A nano-antenna made of graphene is a suitable option since a 1 μm long graphene nano-antenna is capable of producing the range of 1-10 THz band.
- **Electromagnetic nano transceiver** – as the frequency of the incoming wave matches the resonance of the nanotube, the vibration of a nanotube tunes the wave frequency so that the nanotube receives the signal.

There are different types of nano-sensors. Below are different types of sensors and their applications [11]:

- **Physical nano-sensors** – are mainly used for measuring quantities like pressure, mass, force, displacement, or distance.
- **Chemical nano-sensors** – these used for measuring quantities like molecular composition, gas concentration, etc.
- **Biological nano-sensors** – antibody interaction, DNA interaction and cellular communication are biological processes that can be monitored by these types of sensors. The properties of physical nano-sensors change when protein and other chemical composition are attached to the nanotubes, when a specific antigen is attached to an antibody that located on the nanotube, and when a single-stranded DNA is attached to another DNA chain.

The architecture of electromagnetic wireless nano-networks has different components and they are as follow [11]:

- **Nano-nodes** – nano-nodes are used for computation purposes and can only communicate over a very short distance.
- **Nano-routers** – nano-routers are used to combine the data that comes from nano-sensors and are capable to issue command for directing the performance of nano-nodes.
- **Nano-micro interface** – is responsible for combining the data that comes from nano-routers and pass it to microscale device and from microscale device back to the nano-routers.
- **Gateway** – gateway is responsible for controlling nano-sensor network remotely.

2.4 Technologies used in THz

The THz employs systems of different technologies for realization of wireless telecommunication system and those are (a) terahertz solid state superheterodyne receiver, (b) terahertz modulators, (c) terahertz channel model, (d) terahertz channel estimation, (e) terahertz beamforming and (f) terahertz beam tracking [13]. The article [14] explains the technologies as briefly discussed below:

- **THz solid state superheterodyne receiver** – this is a receiving system for the hot use in THz band. The circuits of these kinds of receivers normally contain frequency conversion, generation of signal and amplification. These receivers are not widely used as there are only a few countries that make use of solid-state superheterodyne receivers [13].
- **THz modulators** – these modulators are widely and commonly used in THz system. Semiconductors and metamaterials technologies were discovered to found to be more suitable in dynamic THz functional devices. Different types of modulators that have been discovered are (a) THz Amplitude Modulator, and (b) THz Phase Modulator [13].
- **THz amplitude modulator** – the laboratory in the United States of America proposed artificial micro structured THz wave modulator grounded around Schottky diode principle where the modulator is being driven by controlling the carrier concentration at the gap for the split ring resonator (SRR) ring. The depth of modulation for the SRR is 50%. The carriers produced by photon in the semiconductors is changed by photo-doping of these semiconductors. The same principle is applicable to THz modulation by electric injection or depletion of charge carriers [13]. Later, the researchers at one of the universities at the United States demonstrated an experiment where the metal ring holes are positioned on a single layer of graphene to obtain 50% modulation depth thereby injecting gate voltage. A year later, researchers of the Nanyang Technology University demonstrated a single-chip integrated device of graphene and THz quantum cascade lasers, and this produced the modulation depth ranging from 94% to 100%. A year later, researchers of the University of Maryland demonstrated a covered graphene sheets on the surface of a passive silicon dielectric waveguide. The highest depth of modulation obtained exceeded 90% with the applied voltage [13].
- **THz phase modulator** – Recently, the researchers suggested a ring-dumbbell composite resonator housed inside vanadium dioxide nanostructures in order to attain large phase shift. In the ring-dumbbell composite resonator, experimented was the hybrid mode with enhanced resonant intensity couples by LC resonance and dipole resonance. The control of the resonant intensity of the mode is by applying the photo-induced phase transition characteristics of vanadium dioxide and this produces a large phase shift in the incident THz wave. The results of this dynamic experiment reveal that controlling the power of the external laser is capable to attain phase shift to the value of 130 degrees close to 0.6 THz. Lately, metamaterials have been discovered. The discovery of metamaterials enhanced competencies of the users to influence electromagnetic radiation in the THz band [13].

2.5 THz antennas

The article [13] mentions that it is crucially important to design an efficient antenna for THz wave transmission and receiving. This device is an important part that allows transmission and receiving of THz waves in THz system. Different types of THz antenna available are (a) photoconductive antenna (most recent one), (b) conventional horn antenna, (c) reflector antenna, and (d) dynamic antenna.

The flow on the TCP involves data packets transmitted from the sender to the receiver, with acknowledgements received by the sender flowing opposite direction [3]. The congestion window also called the number of packets can be sent before an acknowledgement is received. Each congestion control mechanism consists of four stages, namely, slow start, congestion avoidance, fast retransmit, and fast recovery as shown in Figure 1 [3]. For every round trip made by the packet and it is acknowledged, the packet or congestion window doubles. The congestion avoidance is entered into if the congestion window is greater than the slow start threshold [3]. TCP performs fast retransmit if a packet loss event gets detected by three duplicate acknowledgements there by the missing packet gets retransmitted and fast recovery stage is entered into. TCP Reno and TCP CUBIC amongst others are the two main congestion control algorithms widely used. For the purpose of the experiments, the New Reno, which is the latest model available in the Linux Kernel [3], will be used to demonstrate the behavior of the packets when different frequencies are applied to a OPNET 14.5 Modeler. The article [3] reveals that the New Reno algorithm advances retransmission during the fast recovery stage. Furthermore, this algorithm presents certain algorithm that uses partial acknowledgements by using selective acknowledgement (SACK) option [3]. TCP CUBIC is used as default algorithm in Linux machines [3]. This kind of algorithm adjusts the congestion window based on the passed time from the previous congestion event. The constancy of the algorithm is enhanced at the same time upholding high network usage [3]. Some of the challenges faced by wireless networks are poor connectivity, interference, congestion, etc. Congestion on the network happens when a buffer overflows in an intermediate node due to multiple devices utilizing the same path or huge amount of data transfer. This congestion causes loss of packets, and queueing delay, which cause poor quality of the network [3].

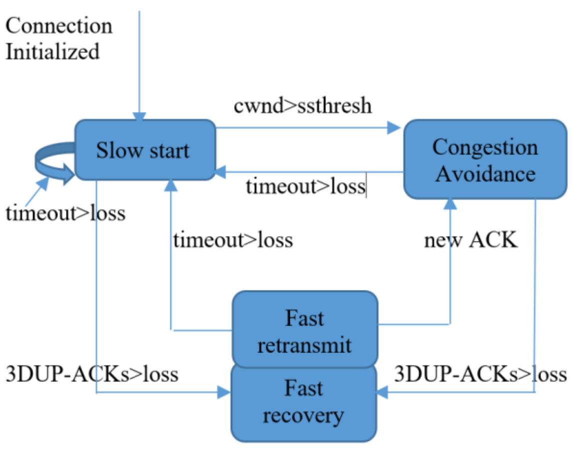

Figure 1. Different stages of congestion control mechanisms [3]

2.6 Wireless Body Area Network (WBAN)

Wireless Body Area Network (WBAN) is defined as a special purpose sensor network meant to function independently to connect together different sensors and device inside and outside of the body of a human being or patient [14]. According to the study [15], WBAN are sensing and monitoring nodes that can be worn that contain processing and computing capabilities. Article [16] states that sensors are planted around the human body monitoring different physiological parameters and these sensors are used for monitoring patients in healthcare systems. A WBAN architecture has the following features: (a) network around the body of a patient, (b) gateway also known as sink, (c) wide network i.e., intranet or internet network, and (d) graphical user interface (GUI) for medical and other healthcare practitioner's applications [15, 16]. In healthcare uses, data rates for sensor are useful and each use has a best data rate, hence the network and protocols related should contain sufficient bandwidth for backing all uses. Sensor node consists of four apparatuses, and they are (a) sensing, (b) processing, (c) transceiver, and (d) power units [16]. WBANs are dependent on their applications and are being divided into two divisions i.e. (a) periodic event, and (b) event detection. On the event detection, sensor nodes only send data when the event takes places, for an example, if a patient trips and falls down, whereas on the periodic event, sensor nodes only send data at the periodic intervals e.g., sending heartbeat information every after a certain period of time [16]. In the study, Akyildiz et al. [17] mentions that sensors further monitor sodium, glucose and many other ions in a human body. Sensor nodes should be reduced, very low power and must be able to detect signals like electrocardiogram (ECG), blood pressure and body temperature, etc. Each individual sensor node collects data from the body and transfer that data to the control unit and then to the remote destinations for diagnostic and analysis purposes by relevant authorities [14].

The Figure 2 below illustrates the wireless nano sensor network for health monitoring:

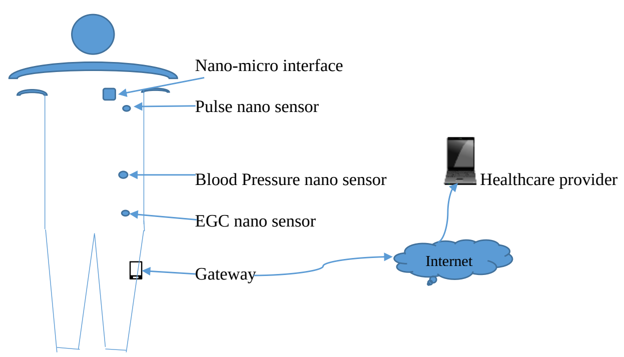

Figure 2. Wireless nano sensor network for health monitoring

2.7 Performance of WBAN

WBAN that is used for collection of different data from the patient's body is designed taking into consideration the following factors: (a) reliability, (b) power efficiency, and (c) scalability [18]. The architecture of BAN communication is classified into three tiers, namely (a) Tier 1: intra-BAN communications, (b) Tier 2: inter-BAN communications, and (c) Tier 3: beyond-BAN communications [18, 19]. Tier 1 consists of gateway and sensors around the patient, while Tier 2 attaches sensors to patients, and Tier 3 characterizes the current network system in the hospital [19]. Protocols in WBANs.

2.8 Application layer

The role of an application layer is to subdivide the content of the message, extract the command number, execute the command, and to generate responses [19]. The article [19] identifies three protocols of the application layer i.e., (a) the Sensor Management Protocol (SMP), (b) Task Assignment and Data Advertisement Protocol (TADAP), and (c) Sensor Query and Data Dissemination Protocol (SQDDP). SMP interact with the system, TADAP enables the users to send data to (a) sensor node, (b) the nodes subset, or (c) entire network, while SQDDP affords user with interfaces to (a) send queries, (b) reply to queries, and (c) gather received responses [19]. At WBAN level, data is sent at one time through data aggregation, which means there is less transmission being done, hence congestion is very minimal and therefore no need to search for ways to overcome it at this stage. The three protocols and their functions on the internet belonging to TCP stack under application layer are (a) hypertext transfer protocol (HTTP) and is used to browse the web, (b) file transfer protocol (FTP) used for file downloading; and (c) simple mail transfer protocol (SMTP) used for electronic mails (e-mails) [19].

2.9 Transport layer protocol

Transport layer Protocol's responsibility of the Open System Interconnection model (OSI) is to deliver data from the source to the receiver. It also contains a facility to check if the data sent does not contain errors. There are two transport layer protocols normally used i.e., TCP and UDP. The two protocols and their functions on the internet belonging to TCP stack under transport layer are (a) TCP and it is reliable in data transmission, and (b) User Datagram Protocol (UDP) and it is unreliable in data transmission [20]. The two approaches used to improve end-to-end reliability in WBAN are (a) use of reliable transport protocols; and (b) use of redundant transmission and coding techniques [16]. In an attempt to overcome congestion of the network, tunable reliability with congestion control for information transport in wireless sensor networks (TRCCIT); real-time and reliable transport (RT2) protocol for wireless sensor, priority-based congestion control protocol for controlling upstream in wireless congestion (PCCP) and Prioritized Heterogeneous Traffic-Oriented Congestion Control Protocol (PHTCCP) networks have been discovered and used [15]. Congestion Detection and Avoidance (CODA) – has been defined by Rohrer [20] as an upstream congestion protocol that is energy efficient. The journal [20] indicates that congestion detection avoidance consists of (a) receiver-based congestion detection, (b) open loop hop-by-hop backpressure, and (c) closed-loop end-to-end multisource regulation. CODA pretends the event occurrence is the source of congestion and it utilizes occupancy of buffer and sampling of channel to detect congestion [20]. The congestion on the TCP consists of four phases of congestion control mechanisms i.e., (a) slow start, (b) congestion avoidance, (c) fast retransmit and (d) fast recovery of which slow start and congestion avoidance deal with the identification of congestion while fast retransmit and fast recovery give response to overcome congestion [17].

(a) The Tunable Reliability with Congestion Control for Information Transport in Wireless Sensor Networks (TRCCIT)

Tunable Reliability with Congestion Control for Information Transport (TRCCIT) is defined as the wireless sensor network protocol that picks between Automatic Repeat Request (ARQ) and multipath possibilities for tunable reliability. TRCCIT makes use of implicit and explicit acknowledgements on each hop and also uses timers to activate transmissions whenever a packet has not been acknowledged by the following hop. In cases where there is congestion, nodes make use of an alternative route [21]. The reliability level of Hybrid Acknowledgement (HACK) is guaranteed by the application of TRCCIT protocol. If the level of reliability needed is attained beforehand, the receiver decreases the packet received and sends an acknowledgement to the sender. TRCCIT controls congestion through multipath forwarding during the detection of the congestion and using multi-paths forwarding is not always possible and therefore TRCCIT control alone is not adequate [8].

(b) Real-Time and Reliable Transport (RT2) Protocol for Wireless Sensor

Real-time and reliable transport (RT2) Protocol is used to attain reliable detection and is very efficient in energy consumption. RT2 manipulates correlation and collaborative nature of Wireless Sensor and Actor Networks (WSANs), hence it ensures that the applications execute the correct activities timeously. It also deals with heterogeneous reliability requirements of sensor-actor and actor-actor communication. In the case of sensor-actor communication, RT2 outlines delay-constrained incident reliability motion grounded on event-to-action bounds and incident reliability objectives, while in the case of actor-actor communication, RT2 delivers package level reliability mechanisms so as to prevent incorrect action decisions in the deployment field. RT2 protocol overcomes incident transport reliability and timely action performance objectives of WSANs at the same time [22].

(c) Priority-Based Congestion Control Protocol for Controlling Upstream in Wireless Congestion (PCCP)

PCCP takes into account that different sensor nodes have different roles and therefore require different throughput [23]. A scheduler between MAC layer and network layer is being utilized and furthermore two queues at each and every node are also being utilized. One queue is for transit traffic and the other is for sourced traffic. PCCP senses congestion occasionally with the use of ratio between packet service and packets inter arrival time at the MAC layer. Priority based Rate Adjustment (PRA) algorithm ensures impartiality between sub tree transit traffic and source while PRA modifies the scheduling and the source rate by means of the priority weight of the sourced data and the global priority of the node of control link and node level congestion. PCCP makes use of the information around active nodes and also increases scheduling and source rate without priority index during low congestion; while the rate of sending of all traffic sources based on their priority index decreases during high congestion [21]. The two types of traffic in wireless senor networks are (a) downstream traffic, and (b) upstream traffic, where downstream traffic is one-to-many multi casts and upstream traffic is many-to-one multi hop convergent. Upstream traffic is also grouped into four classes [23]; namely:

(a) Event based – in this category, whenever target events occur, the sensor node will report,

(b) Continuous – in this category, sensor nodes report to the sink periodically and often develops data transmission,

(c) Query based – in this category, sensor data is transmitted to sink on demand,

(d) Hybrid – in this category, the higher the source rate the more the more the congestion that causes packet drops and then increases the delay. This decreases the quality of service (QoS). There is therefore need control that kind of congestion to obtain flexible throughput and QoS [24].

Congestions such as node and link level congestion can occur in wireless sensor networks. Node level congestion occurs as a result of overflowing of buffer in the node that results in packet loss and increasing queuing delay; and link level congestion could cause increase in service time, decrease in the utilization of link and the total throughput, and loss of energy at the sensor nodes [24]. There are three steps that congestion control follows i.e., (a) any detection, (b) congestion notification, and (c) rate adjusting [25]. The protocol which can detect, and control congestion is required, and its efficiency relies on how much energy efficiency can it attain and to what extent can it support quality of service. Two approaches are generally used for congestion control i.e. (a) network resource management, and (b) traffic control. To increase bandwidth and weaken the congestion, multiple interfaces can be employed [24].

(d) Prioritized Heterogeneous Traffic-Oriented Congestion Control Protocol (PHTCCP) Networks

In the paper [24], PHTCCP is used for controlling various data with different priorities within one single node. Its module cooperates with MAC layer thus functioning as a congestion control. PHTCCP is responsible for ensuring effective rate control for prioritized heterogeneous congestion through node priority-based hop-by-hop dynamic rate adjustment technique [26]. Intra-queue and inter-que priorities together with weighted fair queuing are being used by PHTCCP for guaranteeing viable transmission rates of heterogeneous data. Packet service ratio is employed by the packet service ratio (average packet service rate and packet scheduling rate ratio) to check the size of congestion level at each sensor nodes. This protocol also ensures effective link utilization by means of dynamic transmission rate adjustment. In this protocol, by reducing scheduling rate to the value equal to the packet service rate, congestion is being controlled. PHTCCP is said to be energy efficient, viable due to meeting memory requirements and delivers lower delay [27].

2.10 Network layer protocol

Network layer allows data communication between THz nano nodes at random distance from one another [28]. This layer consists of routing functionality, which is responsible for ensuring that the behaviour of forwarding allows the effective routing between sources and receivers. In THz nano communication, network layer protocol is classified into (a) relaying & forwarding, and (b) Routing. Routing is further classified into (a) flooding-based routing, and (b) Pathfinding [28]. In WBAN, trees routing topology is used where data aggregation is used for reducing the data volume by putting together data that is highly correlated [15]. The article further says, in this layer, researchers solve the problems of routing and energy consumption. Filipe further says that any other problems of single node of the networks also get solved by researchers in the network layer protocol. The article [15] reveals that factors like power efficiency, data-centric approach, attribute-based addressing and data aggregation are taken into consideration when designing and constructing network layer of the sensor networks. Further research [15] reveals that network layer also delivers internetworking with external networks. The external networks are command systems and control systems, sensor networks, and internet. This layer is an internet protocol responsible for end-to-end addressing [20].

2.11 Data link layer protocol

This layer enables direct or straight communication between a pair of nano nodes or a nano node and other devices like nano router, nano controller, gateway, etcetera [29]. The purposes of the link layer protocol are to coordinate channel access and recover from bit transmission errors. The article [16] further says that this protocol defines the suitable times for transmission for nano nodes so that the biggest set of transmission rates can be sustained. Link layer consists of two sub-layers i.e., Media Access Control, and (b) Logical Link Control (LLC). The two protocols and their functions on the internet belonging to TCP stack under data link layer are (a) IEEE 802.3 ethernet protocol responsible networking in a local area; and (b) IEEE 802.11 wireless LAN responsible for networking in a local area [18].

2.12 Physical layer protocol

The article [16] defines physical layer as a layer that its function is to encrypt modulation, frequency generation, frequency selection, signal detection and signal. In wireless communication, physical layer performs modulation, coding, error control, etc. [28]. For low power and wireless connectivity for network applications that deal with monitoring and control, ZigBee was established for the purpose [16]. Surveys show that IEEE 802.15.4 for a WBAN has been considered since it provides for low data applications. The article [16] argues that IEEE 802.15.4 is very poor in the multi-hop environment. The two protocols and their functions on the internet belonging to TCP stack under physical layer are (a) IEEE 802.3 Ethernet responsible for networking in a local area; and (b) IEEE 802.11 Wireless LAN responsible for networking in a local area [18].

2.13 Medium Access Sublayer (MAC)

Medium Access Sublayer integrates the physical layer with upper layers. Services that are provided by MAC include (a) link management, (b) security, (c) channel access, (d) frame validation and (e) node synchronization as alluded in the study [16]. The article further mentions some of the tasks and these are (a) data frame detection, (b) addressing and package coding, medium access and error control, (e) and multiplexing of data streams. It is expected that MAC attains the best energy efficiency and data throughput. This protocol does not have mechanisms for energy conservation, which is a major drawback in WBANs. The energy efficiency plays an important in WBAN since the waste of energy is as a result of idle listening, control packet overhead collisions, and overhearing and therefore it is crucially imperative to safeguard energy efficiency, enough quality of service and huge network capacity when designing MAC protocol [16].

Single-hop and multi-hop protocols form part of MAC protocols [16]. The functions of single-hop and multi-hop protocols in multi-hop self-organizing sensor network are (a) the creation of network infrastructure, and (b) sharing of communication resources between sensor nodes [15]. Mechanisms that can be used in MAC can be divided into (a) schedule-based, predominantly Time-Division Multiple Access (TDMA) but also Code-Division Multiple Access (CDMA), (b) Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and (c) hybrid schemes, combining contention and scheduled methods [16]. The article further mentions that CSMA and TDMA are mostly used in WBANs with TDMA having the highest utilization of bandwidth and low consumption of power that CSMD/CA. For CSMA/CA the firstly the node listens to the medium and when no activity is happening, transmission starts immediately and if transmission does not start, back-off procedure will start thereby waiting for a certain amount of time [16]. For this type of protocol, one transmission happens at a time, if the second node gets heard when there is already transmission, it waits for some time until the node starts transmission before the node listen for the second time [16]. When there are high levels of traffic and low bandwidth, CSMA/CA that are not slotted produce too much collision that can result high use energy and high levels of latency and hence energy saving is compromised [16]. The survey [16] further says that Slotted CSMA/CA allows for operation in the mode enabled by beacon that makes use of superframe. If superframe is used, delivery of communication can be ensured [16]. The study [16] reveals that TDMA distributes time into tiny slots and then nodes are allocated slots. Some of the nodes can transmit the communication at the same time through the single communication channel for CDMA method and for this to happen without any disturbance between different transmissions of which, each of the transmitters is allocated special coding scheme and spread spectrum technology that is used by the CDMA [16]. Frequency band is divided by FDMA into slots and nodes. This benefits during the time of too many nodes to transmit simultaneously as well as when very high data amount needs to be transmitted [16]. Nodes are planted around the body of a human being and each node sends communication about parameters such as temperature, blood pressure, etc. in WBANs and the FDMA method ensures accessibility for the transmission channel [16]. Method such as slotted Additive Links Online Hawaii Area (ALOHA) are utilized for Wireless Sensor Networks (WSNs) and in this method, predefined user priorities are used by the nodes to access the channel [16]. The main function of predefined user priorities is to prioritize some of the critical nodes on the body in body area networks [16].

Cognitive radio (CR) has been the recent technology used with a capability to determine which spectrum has not been used in both licensed and unlicensed spectrum bands and then makes use of the unused spectrum, and it can easily be programmed and configured dynamically [16]. The CR has transceivers that identify channels that are open and alter transmission factors to cater for improved wireless communications. The authors have mentioned that studies recommended CR technology as a suitable answer to cater for opportunistic admission to the spectrum resources [16].

One of the methods to monitor the heartbeat is H-MAC, which denotes heartbeat MAC method. This H-MAC is an access method based on TDMA and is commended for star topology wireless body are networks [16]. Synchronization can be achieved without periodic information from the nodes as the rhythm from the heartbeat synchronizes the nodes thereby improving energy efficiency [16]. The system is such that if the sensor for the heartbeat malfunctions, the whole WBAN network will also malfunction [16]. One method that was also recommended for WBAN is DTDMA, which denotes Reservation-based Dynamic (TDMA) method, however, this method did not make provision for emergency traffic and on-demand traffic, of which is crucially important on sensor nodes for WBANs [16]. SMACS, which denotes Self-Organizing Medium Access Control for Sensor nets permits the development of random network topologies without creating global synchronization between the rest of the nodes [16]. Bandwidth is likely to be bigger compared to the sensor nodes maximum data rate and that what makes it viable in WBANs [16]. This will render the need for network-wide synchronization unimportant. Random wake-up schedule ensures power conservation at the connection phase thereby ensuring that the radio is turned off at the idle timeslot [16]. Whenever the node hast to transmit a packet, it does so in the ALOHA and when there is collision, the packed that has collided gets left behind or unused and that packet gets transmitted again after a certain time period [16]. For the slotted ALOHA, time gets divided into a number of timeslots where each and every node gets its own timeslot, the node does not transmit until the next timeslot begins [19]. For the slotted ALOHA, predetermined user priorities are utilized to gain access to the channels and to categorize the high and low priority traffic [16]. IEEE 802.15.6 standard is a standard associated with WBANs that puts emphasis on the short range as well as low power apparatus and is suitable for healthcare, defence, sports, etc. applications [16]. This standard makes mention of MAC layer protocol as a protocol that support physical layer, high priority traffic as well as security levels. The security level that the standard supports include authentication, unsecured communication level and authentication level [16].

HEH-BMAC, which denotes the polling MAC protocol with Human Energy Harvesting Capabilities makes use of catching human energy from heart contractions, body temperature difference, and many more [16]. The protocol uses probabilistic polling and contention random access to cater for adjustment of its operation [16]. Tests comparing HEHBMAC with IEEE 802.15.6 standard were carried out and it was found that HEHBMAC attained higher energy efficiency when number of nodes increased than IEEE 802.15.6 standards [16]. MAC protocols are categorized under Tier 1, Tier 2 and Tier 3, with the first Tier, i.e., Tier 1 representing intra BAN and the second Tier, i.e., Tier 2 representing inter BAN [16]. WBANs at Tiers 1 and 2 make use of the standard IEEE 802.11.6, which makes provision for authentication, high priority traffic, low power, encryption, and slotted channels [16]. In the study [9] Wireless Personal Area Network (WPAN) is categorized under wireless technology of low power. This network is responsible for moving and/or stationery systems that are within personal operating space, which covers up to 10 metres from the body of a human being and it can extend to 100 metres with the use of amplifiers. These different IEEE systems or technologies are defined as follow:

- IEEE 802.15.1: Bluetooth
- IEEE 802.15.4: ZigBee
- IEEE 802.15.6: WBAN

The standard IEEE 801.11ah was established to address the WLAN, which functions in the region of 900 MHz. This standard is the extension of IEEE 801.ac standards and is meant for low power. Bluetooth is meant for short distances. It is also a preferred technique for it is a cheaper option. This wireless option is mainly for devices like laptop or computer mouse, keyboard, etc. and is also compatible for transmitting voice messages and data [9]. The Association of ZigBee (ZigBee Alliance) introduced the extension of the standard IEEE 802.15.4 WPAN as the ZigBee. This standard is built within the IEEE 802.15.4, and it is responsible for defining PHY (physical) and MAC layers and is mainly for the advancement of Power Area Network (PAN). ZigBee provides for various topologies. It produces low throughput, uses low power and provides long battery life expectancy. ZigBee operated within the range of 10 to 100 metres, depending on the environment which it is operated at the study [9].

2.14 Multipath TCP

The paper [26] indicates that the Internet Engineering Task Force (IETF) work group was put together to identify protocol for the transport layer. The team recommended Multipath transmission control protocol (MPTCP), which was discovered to be the extension of transmission control protocol (TCP) that can handle multiple paths between different endpoints [29]. The aim of developing the MPTCP is to increase throughput, ensure the multipath flow does not take up any further capacity on the paths, and ensure balance congestion. In this kind of transmission control protocol, the transport layer gets divided to form two sublayers i.e., the upper sublayer and the bottom sublayer. The upper sublayer collects the capabilities and functions for connection management (establishment of connection, etc.), while the lower sublayer controls a set of different sub-flows which appear as one TCP flow each [26]. Chihani, and Denis [28] further reveals MTCP differentiates two sequence number spaces, of which one space is allocated to each sublayer. Each sequence space is allocated to each sub-flow in a similar manner as the standard TCP, sub-flow displaying the bytes.

One sequence at the connection level is for ordering the TCP segments before they are being sent to the application layer [29]. This kind of protocol makes use of the new options to exchange signaling information between different peers. Some of the peers are Multipath Capable (MPC) meant for establishment of a multipath TCP connection during the three-way handshake [29]. The distinction between TCP and UDP is that TCP is user friendly i.e., transmits data reliably and provides data re-transmission through the network and it is most reliable end-to-end communication in the transport layer protocol, while UDP is not user friendly i.e., does not provide re-transmission of data and keeps on sending data through the network that is congested already [26, 30]. TCP is responsible for providing reliable in-order transport of data, monitoring traffic congestion in the network system performance, and monitoring flow of packets between the transmitter and receiver. The different mechanisms are used by TCP to attain high level of performance thereby avoiding the collapse of congestion. The mechanism used control data rate getting into the network thereby ensuring the movement of data is always less than what can activate collapse of the system. The effectiveness of the TCP is determined by mechanisms such as congestion control, slow start, fast re-transmit, and mobility implications [26, 30].

3. RESEARCH METHODOLOGY

3.1 Methodology

The aim of this paper is to suggest the suitable congestion control in the transport layer protocol for wireless body area networks. This section covers the methodology used in this minor dissertation. This paper will also cover the architecture and software program applied. In the paper [31] wireless communication makes use of three approached to check the performance in evaluating the proposed protocol, namely (a) mathematical analysis, (b) simulation analysis, and (c) test-bed evaluation. Simulation, measurement and analytical modelling are the appropriate instruments to analyse performance of computer system [28]. The study indicates that NanoSim is the innovative simulator in the THz band. Studies have used NS-2, NS-3 modules and OPNET simulator. This research will therefore make use of the OPNET simulation analysis to test the performance of the proposed protocol. The paper [29] reveals that researchers recommend the use of simulation analysis when evaluation wireless network because they allow for repetitive condition. Furthermore, several research already undertaken make use of simulation analysis, therefore, it will be easy to compare and analyze the results obtained in this research with other research work. Optimized Network Engineering Tool (OPNET) 14.5 Modeler will be used to model the results in this research. This work will make comparison between normal frequencies and higher frequencies in the terahertz band. Under methodology, this paper identifies the different types of components to be used in developing the system, modelling the architecture, developing the code that will be used to run the model, and using the OPNET simulation method to simulate the results. It also indicates connections and the interaction of this wireless system. A qualitative approach has been used to carry out this research.

3.2 WBAN architecture

The following diagram illustrates a WBAN architecture with EMG, ECG, Temperature, Pulse, Gluecose, Motion, and SPO_2 sensors.

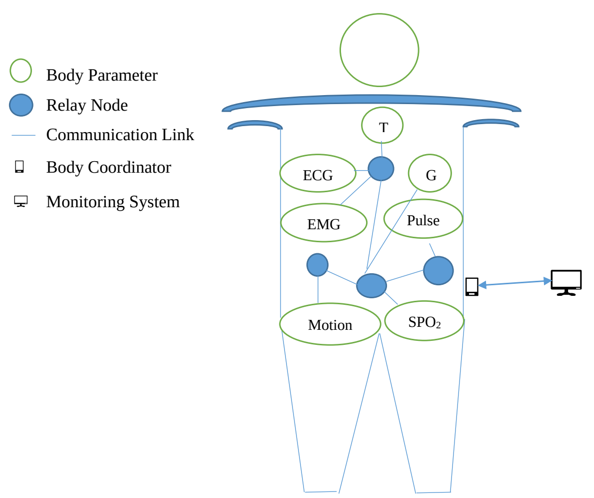

Figure 3. WBAN architecture

From Figure 3 above, the architect represents the WBAN with different types of implanted body sensors, relay nodes, and body coordinator (also known as gateway) attached to the surface of the body (central data sink) [32]. The sensors implanted on the body detect physiological data i.e., body temperature, electrocardiogram, oxygen saturation (SPO_2), etc., which get sent to the medical doctors for diagnosis and analysis [32]. The relay nodes are placed at short distances apart and this results in a high efficiency. The sensors transmit the data to the relay nodes, which in turn transmit the data to the body coordinator in multi-hop form. The body coordinator transmits obtained data to the monitoring station (MS) for monitoring, analysis and storage by the medical doctors and other responsible officials. Body sensors and relay nodes get their power supplies from the batteries embedded in them while the body coordinator is connected to the external power supply. The data is transmitted from the sensor node to the body sensors through routing path [31]. The literature survey reveal that it is essential to do further research on the improvement of congestion control in the transport layer protocol. Since the frequencies in the spectrum are already fully occupied, there is a need to concentrate on higher frequencies i.e., terahertz frequencies. This will increase the bandwidth thereby allowing free flow of data in the transport layer protocol.

3.3 Design of the simulation model

This research makes use of the Optimized Network Engineering Tool (OPNET) Modeler 14.5. The decision of using this version of OPNET is that it is an open source. OPNET is simple to model as compared to NS-2 and NS-3. In the paper [31], OPNET plays an important role in emerging technical world in developing and improving the wireless technical protocols. Some of the functions that OPNET can perform are (a) to afford virtual real time environment with GUI, (b) contribute towards the evaluation of designs for new network models and architectures, (c) network models are already pre-defined for research and educational purposes, (d) easy to do interfacing, (e) reliable, efficient and easy to use, etc. [31]. OPNET operates in four different parts, namely, design of the model, statistics application, the running of simulations, and view and analysis of results. The study [33] reveals that OPNET is a suitable option for network which is virtual that simulates networks making use of switches, servers, routers and other native applications. OPNET modelling is mainly used in operation research, which includes but not limited to importing and exporting topology and network traffic data; multi-protocol modelling; etc. Similar to the rest of simulation methods, OPNET arrangement also represents the behaviour of and object over a period of time, and it makes use of computer program. This kind of modelling is suitable for use in a wireless communication network as it permits the researcher to construct networks and chooses equipment, set the equipment up, and then conduct the experiments and obtaining results in a form of graphs [32, 33]. The parameter analyzed in the experiment is a throughput, and is defined as follows:

- Throughput - refers to the total data traffic or average data traffic received or sent in bits per second.

The model was created with the application and profile configurations, with two subnets labelled as department 1, and department 2. These subnets are all connected to the sever department. This server department acts as a gateway. The departments are also referred to as relay nodes and are responsible for collecting data from the sensor nodes. Each node has ten sensor nodes connected to it. These sensors collect data from the body of a human and transfer it to sensor nodes. Sensor nodes send data to the gateway referred to as sever department and then transfer it to the doctor or health practitioners through transport layer protocol. A switch divides the networks into different departments and is also used to improve the performance of the network thereby improving the delay and throughput and does so independently. A server is used to produce application traffic which gets transmitted to the workstations through the router and switch.

This research makes use of PCCP in the Multipath TCP. The normal frequencies are used to run the model and then the frequency will be varied until it reaches THz frequency and then the results will be compared for different frequencies. PCCP has three elements i.e., intelligent congestion detection, implicit congestion notification, and priority-based rate adjustment. This congestion control makes use of inter-arrival time and packet service time for congestion inference. As soon as congestion is detected in the network, all sensor nodes perform rate adjustment. This will ensure that nodes considered to be of high importance receive more bandwidth, nodes with same priorities share equal bandwidth, and nodes with more packets to be sent get enough bandwidth [14].

When the results are analyzed, this research only analyses the total number of events generated, the total number of packets created, and the total number of packets received. The re-transmission of the packets that were not transmitted is left for further research work to be undertaken. Table 1 shows simulation parameters that are used for this research.

Parameters that were used to do simulations are presented in Table 1 that follow:

Table 1. Simulation parameters

Parameter	Size
Buffer size	100 packets
Simulation time	0.1 picoseconds
Network size	4 nodes
Service time	Not applicable
Transmission range	35m
Total Area	100m×100m
Routing type	Single-path, Multi-path

3.4 Proposed model outcome

OPNET 14.5 Modeler was used to obtain the results in this discussed in this paper. The simulator tool has different simulation modules, namely, Wireless Body Area Network (WBAN), Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN), etcetera. The latest OPNET 17.5 simulator is not available freely for use by researchers and students in general. OPNET 17.5 simulator consists of WBAN simulator module already built in, however, it could not be used due to its unavailability and user unfriendliness. OPNET 14.5 Modeler allows for addition of WBAN in it, however, the results at the end of the loading of data are not obtainable as the programme contains errors and error messages that cannot be eliminated. The tool used to eliminate existing error messages has been blocked. This research made use of OPNET 14.5 simulator wireless local area network (WLAN) together with the transmission control protocol (TCP). It is assumed that data is collected from the body of the patient and then transmitted through the local area network and to the doctor or Healthcare staff through the transport layer protocol. The following components have been used to set up the model:

- Application Configuration Module (Application Config): used for specifying the applications for user's profiles configuration.

• Profile Configuration Module (Profile Config): This application deals with the pattern of activities that the user specifies for a certain period of time.

• Department 1 and department 2: These departments consist of two (2) sensor nodes that are used to take measurements from the body of a patient and transmit the data to gateway, where a gateway is a router.

• Router: The router in this case operates as a gateway. The gateway in this case represents a node and it connects together two networks with different types of protocols for communication purposes. All communications converge to the gateway before the data is transmitted through transport layer protocol i.e., transmission control protocol (TCP) to the receiver i.e., doctor or healthcare practitioner.

The options that are given to test the model are as follow:

• IEEE 802 (Frequency Hopping), which can take data up to the maximum of 2 Mbps,

• IEEE 802b (Direct Sequence), which can take data up to the maximum of 2 Mbps,

• IEEE 802 (Infra-Red), which can take data up to the maximum of 2Mbps,

• IEEE 802a (OFDM), which can take data up to the maximum of 54 Mbps; and

• IEEE 802g (Extended Rate PHY), which can take data up to the maximum of 54 Mbps.

IEEE 802.11g (Extended Rate PHY) was used as it can transmit the highest data in Megabits per second (Mbps) compared to first three specifications. IEEE 802 wireless local network specifications that defines requirement for an orthogonal frequency-division multiplexing (ODFM) was also eliminated in this research. The testing of data was made by transmitting the highest data of 54 Mbps so that the model is tested at its extreme condition.

3.5 Experiment

Basic Service Set 1 (BSS1)

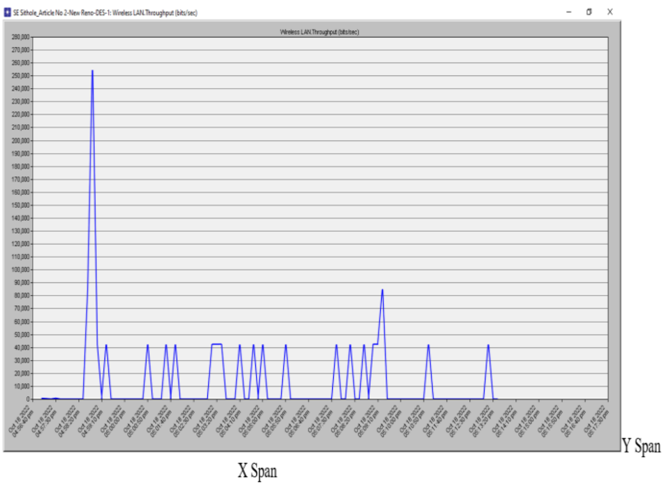

Figure 4. Throughput (bits/sec) at 0.001 s

Figure 4 shows wireless throughput (Body Area Network) in bits per second on BSS1. The number of packets copied is 46,683, the number of packets created is 12,305 and the number of packets destroyed is 54,536 packets as recorded from the simulation results. There is a very high number of packets copied and destroyed in this case. Here, 54 Mbps is used to do this modelling. The time applied is 0.01 seconds, which is equivalent to the frequency of f=100 Hz.

Figure 5 shows wireless throughput (Body Area Network) in bits per second on BSS1. The number of packets copied is 128, the number of packets created is 51 and the number of packets destroyed is 161 packets. As the frequency decreases, the number of packets copied and destroyed decrease. Here, 54 Mbps is used to do this modelling. The time applied is 0.001 seconds, which is equivalent to the frequency of f=1 kHz. The number of packets copied is 0, the number of packets created is 6 and the number of packets destroyed is 6 packets. The total number of packets that is created is equal to the number of packets created and that shows that all the data being transferred from the patient to the office of the doctor gets lost.

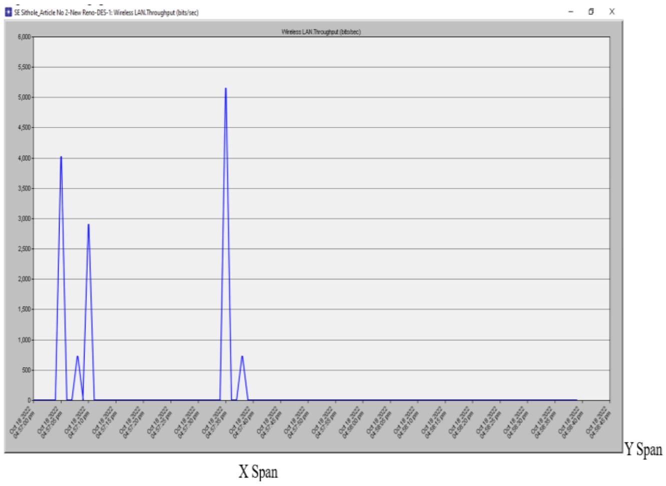

Figure 5. Throughput (bits/sec) at 0.01 s

When 54 Mbps is used, the time applied is 1×10^{-6} seconds, 1×10^{-9} seconds and 1×10^{-12} which are equivalent to the frequencies of f=1 MHz, 1 GHz and 1 THz, respectively, the number of packets copied is 0, the number of packets created is 6 and the number of packets destroyed is 0 packets. In these cases, the systems improve as the frequencies increase to towards Terahertz band.

Figures 4 and 5 depict throughput in bits per seconds at 0.00 Hz and 0.0001 Hz, respectively. The abscissa (X span) represents the time of simulation in totalling to forty-five (45) seconds, while the ordinate (Y span) represents the traffic received in bits per seconds. From Figure 5, there is no traffic between 04:57:40 until 04:57:48. The traffic starts and increases rapidly just after 04:57:48 and it drops to zero at 04:59:10.

3.6 Findings

The normal frequency of f=1000 Hz was applied, and different values were obtained i.e., total number of events registered, total number of packets copied, total number of packets created and total number of packets destroyed. The 54 Mbps data was used to perform the first modelling. At high frequencies, the total throughputs were very poor such that there were no waveforms generated by OPNET simulation method. There were also no packets copied, created and destroyed and this rendered the results meaningless. In the case where lower frequencies were applied, the total number of packets copied were high with the number of packets destroyed also being very high leaving the number of packets created low. As the frequencies were increased by decreasing time applied, the total number of packets improved. At Megahertz, Gigahertz, and Terahertz frequencies, the total number of packets destroyed were zero (0). This means that the total data that was transferred from the sensors of the patient was successfully transmitted to the doctor or health practitioners, which is desirable.

4. CONCLUSION

From the observations of the research findings, it can be concluded that as the applied frequency is increased the better the total number of packets is being transmitted without failure and conversely, lower the frequency applied on the modelling, the poor the total number of packets is being transmitted. The theory of terahertz frequencies has been proven by this research that whenever the frequency is being increased the better will be the performance of the system. The bandwidth and throughput also improve.

It is concluded through the demonstration of the model that for frequencies (f) greater or equal to 1 THz (or any value of frequency in the terahertz range), the total number of events formed is 6 and remains the same for higher frequency values if the same data i.e., 54 Mbps is being transmitted. There are no packets that get destroyed. This reveals that the frequencies at terahertz band is a feasible alternative to deal with the drastic increase in network connection i.e., frequencies at the terahertz band are a feasible alternative for future use to combat drastic increases in network connections. The use terahertz nano-communication systems, nano-machines and nano-sensors will always be the future of this world. The employment of these kinds of electronic components and systems will decrease the possibility human errors when used wirelessly.

Further research in this topic needs to be undertaken. Congestion within the physical layer in the WBAN still needs to be studied. At some point during this research, the results i.e., total number of packets copied, total number of packets created, total number of packets created, and the total number of packets destroyed remained constant and therefore further investigation needs to be conducted to find out why was this the case. As the frequencies were increasing in the terahertz band, the results were unable to display in a graphical form and this needs further investigation.

The study showing the comparison between OPNET 14.5 Modeler, OPNET 17.5 Modeler and NS-3 Simulation methods also needs to be caried out in the transport layer protocol in wireless body area network applying higher frequencies in terahertz band. Once the study is done, recommendation on which simulation method is more accurate should be outlined. It is expected that NS-3 method should give more accurate results as it is one of the newer methods recommended by most researchers. The study to be carried out should only concentrate on the transport and physical layer protocols as they form a very important part of a wireless communication network.

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