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Performance Analysis for TCP Protocol Over mmWave in 5G Cellular Networks

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ABSTRACT

5G technologies are expected to connect people, objects, data, applications, transport systems, and cities in intelligent networked communication environments. An enormous amount of data should move much faster, reliably deliver too many devices, and handle very large amounts of data with minimal delay. However, the performance will be required TCP protocols to effectively utilize the large air link capacity and provide the end-to-end performance required by future networks and mmWave (Millimeter Wave) technology. In this paper, the implemented framework of mmWave modeling has been analyzed using matlab simulator. The framework is demonstrated through several simulation scenarios to analyze the performance of TCP protocols over mmWave using three main performance measurements, which are Round Trip Time (RTT), Congestion Window size (CWnd) and Throughput. The achieved results show that it would provide internet connections 40 times faster. The coverage four times more worldwide than the current 4G.

1-INTRODUCTION

Recent years have witnessed exponential growth in mobile data and traffic due to, e.g., ever increasing use of smart phones, portable devices, and data-hungry multimedia applications. According to the UMTS traffic forecasts, 1000 fold increase in mobile data traffic is predicted by the year 2020. In another estimate, more than 50 billion devices may be connected wirelessly by 2020 which may cause a capacity crisis. Limited available spectrum in microwave (μWave) bands does not seem to be capable of meeting this demand in the near future, motivating the move to new frequency bands. Therefore, the large available bandwidth at millimeter wave (mmWave) frequency bands, between 30 and 300 GHz, becomes a good candidate for the fifth generation (5G) cellular networks and has attracted considerable attention recently.

Despite the great potential of mmWave bands, they have been considered attractive only for short range-indoor communication due to increase in free-space path loss with increasing frequency, and poor penetration through solid materials such as concrete and brick. However, these high frequencies may also be used for outdoor communication over a transmission range of about 150-200 meters as demonstrated by recent channel measurements. Also, comparable coverage area and much higher data rates than μWave networks can be achieved provided that the base station density is sufficiently high and highly directional antennas are used. With the employment of directional antennas, mmWave cellular networks can be considered as noise-limited rather than interference limited.

The critical need for next-generation wireless communication technologies, specifically focusing on the shift towards millimeter-wave (mmWave) frequencies for 5G cellular networks. It highlights the exponential surge in mobile data traffic, driven by the proliferation of smartphones and data-intensive applications, which current microwave (μWave) bands cannot adequately support. The paragraph acknowledges the initial perception of mmWave's limitations, such as high path loss and poor penetration, butemphasizes recent research demonstrating its potential for outdoor communication with enhanced data rates and coverage through the use of directional antennas and increased base station density. In essence, it sets the stage for exploring mmWave as a viable solution to the impending capacity crisis in wireless communication.

The current public cellular wireless communications use the microwave carrier frequency spectrum which is ranging from 700 MHz to 2.6 GHz with a total bandwidth of less than 780 MHz bandwidth. However, there are much more frequency resources and bandwidth in the underdeveloped and underutilized high frequency spectrum between 30 GHz and 300 GHz, which is called millimeter wave, because of the wavelength of the spectrum ranging between 10 mm to 1 mm.

2-LITERATURE SURVEY

The first wireless networks, by means of smoke signals, flashing mirrors, or semaphore flags, etc., were developed long before industrial revolution. More than one hundred and twenty years ago, Guglielmo Marconi demonstrated the first radio transmission, in mid 1890s, and era of radio communication started. Since then, wireless communications have evolved continually, and new methods and systems were introduced. A new era of wireless communication was born in the 1960s and 1970s after the introduction of cellular concept, and advancement in radio frequency hardware.

Today, wireless communication is the fastest growing engineering field with its wide spread applications prevailed in all aspects of 21stcentury humankind life. According to T.S. Rappaport et al. in since the new era and the beginning of 1980, every 10 years has witnessed a new generation of wireless communication systems with more advanced technology in terms of data rate, spectrum efficiency, coverage and applications.

Although early wireless Local Area Networks (LANs) could not compete with wired Ethernet technology, the most successful application of wireless communication has been the cellular systems. The 1stgeneration (1G) cellular was announced at the beginning of 1980’s, which was an analog system with a few kbps data rates and a lot of disadvantages. In 1993, the 2ndgeneration (2G) was introduced, which is a digital technology mainly used for voice communication and new capabilities such as roaming and Short Message Service (SMS) and with a bit rate of upto64kbps.Global System for Mobile communications (GSM) and Code Division Multiple Access (CDMA) and IS- 95, were the famous technologies of 2G. The data rate was improved by introducing upgrades into 2G, such as General Packet Radio Service (GPRS) and Enhanced Data Rate for GSM Evolution (EDGE) to 144kbps and 384kbps respectively.

The 3rd generation was introduced in 2000 with new technologies and features. The initial transmission rate was 2Mbps which was improved up to 30Mbps as the evolving technologies such as High-Speed Uplink/Downlink Packet Access (HSUPA/HSDP) were added to the network.The 3rdGeneration Project Partnership (3GPP) introduced Long Term Evolution (LTE) technology as the descendant of previous cellular generations which is considered as 4G and was followed by LTE- Advanced with even higher bit rate. The higher bit rate compared to 2G and 3G,and new applications such as Multimedia Messaging Service (MMS), Digital Video Broadcasting (DVB) and High Divination (HD) mobile TV are among the features 4G operators offer to the subscribers.

An overview of 5G Cellular Systems

The explosive growth of mobile traffic and exponentially increase in the demand of users for new services and applications, 5G mobile systems are now being designed to fulfill the requirements of these services, in terms of date rate, latency, reliability, and with low cost and massive connectivity. The early researches on different aspects of 5G cellular system appeared in literature in mid-2013.From that year on, several programs and projects initiated globally to deeply study 5G and its enabling technologies in the years to come. The academia and industry under the following major projects such as the European Union framework program for research and innovation(Horizon 2020) and 5G Infrastructure Public Private Partnership(5GPPP) in Europe, NYU WIRELESS research center and 5G Americas in the United States, IMT-2020 (5G) Promotion Group in China, 5G forum in Korea, the5G Mobile communications promotion Forum (5GMF) in Japan, have been actively promoting 5G research and development, in which in parallel 3GPP and other concerned standardization bodies are finalizing the 5G NR and related standards. The emerging applications and new services for the mobile communications in 2020 and beyond, and key capabilities and minimum requirements of IMT-2020 for the realization of envisioned usage scenarios was released in the ITU-R in 2015.Some instance of environed usage scenarios for IMT for 2020 and beyond.

Average Error Probability Analysis in millimeter Wave Cellular Networks

Evaluating the system performance of mmWave cellular networks is a crucial task in order to understand the network behavior. There are several recent studies which analyze the coverage probability and average rate in mmWave cellular networks using results from stochastic geometry and the theory of point processes for different BS user associations, Stochastic geometry is a commonly used powerful mathematical tool to evaluate the average network performance of spatially distributed nodes. Round Trip Time (RTT) is a widely used model in wire- less networks in general and in cellular networks in particular due to its analytical tractability.

However, average error probability in RTT-based cellular networks has only been barely analyzed in the literature. For instance, there is work focusing on the computation of ASEP in the presence of Poisson field interferers. In a mathematical framework to compute the ASEP in cellular networks, where the BS locations are modeled as independent homogeneous RTTs, is established for the first time. Their approach is based on the shortest BS-to-MU distance cell association criterion, which guarantees that the interfering BSs are located farther than the serving BS, so it is applicable to cellular networks.

System Model

In this section, we introduce our system model for the down link mmWave cellular network consisting of BSs distributed according to some homogeneous RTT Ψ of density λ in the Euclidean plane. Without loss of generality, we consider that a typical MU is located at the origin. A shortest distance cell criterion is assumed, i.e., MU is served by the nearest BS which is denoted by BS_0. The distance from the ith BS to the MU is denoted by r_i for $i \in \Psi$. Thus, the distance between the MU and serving BS (BS_0) is r_0 which is a random variable (RV) with PDF $f_r(\xi) = 2\pi\lambda\xi \exp\{-\pi\lambda\xi^2\}$ [33]. The set of interfering BSs $i \in \Psi - BS_0$ is still a homogeneous RTT, denoted0 by $\Psi^{(\backslash 0)}$, according to the Slivnyak-Mecke's Theorem. We assume that all the interfering BSs are transmitting in the same frequency band as the serving BS (full frequency reuse), therefore $\Psi^{(\backslash 0)}$ has density λ as well. We have the following two assumptions in the construction of the system model.

Average Error Probability Analysis:

In this section, we investigate the error performance of a downlink mmWave cellularnetwork. The first step in obtaining an approximation of the average error probabilityis to compute the pairwise error probability (PEP) associated with the transmitted symbols. Hence, initially we derive an expression for PEP, conditioned on fading gain($|h0|$) and random shortest distance of the MU-serving BS link ($r0$), in terms of the characteristic function (CF) of the aggregate network interference and the noise. Then, APEP is computed by averaging the conditional PEPover fading and the position of the serving BS. Finally, ASEP is approximated from APEP using the NN approximation.

3-EXISTING SYSTEM

In this chapter, energy efficiency of relay-assisted mmWave cellular networks with RTT distributed BSs and relay stations (RSs) is analyzed using tools from stochastic geometry. The distinguishing features of mmWave communications such as directional beamforming and having different path loss laws for LOS and NLOS links are incorporated into the energy efficiency analysis. Following the description of the sys- tem model for mmWave cellular networks, coverage probabilities are computed for each link. Subsequently, average power consumption of BSs and RSs are modeled and energy efficiency is determined in terms of system parameters.

Energy efficiency in the presence of beamforming alignment errors is also investigated to get insight on the performance in practical scenarios. Finally, the impact of BS and RS densities, antenna gains, main lobe beam widths, LOS interference range, and alignment errors on the energy efficiency is analyzed via numerical results.

While existing tools like ns-3's mmWave module provide a robust platform for simulating 5G mmWave networks, there is room for enhancement in terms of realism and scalability. Integrating advanced channel models, such as those based on ray tracing or measured traces, can offer more accurate representations of real-world environments. Additionally, incorporating dynamic mobility patterns and heterogeneous network scenarios can help in assessing TCP performance under diverse conditions. Existing TCP variants like Reno and Cubic have limitations in handling the high variability and directionality of mmWave links. Developing and implementing new congestion control algorithms that are specifically designed for mmWave characteristics, such as rapid fluctuations in signal quality and frequent link blockages, can significantly improve TCP performance. Algorithms that adapt to real-time network conditions and provide feedback to the sender can enhance throughput and reduce latency.

Energy Efficiency in Relay-Assisted millimeter Wave Cellular Network.

As we discussed, it has been shown that mmWave networks can achieve comparable coverage area and much higher data rates than μWave networks when the BS density is sufficiently high and highly directional antennas are used. With increase in the number of BSs in mmWave networks, however, energy efficiency is becoming an important consideration as well.

Energy efficiency of cellular networks has been extensively studied recently. Use of RS has been considered an effective way to have energy efficient and flexible networks while maintaining the coverage area and date rates.

Unlike the BSs, RSs are not connected to the core network with wired backhaul, and therefore this provides a significant reduction in energy consumption.

In energy efficiency of relay-assisted networks are investigated using stochastic geometry. Authors of analyzed the effect of station density on the energy efficiency of relay-assisted cellular networks. However, these studies cannot be directly applied to mmWave cellular networks since unique features of mmWave communication have not been considered. Energy efficiency of millimeter wave cellular networks is studied In the impact of mmWave cellular channels on data rates and power consumption is analyzed using consumption factor framework. In employment of RSs are combined with mmWave channel model.

However, these two papers have not taken into account, in their energy efficiency analysis, the network model based on stochastic geometry. Therefore, we employ stochastic geometry to analyze the energy efficiency of relay-Assisted downlink mmWave cellular networks. Selecting optimal relay stations (RSs) and strategically deploying them can significantly impact energy efficiency. Utilizing algorithms that consider factors such as channel conditions, distance, and interference can help in selecting the most energy-efficient RSs. Additionally, deploying RSs in locations that minimize path loss and interference can further enhance energy efficiency.

System model

In this section, we introduce our system model for the relay-assisted downlink mmWave cellular network. The locations of BSs and RSs are modeled according to two independent homogeneous RTTs Φ_B and Φ_R of densities λ_B and λ_R, respectively, on the Euclidean plane. Mobile users (MUs) are distributed according to some independent stationary point process. Two different types of MUs are considered: non- cooperative MU (MU_{nc}) and cooperative MU (MU_c).

MU_{nc}s directly communicate with the serving BS which we denote by BS_0, while MU_cs communicate with the serving BS via the help of the RSs. It assumed that the MUs are served by the closest nodes in the network. Let BS_0 and RS_0 be the closest base station and the closest relay, respectively, to a typical MU. MU is classified as MU_{nc} if its distance to BS_0 is less than that to RS_0. Similarly, it is designated as a MU_c if RS_0 is closer to this MU than BS_0. Also, RSs are associated with the closest BS, denoted by BS^R.

As shown in Fig. 1, BS0-MUnc and BS0-RS0-MUc links work in non-overlapping frequency bands with bandwidths Bnc and Bc, respectively. A two-slot synchronous communication protocol is assumed in each cell for the BS0-RS0MUc link. In the first time slot, BSs transmit signals to RSs, while in the second time slot, RSs forward the data (decoded from the received signal in the first time slot) to the MUcs.

The time duration of both time slots are assumed to be equal. Since separate frequency bands are assumed, the other-cell interference at MUnc is due to the BSs that use the same resource block with BS_0. Similarly, the other cell interference at RSs is from the BSs operating at the same frequency with BS^R, and interference at MU_c is due to the RSs using the same frequency with RS_0.

Incorporating emerging technologies such as Reconfigurable Intelligent Surfaces (RIS) and Unmanned Aerial Vehicles (UAVs) can significantly improve the performance of relay-assisted mmWave networks. RIS can be utilized to passively reflect signals towards the receiver, enhancing signal strength and reducing the need for high transmit power.

4-PROPOSED SYSTEM

A key feature of mmWave cellular networks is expected to be heterogeneity to have higher data rates and expanded coverage. A general model for heterogeneous cellular networks is described as a combination of K spatially and spectrally coexisting tiers which are distinguished by their transmit powers, spatial densities, blockage models.

For example, high-power and low-density large-cell BSs may coexist with denser but lower power small-cell BSs. Small cell BSs can help the congested large-cell BSs by offloading some percentage of their user equipments (UEs), which results in a better quality of service per UE. Moreover, to provide more relief to the large-cell network, cell range expansion technique which is enabled through cell biasing for load balancing was considered.

Several recent studies have also addressed heterogeneous mmWave cellular networks. In authors consider two different types of heterogeneity in mmWave cellular networks: spectrum heterogeneity and deployment heterogeneity. In spectrum heterogeneity, mmWave UEs may use higher frequencies for data communication while the lower frequencies are exploited for control message exchange. Regarding deployment heterogeneity, two deployment scenarios are introduced. In the stand-alone scenario, all tiers will be operating in mmWave frequency bands, while in the integrated scenario, µWave network coexists with mmWave networks.

A similar hybrid cellular network scenario is considered in for characterizing uplinkdownlink coverage and rate distribution of self-backhauled mmWave cellular networks, and in for the analysis of downlink-uplink decoupling. In both papers, mmWave small cells are opportunistically used and UEs are offloaded to the µWave network when it is not possible to establish a mmWave connection.

In a hybrid spectrum access scheme (where exclusive access is used at frequencies in the 20/30 GHz range while spectrum sharing is used at frequencies around 70 GHz) is

considered to harvest the maximum benefit from emerging mmWave technologies. A more general mathematical framework to analyze the multi-tier mmWave cellular networks is provided. In benefits of BS cooperation in the downlink of a heterogeneous mmWave cellular system are analyzed. Contrary to the hybrid scenario, each tier is assumed to operate in a mmWave frequency band.

Similarly, in this chapter we consider a cellular network operating exclusively with mmWave cells, while, as we demonstrate extension to a hybrid scenario can be addressed and a similar analytical framework can be employed by eliminating the unique properties of mmWave transmissions in the analysis of the µWave tier.

Stochastic geometry has been identified as a powerful mathematical tool to ana lyze the system performance of mmWave cellular networks due to its tractability and accuracy. Therefore, in most of the recent studies on heterogeneous and/or mmWave cellular networks, spatial distribution of the BSs is assumed to follow a point process and the most commonly used distribution is the RTT due to its tractability and accuracy in approximating the actual cellular network topology.

In authors provide a comprehensive tutorial on stochastic geometry based analysis for cellular networks. Additionally, a detailed overview of mathematical models and analytical techniques for mmWave cellular systems are provided Since the path loss and blockage models for mmWave communications are significantly different from µWave communications, three different states, namely LOS, NLOS and outage states, are considered for mmWave frequencies For analytical tractability, equivalent LOS ball model was proposed. In authors considered probabilistic LOS ball model, which is more flexible than the LOS ball model to capture the effect of different realistic settings.

In, probabilistic LOS ball model is generalized to a two-ball model, which is based on path loss intensity matching algorithm. Path loss intensity matching approach to estimate the parameters of the path loss distribution is also employed.

Coverage in millimeter Wave in 5G Cellular Networks

We provide an analytical framework to analyze heterogeneous down-link mmWave cellular networks consisting of K tiers of randomly located BSs where each tier operates in a mmWave frequency band. Signal-to-interference-plus-noise ratio (SINR) coverage probability is derived for the entire network using tools from stochastic geometry.

The distinguishing features of mmWave communications such as directional beamforming and having different path loss laws for LOS and NLOS links are incorporated into the coverage analysis by assuming averaged biased-received power association. By using the noise-limited assumption for mmWave networks, a simpler expression requiring the computation of only one numerical integral for coverage probability is obtained. Also, effect of beamforming alignment errors on the coverage probability analysis is investigated to get insight on the performance in practical scenarios. Downlink rate coverage probability is derived as well to get more insights on the performance of the network. Moreover, effect of deploying low-power smaller cells and the impact of biasing factor on energy efficiency is analyzed. Finally, a hybrid cellular network operating in both mmWave and µWave frequency bands is addressed.

Millimeter-wave (mmWave) frequencies, typically ranging from 24 GHz to 100 GHz, are pivotal in realizing the high-speed, low-latency objectives of 5G cellular networks. These frequencies offer substantial bandwidth, enabling ultra-fast data rates and supporting applications such as augmented reality (AR), virtual reality (VR), and the Internet of Things (IoT). However, mmWave signals exhibit significant propagation challenges that can impact coverage, especially in urban and indoor environments.

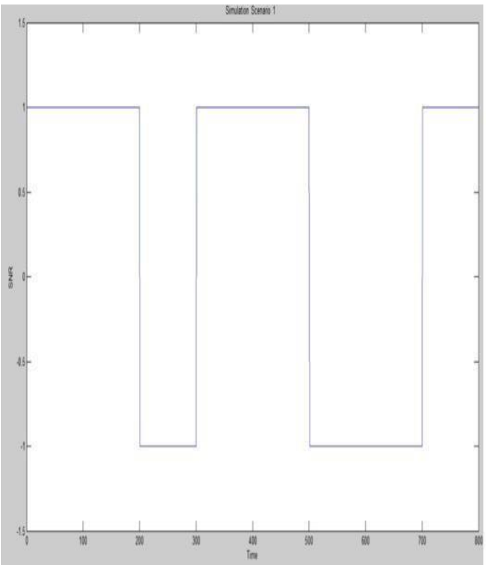
The primary challenge in mmWave propagation is the substantial path loss, which escalates with frequency. This phenomenon is exacerbated in non-line-of-sight (NLOS) conditions, where obstructions such as buildings and foliage impede signal transmission. Consequently, mmWave signals are highly susceptible to blockage, resulting in reduced coverage areas and potential service outages in obstructed regions. Additionally, atmospheric factors like humidity and rain can further attenuate mmWave signals, though their impact is generally less pronounced than that of physical obstructions.

5-RESULT AND ANALYSIS

Phase-1

In the phase 1 output, we will show the efficiency for multiple users using mm wave.We applied two scenarios the first scenario similar to the simulation which is related to TCP performance over mmWave for RTT, CWnd, throughput and SINR. That has been done through running the mmwave-tcp-building example, which is publicly available at GitHub, to analyze the performance of TCP flows over an mmWave link even to get the same RTT, CWnd, throughput and SINR results for this scenario.

The procedure of performance analysis for the previous results is shown in the previous section. The scenario creates 10 buildings distributed between BS and UE randomly. The number of antennas at the BS and UE is 70 and 20.



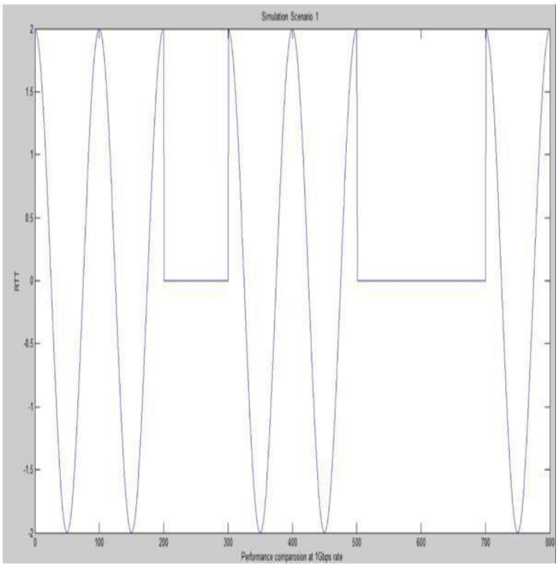
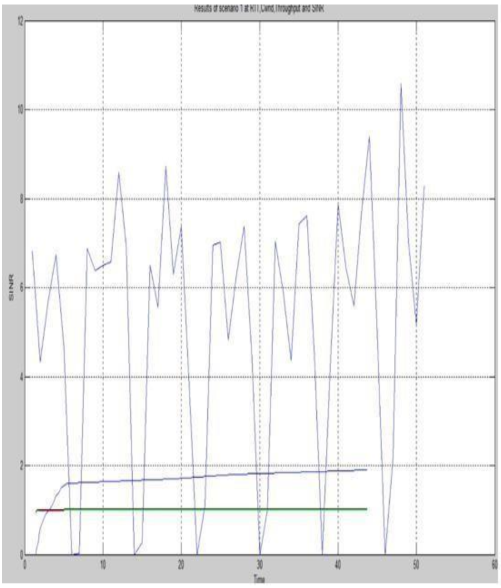


Figure 1: Time Vs SNR

Figure 2: Performance Comparison at 1Gbps Rate Vs RTT



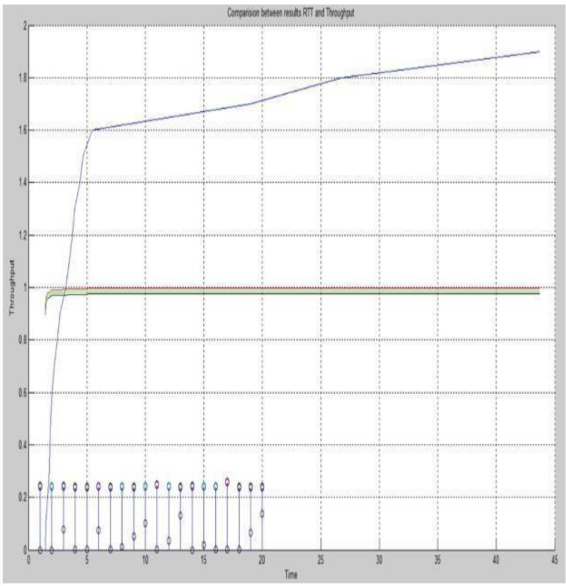
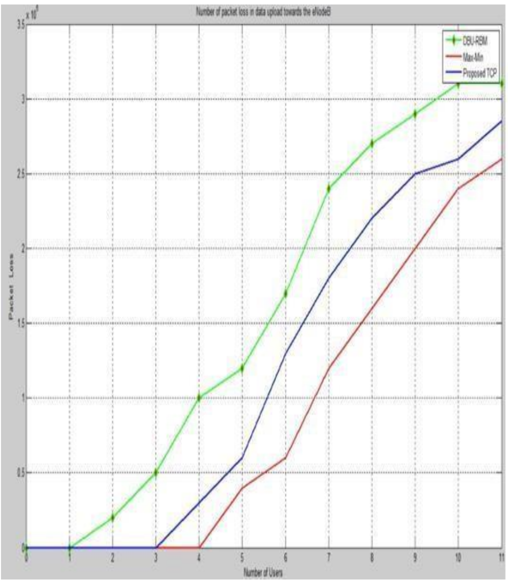


Figure 3: Time Vs SINR

Figure 4: Time Vs Throughput

Phase-2

In the 2nd output, we will show the efficiency for multiple users using TCP mechanism in mmwave and it is essential to have minimize latency and maximize throughput.



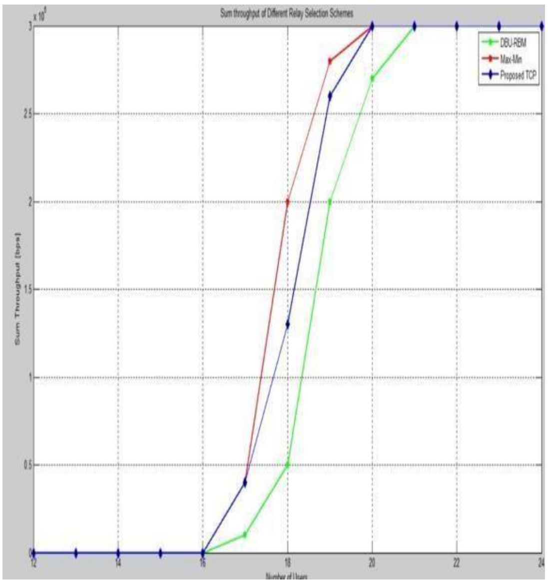
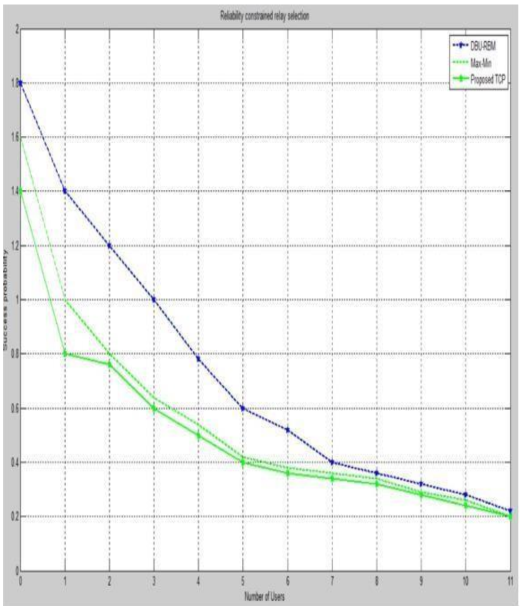


Figure 5: Number of Users Vs

Figure 6: Number of Users Vs Packet Loss

Sum Throughput



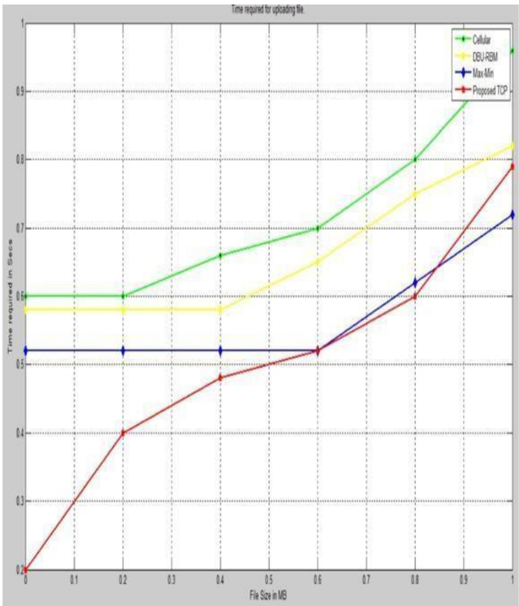


Figure 7: Number of Users Vs

Probability

Figure 8: File Size Vs Time Success

Required in Sec

Analysis

The analysis of TCP protocol performance over mmWave in 5G cellular networks was conducted using two distinct scenarios. The initial scenario focused on replicating existing simulation results, specifically examining Round Trip Time (RTT), Congestion Window size (CWnd), throughput, and Signal-to-Interference-plus-Noise Ratio (SINR). This was achieved by utilizing the publicly available "mmwave-tcp- building" example from GitHub, allowing for a comparative analysis of TCP flow performance over mmWave links.

This replication served to validate the simulation framework and establish a baseline for further investigation. The simulation involved a realistic urban environment with 10 randomly distributed buildings between the Base Station (BS) and User Equipment (UE), employing 70 and 20 antennas at the BS and UE, respectively. This setup allowed for a detailed examination of TCP's behavior in a complex, multi-path propagation environment characteristic of mmWave deployments.

Comparison Table

Comparison Table for mmWave and TCP over mmWave is as shown below:

Parameters	mmWave	TCP over mmWave
Throughput	50Mbps-1200Mbps	100Mbps-2000Mbps
Packet Loss	0.1%-9%	0.1%-5%
RTT	10msec-250msec	5msec-150msec
SINR	0dB-20dB	>20dB
Efficiency	40%-65%	70%-90%

Table Comparison Table

The comparison table highlights the distinct characteristics of mmWave and TCP over mmWave technologies. While mmWave offers superior raw throughput and extremely low RTT, suggesting its potential for high-bandwidth, low-latency applications, it also exhibits higher packet loss and lower efficiency. In contrast, TCP over mmWave prioritizes reliability and network efficiency, achieving lower packet loss, slightly higher RTT, and significantly better efficiency, with a generally lower maximum throughput. The SINR values also indicate a better signal quality for TCP over mmWave.

However, these gains come with increased energy consumption and greater complexity in channel estimation, as well as a higher dependence on network conditions. Therefore, while TCP over mmWave is highly advantageous for applications requiring ultra-high-speed and low-latency communication

6-CONCLUSION

In this paper, introduced the designing an end-to-end mmWave module to analyze the performance of TCP through increasing the data rate and decreasing latency not only inside the PHY and MAC layers but also in mmWave TCP protocols. To achieve the design end-to-end mmWave module, the simulation used LENA mmWave module for matlab. This module is the first open-source framework that allows the simulate end-to-end performance of 5G mmWave networks. The structure of the classes is based on the ns-3 LTE module, which is implemented with an interface paradigm. Two scenarios 3and 6 buildings are used in this paper, these scenarios have been applied to the analysis of the performance of TCP flows over a mmWave link even to get the same parameter measurements RTT, CWnd and throughput results for these scenarios.

The study emphasizes the need to balance high data rates with low latency in mmWave deployments. TCP's sensitivity to latency makes it crucial to address factors that contribute to increased RTT, such as signal blockages and handovers. The results further reinforce the necessity of adaptive TCP protocols that can dynamically adjust to the rapidly changing channel conditions in mmWave networks. This includes mechanisms for efficient congestion control and robust error

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