Analysis of High Frequency Uplink Downlink Channel Parameter with Various K Factor

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***Abstract*—This paper presents an in-depth analysis of high-frequency uplink and downlink channel parameters, exploring their dynamics under varying K-factor conditions. The ratio of the power in the direct path to the power in the distributed paths, or K-factor, must be thoroughly understood in order to optimize performance in wireless communication systems. The study employs a comprehensive approach to investigate how different K-factor values influence key channel parameters in both uplink and downlink transmissions. Through systematic experimentation and analysis, the research sheds light on the variability of signal strength, delay spread, and other essential parameters across a spectrum of K-factor scenarios. The findings provide valuable insights into the nuanced interactions between K-factor and channel characteristics, offering a foundation for the development of adaptive communication systems that can dynamically adjust to diverse propagation environments. This research contributes to the refinement of high-frequency communication strategies, fostering advancements in the design and implementation of wireless networks for enhanced reliability and efficiency across a range of K-factor scenarios.**

***Index Terms*—High Frequency; Uplink; Downlink; Channel parameters; K-factor; Wireless Communication Systems; Signal Strength; Delay Spread; Adaptive Communication Systems; Propagation environments.**

I. INTRODUCTION

Wireless communication involves data transmission between two or more devices without the reliance on physical wires. The converted data into signals by transmitting devices are transmitted through the air. To retrieve the original data, receiving devices decode these transmitted signals [1]. The adoption of wireless communication technology offers unparalleled mobility and flexibility, allowing users to communicate without being confined to specific geographical regions. This is particularly vital in scenarios where individuals need to communicate on the move, as exemplified by the widespread use of mobile phones [2]. A significant advantage of wireless communication lies in its ability to provide communication services in areas where constructing traditional cable infrastructure may be impractical or cost-prohibitive. This accessibility makes wireless networks particularly beneficial for remote and underdeveloped regions. Moreover, wireless networks exhibit high scalability, enabling the seamless addition of more users and devices. This scalability contributes to the adaptability and efficiency of wireless communication systems, making them well-suited for dynamic and evolving communication needs [3-4].

In the rapidly evolving landscape of wireless communication systems, the optimization of channel parameters plays a pivotal role in ensuring robust and efficient data transmission. As the demand for higher data rates and improved connectivity continues to surge, understanding the intricacies of uplink-downlink channel behaviour becomes paramount [5]. The uplink, also known as the "reverse link" or "upstream," is the communication channel required to transfer user-generated data, requests, or signals from the user equipment to the network infrastructure [6]. The downlink sometimes referred to as the "forward link" or "downstream," is responsible for information transfer from the network infrastructure to the user devices [6]. The uplink and downlink communication channels, being the lifeline of wireless networks, exhibit complex behaviour influenced by factors such as fading, interference, and environmental conditions. The K-factor, representing the ratio of the power in the direct path to the power in the scattered paths, emerges as a critical determinant in characterizing the channel's reliability and performance. As high-frequency communication technologies become integral to modern telecommunications, unravelling the dynamics of these channels and their correlation with different K-factors becomes imperative [7].

In this paper, we employed the Qualnet real-time simulator to conduct simulations, systematically varying the K-factor to observe its influence on path loss, signal power, and end-to-end delay. The resulting dataset encapsulates the outcomes of these simulations, and leveraging the matplotlib library, we visually represented the collected data through graphs. By plotting the performance metrics against varying K-factor values, we aimed to discern trends and patterns that could inform us about the optimal K-factor for enhanced high-frequency communication. Our analysis and interpretation of the graphs are focused on identifying the K-factor values associated with minimized path loss, maximized signal power, and reduced end-to-end delay. Ultimately, this data-driven approach allows us to conclude the most suitable K-factor for achieving improved communication quality for real-time wireless communication scenarios.

Rest of the paper is organized as follows: Section 2 reviews related works. Section 3 describes the system model. The graphical analysis is discussed in Section 4. Section 5 concludes the paper.

II. LITERATURE REVIEW

In order to keep up with the increasing network traffic, cellular networks are evolving from a single-tier homogeneous network to multi-tier heterogeneous and small cell networks (HetSNets) in which low power nodes offload macrocells and increase the system capacity with an aggressive frequency reuse distance. However, this radio planning paradigm cannot avoid problems, load imbalance and suboptimal uplink (UL) downlink (DL) performance being two of the most important ones [8]. DL and DL joint communication and sensing (JCAS) technologies have been individually studied for realizing sensing using DL and UL communication signals, respectively in [9]. In this paper [9], we propose a novel DL and UL cooperative (DUC) JCAS scheme, including a unified multiple signal classification (MUSIC)-based JCAS sensing scheme for both DL and UL JCAS and a DUC JCAS fusion method. The uplink resource allocation algorithm for LTE/LTE-A is presented in [10]. In order to increase system throughput and spectrum efficiency, a dynamic sliding window-based resource allocator is proposed in this work [10]. A performance analysis of LTE cell capacity is conducted in the presence of several MIMO deployments, where multiple antennas at both the transmitter and the receiver are considered in [11]. A comprehensive simulation study of different multiple antenna configurations in the presence of uplink and downlink ICI and cell edge throughput is presented in [11]. The rician K factor in a lab environment at frequencies between 25GHz and 40 GHz for both the (LOS) Line-of-Sight and (NLOS) Non-Line-of-Sight situations channel parameters performance was analyzed in [12]. In this work [12], the mean value of K is determined for optimum 5G performance. Massive multiple-input and multiple-output (MIMO) systems have become the most persuasive technology for 5G as it increased the energy efficiency gigantically as compared to other wireless communication systems. In [13] a realistic model was proposed that augmented the spectral efficiency (SE) of massive MIMO systems where a multi-cell model scenario is considered. Channel estimation is carried out at the base stations (BSs) based on uplink (UL) transmission. The downlink (DL) transmission model is also modeled in [13] with different preceding schemes by taking the same vectors used in combining schemes. The rician K factor based estimation is made using different carrier frequencies in [14]. The estimation achieves extremely excellent results for low signal to noise (SNR) and K values factor. The proposed system model is discussed in the next section.

III. SYSTEM MODEL

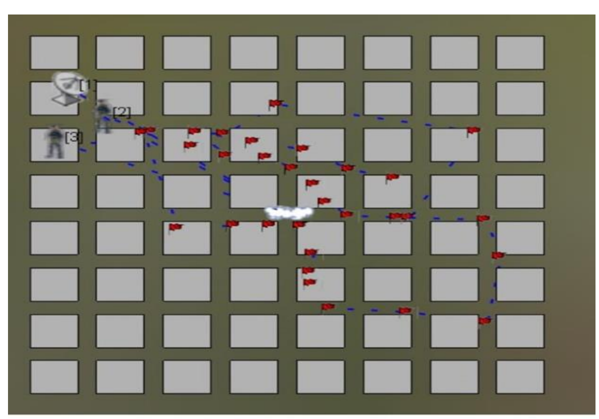

Figure 1: Proposed Network Model

Fig.1 shows the proposed network scenario. This diverse urban environment is characterized by its infrastructure which may include buildings, streets, and other urban features. The geographical details of this location are unspecified, emphasizing the generality of the study to represent a typical urban setting.

The scenario of Fig. 1 comprises three key entities: an access point (AP), user_1, and user_2. The role of the access point is to act as an intermediary for communication between user_1 and user_2. The dynamics of this interaction are crucial for understanding the challenges and optimizations in wireless communication. The network's communication links are divided into downlink and uplink. The transmission of data, signals, or information from the user's device to the central access point is referred to as the uplink, and it is the communication line from user 1 to the access point. On the other hand, the downlink denotes the communication link between user_2 and the access point, including the data or signal flow from the central access point to the user's device.

The choice of a random urban location is significant as it introduces real-world complexities and challenges commonly associated with urban environments, such as signal reflections from buildings, potential obstructions, and varying distances between users and the access point. These factors contribute to the realistic simulation and analysis of wireless communication scenarios. Table 1 represents the simulation parameters of the proposed network model. The high-frequency (HF) channel modelling for uplink and downlink communication involves capturing the characteristics of signal propagation, including attenuation, delay spread, and multipath effects. Attenuation refers to the loss of signal strength as it propagates through the channel. For HF channels, path loss models often incorporate distance-based attenuation and frequency-dependent attenuation due to factors such as free space loss (PL_{FS}) and ionospheric absorption(PL_{ION}). Eq.1 shows the factors influenced the path loss (PL).

$$PL = PL_{FS} + PL_{ION} \qquad (1)$$

Delay spread refers to the temporal spread of the received signal due to multipath propagation. It characterizes the time difference between the arrival of the earliest and latest multipath components.

Table 1: Network Simulation Parameters

SCENARIO PROPERTIES	RANGE	
Location	SW Corner	NE Corner
	Lat:31.306203 Lon: 45.266230	Lat: 31.314303 Lon: 45.274330
Frequency	900MHz to 2000GHz	
K Factor	4 to 12	
Simulation Time	3200 Sec	
Environment	Metropolitan	
Fading Model	Rican	
Default Shape Type	Building	
Roof Height	21.0 meter	
Street Width	20 meter	
Building Separation	30 meter	
Default Foliage Height	25 meter	
Default Foliage Density	0.15 meter	
Signal Propagation Speed(m/s)	3E8	
propagation Limit(dBm)	-111.0	

A simple model for delay spread Δτ in HF channels can be represented by the Ricean fading model is shown in eq.2.

$$\Delta\tau = \frac{1}{B} \qquad (2)$$

In eq.2 'B' represents the coherence bandwidth, which represents the bandwidth over which the channel impulse response is approximately constant.

In high-frequency (HF) channels, the Rician fading model can be applied with appropriate modifications to account for channel characteristics such as ionospheric effects, multipath propagation, and environmental conditions. The Rician K-factor and parameters of the LOS and scattered components can be adjusted based on empirical measurements or channel modeling techniques specific to HF communication. The Rician fading model assumes that the received signal consists of both a deterministic LOS component and a random scattered component. It is characterized by a Rician distribution, which is a variation of the Rayleigh distribution that includes a non-zero mean value. In the Rician fading model, the received signal **(h)** amplitude is expressed in eq. (3).

$$h = \sqrt{K}.h_{LOS} + \sqrt{1-K}.h_{NLOS} \quad (3)$$

Section IV represents detailed analysis of uplink downlink channel behaviour under variable K-factors.

IV. RESULT AND ANALYSIS

This section provides valuable insights into the key factors influencing wireless communication performance, guiding the design and optimization of uplink-downlink for enhanced reliability and efficiency.

A. Average Path loss Vs Frequency

This study aims to evaluate the average path loss behavior for both the uplink and downlink communication systems. The investigation delves into the intricate relationship between Average path loss and frequency across different K Factors. To maintain control and precision in the study, the distance of both the users (U1 and U2) from the Access Point is kept constant, while other parameters are systematically adjusted. This study seeks to provide valuable insights into the system's behavior under diverse circumstance

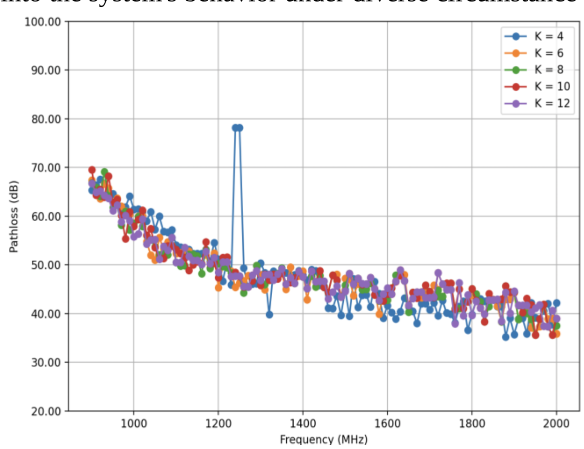

Figure 2: Path Loss Behavior during Communication through Uplink

The graphical representations in Fig. 2 and fig. 3 enhance the path loss relationship with frequency under variable K-factors. Fig.2 illustrates the relationship between path loss and frequency for uplink communication, while Fig.3 provides a corresponding representation for downlink communication.

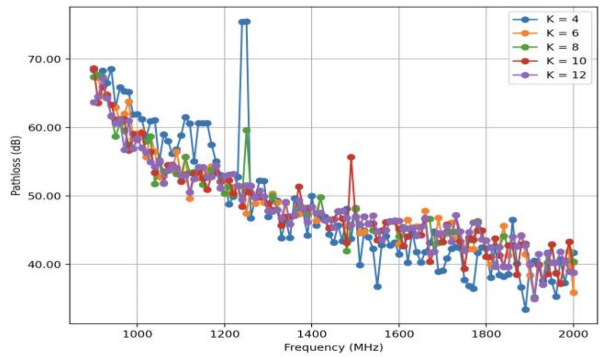

Figure3: Path Loss Behavior during Communication through Downlink

Notably, the consistent observation across both cases is that a K-factor value '10' yields the most favorable outcomes. The identified optimal K-factor of 10 underscores its significance in achieving the best system performance.

The presented data not only contributes to a deeper understanding of the system behavior but also offers practical insights for decision-making in system configuration and performance enhancement strategies.

B. *Average Signal Power vs Packet Loss*

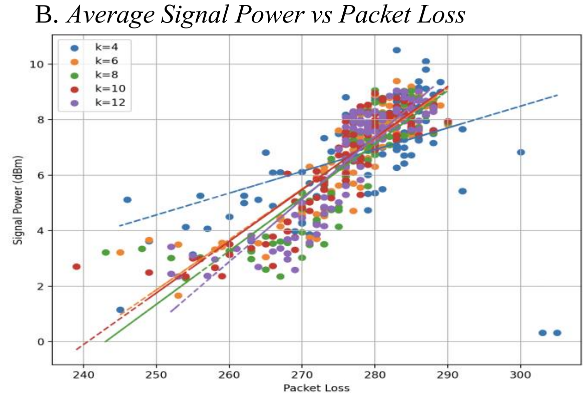

Figure 4: Packet Loss Variation w.r.t Signal Power during Uplink Communication

In fig.4 and fig.5, we explore the graphical representation of packet loss variation concerning average signal power for both uplink and downlink communication. Signal power exhibits an inverse relationship with packet loss. Numerous factors influence the intricate interplay between average signal strength and packet loss in a communication system, with fading channels, especially prevalent in wireless communication settings, often being associated with the K-factor.

A higher K-factor signifies a more pronounced line-of-sight component, potentially leading to increased communication stability and reduced packet loss through diminished fading effects. Notably, in both fig.4 and fig.5, the optimal result is consistently achieved when K-factor is set to 10.

This observation implies that, in comparison to other K values, a K-factor of 10 contributes to minimum packet loss. Consequently, this enhances the efficiency of a scenario, facilitating smoother transmissions with minimal or no packet loss.

The data gleaned from these figures not only sheds light on the nuanced relationship between signal power and packet loss but also underscores the practical benefits of selecting an optimal K-factor for improved system efficiency.

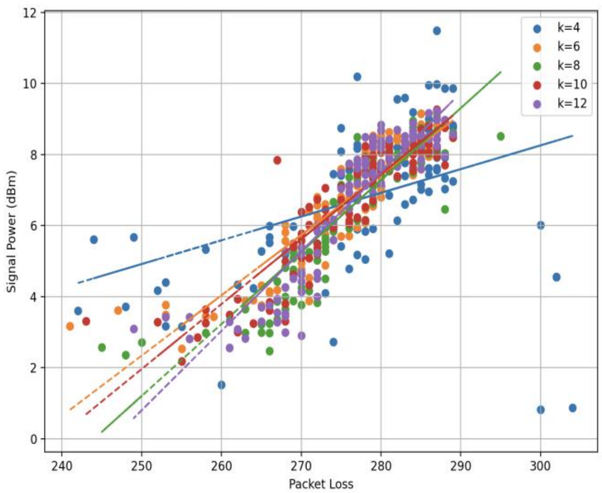

Figure 5: Packet Loss Variation w.r.t Signal Power during Downlink Communication

C. *Delay vs frequency*

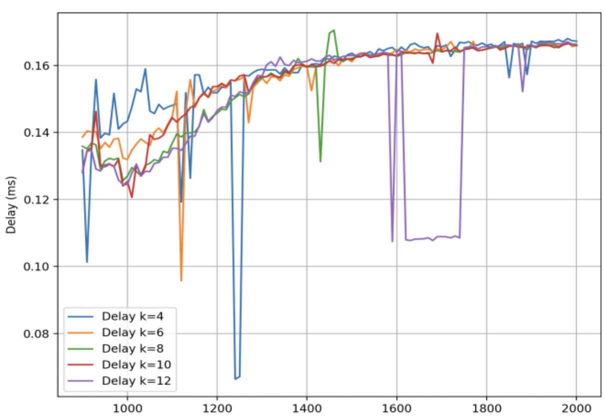

Figure 6: Transmission Delay variation w.r.t Frequency

Fig.6 shows the correlation between frequency and transmission delay for different K-factor values. This relationship is important since it helps to maximize communication effectiveness. It achieves a balance between data transfer speed and coverage, two important factors in creating efficient communication systems. The text indicates that a K-factor of 10 produces the best result when compared to alternative K values. This suggests that the latency reduces and faster signal transmission is possible when the K-factor is set to 10. This result emphasizes how crucial it is to choose the right K-factor in order to attain the best possible communication performance. By understanding and using the inverse relationship between delay and frequency, communication systems can be fine-tuned to match specific requirements, enabling efficient data transfer while retaining acceptable coverage.

V. CONCLUSION

This study provides a thorough analysis of the intricate dynamics of high-frequency uplink and downlink performance under varying K-factor conditions. The K-factor, representing the relationship between direct and scattered power, plays a crucial role in wireless communication systems, necessitating a comprehensive understanding of performance optimization. Through rigorous simulations and analysis, this work has significantly contributed to signal propagation characteristics, encompassing aspects such as path loss, fading, and interference within the context of 5G networks. The study's conclusions not only illuminate the variability of signal strength and delay spread across a spectrum of K-factor scenarios but also deepen our understanding of the intricate connections between K-factor and channel parameters. The proposed network performs most efficiently while selecting the K-factor value 10. This newfound knowledge forms a cornerstone for the advancement of high-frequency communication strategies. By refining our understanding of these relationships, we contribute to the ongoing efforts in designing and implementing wireless networks that exhibit enhanced reliability and efficiency across a diverse range of K-factor scenarios.

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