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Performance Evaluation of Energy Efficiency and Spectral Efficiency: NOMA vs OFDMA

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Abstract

Non-orthogonal multiple access (NOMA) has emerged as a promising technique to satiate the fifth generation (5G) requirements like high spectral efficiency, energy efficiency, increased throughput and optimized sub-channel utilization over the previously deployed orthogonal multiple access (OMA). In this paper, we employ a low-complexity fractional power allocation algorithm to allocate to each user in the Base Stations transmitting area. In this paper, we aim to explore energy efficiency versus spectral efficiency trade off with average signal to noise ratio by employing superposition method to effectively utilize the sub-channel with Successive Interference Cancellation in the downlink case at the receiver end to achieve the expected simulations results. Furthermore, we have also studied the effect on spectral and energy efficiency with increased number of users in the cellular area. Finally, we have presented simulation results to corroborate our proposed results where SE increases when we increase transmission power and Signal to noise ratio.

Keywords: Non-Orthogonal Multiple Access • Orthogonal Multiple Access • Successive Interference Cancellation • Sum rate • Energy Efficiency • Spectral Efficiency • Superposition Theorem • Signal to Interference Noise Ratio

Introduction

For the past two decades the Orthogonal Frequency Division Multiple Access (OFDMA) has been the optimum technique for the LTE (IEEE 802.16standards) or fourth generation (4G) wireless networks and Wi-fi standards (IEEE 802.11). OFDMA or Multiuser-OFDM is the technique which incorporates multiple-users on the same time and frequency multiplexed channel. In OFDMA M users are assigned to N sub-channels and each user is strictly assigned to only one sub-channel. Other previous Orthogonal Multiple Access (OMA) techniques like TDMA, FDMA and CDMA [2] were popular schemes for 3GPP standards in 3G and beyond. But because of improved fast fading following the Rayleigh Model and multicarrier property of OFDMA, it was chosen as a promising scheme for 4G and beyond (LTE and LTE-A) [1].

The problem of ever-increasing data rate and the need to satisfy the users demand of higher data rates, ominous connectivity and to incorporate the 500-1000 times mobile connection in 2020 we need a revamped technique that can keep up with these requirements and Non-orthogonal multiple Access (NOMA) is a promising solution. NOMA is envisaged as a promising solution to the mentioned problem because of high throughput, spectral efficiency and energy efficiency of the entire system across bandwidth B. major NOMA solutions for future communication systems which we have proposed is power domain NOMA [3].

Downlink NOMA at the receiver side works on the principle of Superposition coding where it stacks up the messages for desired users on the constraint of power levels. NOMA is different from the traditional Orthogonal Division Multiple Access (OFDM) where messages are overlapping orthogonally in the entire bandwidth with independent time and frequency slots. Compared to OFDMA where only one user is supported over a particular sub-channel, in NOMA multiple users can be supported over a sub-channel. In this paper to avoid complexity at the receiver side at most two users are assigned over a sub-channel. For power domain NOMA case Successive Interference Cancellation (SIC) is performed at the receiver side. The overall improvement in rate and spectrum efficiency is due to SIC which decodes the messages of the desired user as well as messages of the users having poorer channel gains and treating the users having higher channel gains as interference [4]. Thus, eliminating the unwanted interference as noise and decoding the desired messages.

Related Works and Motivation

Ever since the introduction of NOMA as an alternative technology for 5G communications over OMA schemes the task was to provide the ITU union with solution to higher data rate requirement, trade off between energy and spectrum efficiency and most important optimization of user assignment and power utilization.

The optimization of the power allocation and energy efficient sub-channel assignment are the key schemes for NOMA to outperform OMA. The authors in [7] studied SIC and energy efficient systems for NOMA. The same authors introduced Difference of Convex (DC) to find out the optimal solution for power allocation co-efficient β. In [8] , [9] and [10], the authors implemented MIMO-NOMA scheme over the standard single antenna system for NOMA using DC approach as well . The Fractional Transmit Power Allocation was extensively studied in [8] and [9] where only two users were used to carry out the simulations to avoid complexity and for that the fractional power allocated was same for all the users tagged to a base station. The allocated same power to all

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users was used to witness the energy and spectral efficiency and rate for NOMA with fractional power allocation against the OFDMA[11].

The authors in [9-11] introduced SOMSA algorithm for user assignment and sub-channel power distribution based on energy efficient channel gains with Difference of convex method to implement power allocation for energy efficiency maximization. In [7] the authors used two step heuristic approaches to optimize power and maximizing energy usage in the system via sum rate maximization. The same letter included greedy algorithm for user selection.

Contribution

Work in [7] and [9] was related to equal power distribution across the users which was easier to implement without any real wireless channel fading conditions and produced results which were only theoretically easy to simulate. Hence, to gather information on the real time simulation we have implemented fractional power allocation scheme with varying power levels assigned to each user as depicted in NOMA. Here, we have employed a downlink NOMA scheme where the distance of the users from the BS and the fraction of the total distance serves the purpose of the power allocation to each user. The power allocated is different for each user where each user is randomized. In [9] and [11] authors have used same power allocation to each user but, here we rather deployed different powers to each user in different sub-channels. According to NOMA principle Successive Interference Cancellation (SIC) method can accommodate multiple user and remove users with lesser channel gains as noise resulting in better throughput. In this paper OFDMA scheme is BER driven with same channel conditions to match the two multiple access schemes [1].

While comparing the proposed NOMA fractional power allocation to the existing optimized OFDMA we have used the same channel condition which determine the power allocation to the NOMA scheme and thus provide us with Theoretically expected results for throughput, spectral efficiency and energy efficiency.

System Model

Here, we consider a downlink topology for both NOMA and OFDMA (OMA) which consists of one Base Station, N sub-channels N Є {1,2,......n} and M users where M Є {1,2,.......m}. The Base Station has a total available transmission power Pt. The total transmission power in this model increases for every different channel to noise ratio gain (CRNN values). The sub-channel in both the schemes are assigned equally distributed bandwidth of $B_n = B/N$ where B_n denotes bandwidth of each sub-channel (SCn). All the established wireless links in the downlink NOMA follow Rayleigh slow fading and additive white Gaussian noise (AWGN) with noise spectral density $x_n \sim CN(0, \sigma^2)$ with zero mean and variance $\sigma^2 n$ for each SC in the entire bandwidth. The Rayleigh fading channel co-efficient from the BS to nth user is modelled as $h_{m,n} = g_{m,n} \cdot P\,L^{-1}(d)$ and CRNN gain as $|H_{m,n}|^2 = |h_{m,n}|^2 / \sigma^2$

where $h_{m,n}$ is the channel gain of user m on SCn , $g_{m,n}$ is the channel co-efficient gain of Rayleigh fading model and $P\,L^{-1}(d)$ is the path loss model with

$$PL^{-1} = (Pt/Pr) \qquad (1)$$

and, $Pr = K.(d_m/d)^{\Upsilon}$ where Υ is the path loss exponent for urban area and K is the constant for signal propagation from BS K= (2.pi/lambda)2 .

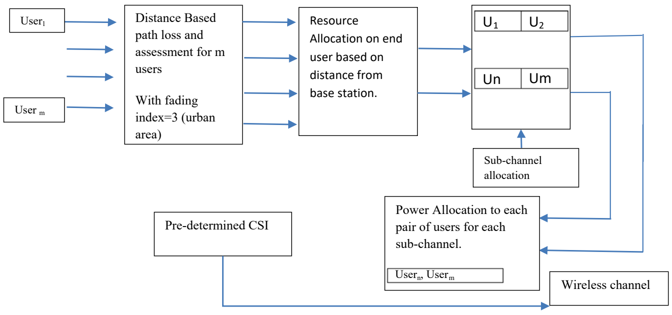

Figure 1.proposed NOMA scheme

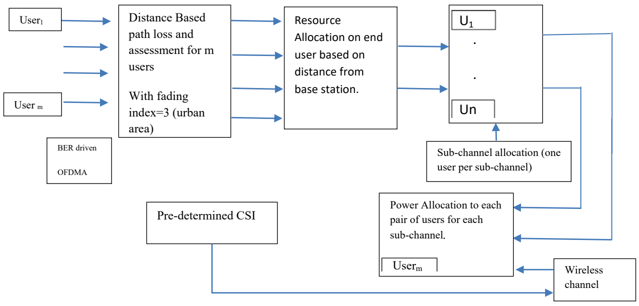

Figure 2. proposed OFDMA model

A. OFDMA

Orthogonal frequency division multiplexing (OFDM) transmission scheme is another type of a multichannel system, which employs multiple subcarriers or single user per sub-channel. OFDM is not a multiple access all by itself but when combined or incorporated with multiple access schemes like TDMA, FDMA and CDMA [2]. The OFDMA system assigns a subset of subcarriers (not all subcarriers in each OFDM symbol) to each user, where the number of subcarriers for a specific user can be adaptively varied in each frame. Unlike in the case of TDMA and FDMA which are fixed resource allocation schemes with independent dimensions like time slot for TDMA and frequency slot for FDMA, OFDMA uses combination of both for resource allocation. In fixed resource allocation optimization is not feasible but in dynamic resource allocation it adapts to user based sub-channel gains. In this paper we take BER targeted one data bit stream to carry out comparisons of OFDMA system with optimized throughput and power allocation which is better than conventional OFDMA.

Each sub-carrier has been assigned equally distributed bandwidth Bn = B/N which is narrower than the coherence bandwidth in the frequency selective fading in the entire wireless channel bandwidth.

Length of OFDMA signal is Tsymbol and each divided time slot is Ts. Here for OFDMA we allocate sm,n as the allocated power on subcarrier n for user m and following the constraint [1];

$$s_{m,n} \geq 0 \;\; \forall m, \forall n \qquad (2)$$

The throughput of the bitstream is given by

$$\gamma_{m,n} = \log 2(1 + a_m\, |Hm,n|^2\, s_{m,n}\, (Ts/T_{symbol})) \quad \forall m, \forall n \qquad (3)$$

where a_m is the coding loss related to BER for MQAM modulation [1] and

$$a_m=1.5/-\ln(5.BER) \quad [1]\ \forall m \qquad (4)$$

B NOMA Scheme

According to NOMA protocol multiple users are stacked in its bandwidth based on difference in their power levels. For example, let's take into account two user systems with sm as modulation symbol of user Um with s1∈ U1 and s2 ∈ U2 as their desired messages. It is also taken into assumption that the BS and User Equipment (UE) are equipped with single antenna system. For NOMA the expression for received signal at the receiver end is given as,

$$y_m=h_{m,n}x_n+\sigma^2 \qquad (5)$$

Considering M=2 users are allocated on the SCn, the transmitted signal x_m consisting of M messages transmitted through the BS to users is given by [6],

$$x_n=\sum_{i=1}^{M}\sqrt{\alpha_i P}\,s_i \qquad (6)$$

where α_i∈(0,1) is the power allocation co-efficient.

In the following figure, a downlink case of NOMA network is being studied. A BS transmits M users through N sub-channels with superposition encoding and SIC is employed at the receiver end to eliminate interference at the receiver end. The main advantage of NOMA over OMA is the SIC decoding technique which increases the throughput of the users in the assigned sub-channel. Working together with optimal power allocation and sum rate maximization for better spectrum and energy efficiency are the reasons for NOMA being preferred over conventional OMA schemes.

In NOMA the decoding order for the users followed by SIC is based on first decoding the messages for user with highest CRNN (Channel Ratio to Normalised Noise) value and then the messages for users with poorer channel conditions. Assuming perfect CSI knowledge at the BS of the users the optimal decoding order is illustrated as

$$|H_{1',n}|^2 \geq |H_{2',n}|^2 \geq \cdots \geq |H_{l,n}|^2 \geq |H_{l+1,n}|^2 \geq \cdots \geq |H_{M,n}|^2 \qquad (7)$$

At the receiver the strong user U_1 with $|H_{1,n}|^2 \geq |H_{2,n}|^2$ in the SCn decodes its message first by performing SIC without suffering any interference from the users with poorer channel conditions. The rate of the strong user U_1 following Shannon's capacity formula is expressed as [7],

$$R_{1,n}=B/N.\log2(1+\alpha\, H_{1',n}{}^2P) \qquad (8)$$

And the weak user U_2 considers the interference from U1 as noise and the rate of U_2 is expressed by [9],

$$R_{2,n}=\frac{B}{N}.\,log2(1+((1-\ \alpha)\mathrm{H}_{2,\mathrm{n}}^2\mathrm{P}/(1+\alpha\mathrm{H}_{2,\mathrm{n}}^2\mathrm{P}) \qquad (9)$$

Problem Formulation

In this section, we discuss the power allocation and sub-channel assignment problem by following three important constraints and then we move to enhance the spectral and energy efficiency of the entire system by maximization the Sum rate formulation of each sub-channel by using the above-mentioned constraints.

First, we look into the signal to interference noise ratio (SINR) of the users on a sub-channel because the sum rate maximization sub problem is dependent on SINR of the users. To perform SIC at the receiver following the optimal decoding order for user l which can successfully decode the messages and remove the interference of i users whose channel conditions are poor as compared to user *l* where, *i*<*l*. However, for users *i*>*l* the users with better channel conditions are treated as noise [8],

Therefore, the SINR of the system is given by,

$$SINR_{m,n}=\frac{\alpha_m P_t|H_{m,n}|^2}{1+\sum_{i=1}^{m-1}\alpha_i P_t|H_{m,n}|^2} \qquad (10)$$

Then the total rate of the system for one time slot is given by,

$$R=\sum_{n=1}^{N}\sum_{m=1}^{M}R_{m,n}\,(Pt_{m,n)} \qquad (11)$$

Resource Allocation

In this sub section the constraints for optimal power allocation and Sub-channel assignment problem are discussed. The authors in [8], [9] and [12] prove that the power optimization problem is a non-convex problem and has no global solution. They also deal with sub-channel assignment problem and power allocation problem separately because of the complexity of the algorithms. The sum rate maximization and energy and spectral efficiency trade off problem. In this paper we have used fractional transmit power allocation method to utilize the power allocation co-efficient α by initializing

$$\alpha_i=\frac{distance\ of\ user_i{}^2}{sum\ of\ users\ distance\ from\ BS} \qquad (12)$$

The sum rate maximization problem is directly affected by rate and thus to maximize the energy and spectral efficiency of the system which are defined by

$$EE=\frac{R}{P_{t\ m,n}+Pc} \qquad (13)$$

Pc is the circuit power of the system.

The following constraints are employed to optimize the energy and spectral efficiency of the system

$$max_{\alpha,P}EE=\frac{R}{P_{t\ m,n}+Pc} \qquad (14)$$

$$\text{s.t. } C1:\ \sum_{n=1}^{N}P_{t\ n}=P_t \qquad (15)$$

$$\text{C2: }\sum_{m=1}^{M}\alpha_i=1 \qquad \forall\ \text{i} \in \{1,2\ \ldots..\text{M}\} \qquad (16)$$

Constraint C1 ensures that the maximum BS transmitted power. C2 holds the power allocation co-efficient to maximum of 1. In this paper we deal with power allotted to each SC as individual problem which is dependent on CRNN gain values and power allocated to every user in the assigned SC. As mentioned earlier this power allocation is non convex and here we assign a solution to this problem based on distance of every user from the BS and thus assign power levels accordingly using (12). The problem for power to every SC used is thus solved. As the author of [9] and [12] (recheck)used equal power distribution to each sub-channel on the other hand we have taken into account the two users into account assigned to the SC and the power to each SC is allocated based on this algorithm.

Sub-channel assignment

Since the complexity at the receiver side of the downlink NOMA is very high the authors in [6] have set the maximum number of users per SC to be two and also in the user allocating algorithm we use only two users to avoid complexity in the algorithm. The Rayleigh fading path loss model employed here is pivotal to user assignment because of the fact that it also computes loss based on distance from the BS. Hence when assigning users we take into account the CRNN gains and path loss for choosing the best suited user pair. The selection of best user pair for SC's is associated with user pair of max channel gain with min channel gain which also compliments the SIC decoding and as a result increases the rate of sub-channels. The following is the user selection and SC assigning algorithm implemented:

Algorithm1: User Selection and SC Assigning

```
Initialize sub_match$_n$ $\forall$ n∈{1,2…..N} cell array for storing allocated user pair in one time-frequency frame.
Initialize sub_unmatch$_n$ $\forall$ n∈{1,2…..N} cell array for leftover user pair in the SC.
Initialize U1 vector for user pairing based on distance from BS.
for m=1:M do
    calculate CRNN gain matrix with user path loss
end for
for n=1:N do
    sort CRNN matrix with user pairing following max-min pairing method.
    pair every CRNN gain values according to user pairs from U1 and,
    for n=1:N do
        while sub_match!=0, find maximum gain value pair and assign the pair to the sub_match array and fill each sub-channel,
        end while
        while sub_unmatch==0, if every pair has been assigned to their desired SC assign zero to sub_unmatch to every SC which has been assigned.
            end if
        end while
end for.
```

Algorithm for assigning power to ever sub-channel using sub_match

After the allocation of user pairs to their desired SC's the problem arises of power distribution across the SC as equal distribution of power would result in approximately same rate for each channel assignment as this power along with CRNN gain or energy efficient power distribution is used to calculate rate from (8) and (9).

Thus to avoid this anomaly we store the power of each sub-channel in a separate matrix.

Algorithm 2: power distribution across SC

```
Initialize zero power across all sub-channel to avoid any interference with rates.
Initialize power on every user through power allocation co-efficientαi.
Initialize numcarry as number of times the user pair occurs in the sub-channels.
for m=1:M do
    assign power to every user pair by using αi and total transmit power.
end for
for n=1:N do
    get the value for number of occurrences of user pair in the time slot and divide the power of users by the numcarry and store the values into a new matrix power_match for later usage to call power for rate.
    if numcarry==0, then the power to that user pair is also zero
    end if
end for
```

For the above-mentioned algorithms, the time complexity for NOMA as well as OFDMA comes out to be

$$O((K\sum_{l=1}^{fm}\sum_{m=1}^{M}R\_sum)+(K\sum_{l=1}^{fm}\sum_{m=1}^{M}r_{total})).$$

Simulation Results

This section shows that various simulations with all the comparative analysis of the NOMA and OFDMA. The variable power allocation factor α, BS power P_{to}, circuit power Pc=1 watt and noise spectral density N_o=-70 dBm [12]. The wireless channel used corresponds to M ϵ {1,2,.......m} users as a frequency selective Rayleigh fading with each frequency multipath modelled by Clarke's Flat Fading model. Considering the Rayleigh path loss to be distance oriented with urban index of the path loss model for both the systems. All the results are averaged over 1000 time slots.

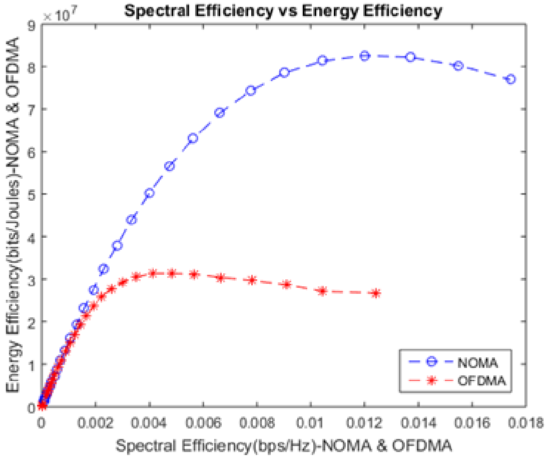

Figure 3. EE vs SE trade-off for NOMA and OFDMA

The figure 3 shows the EE vs SE trade off for both the NOMA and OFDMA schemes. The bandwidth of the system is 1MHz and as theoretically proposed we witness clearly that NOMA has positively matched the simulation results. The NOMA is evidently better than optimized OFDMA with resource allocation, sub-channel assignment and power allocation algorithms.

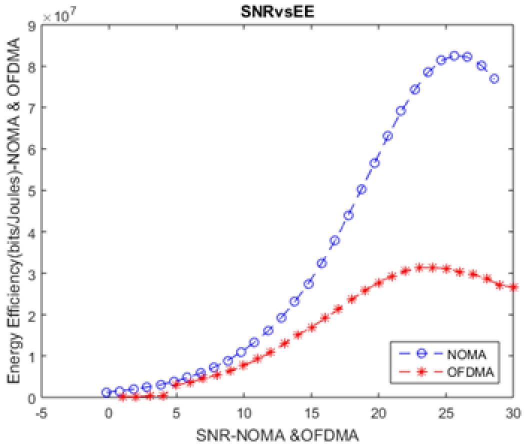

Figure 4. Signal to noise ratio vs EE

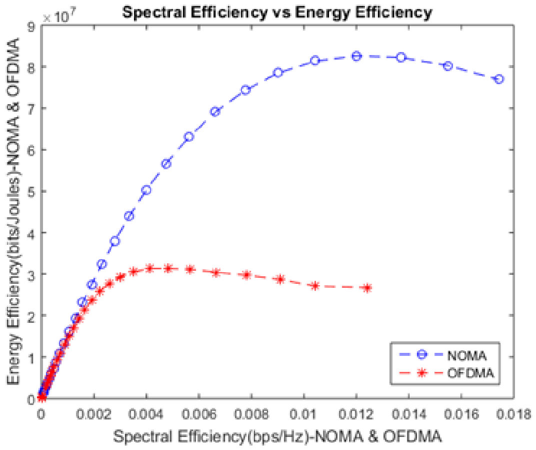

Figure 5. Signal to noise ratio vs SE

In figure 4 and 5 we observe that average SNR over the entire bandwidth the NOMA outperforms optimized OFDMA in subchannel assessment, energy efficiency and spectral efficiency. From the simulations we observe that SE and EE averaged over 1000 time slots against average SNR values are considerably higher in NOMA than In OFDMA scheme.

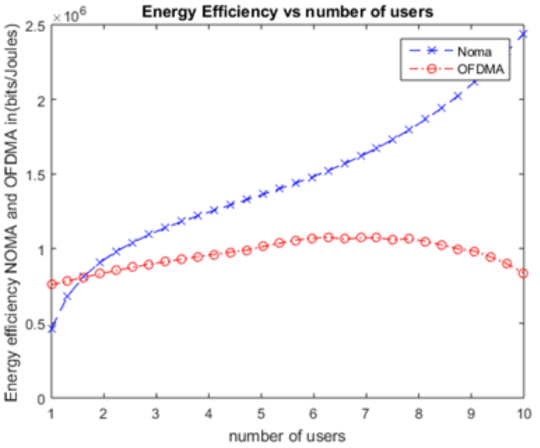

Figure 6. EE trade off vs Number of users

In these figures we have implemented the proposed schemes with increased number of users 10 with different channel conditions for each time slot. As expected with Shannon's capacity equations we have achieved higher EE and SE vs number of users trade off through sum rate capacity. Form figures 6 and 7 we conclude the proposed scheme with power allocation, and sub-channel allocation with SIC reduction has positive response with increased number users. However, a slight decrement is observed in spectral and energy efficiency for both the proposed schemes as we increase the number of users with increment in average power dissipated P_{av}=30 dBm by the base station.

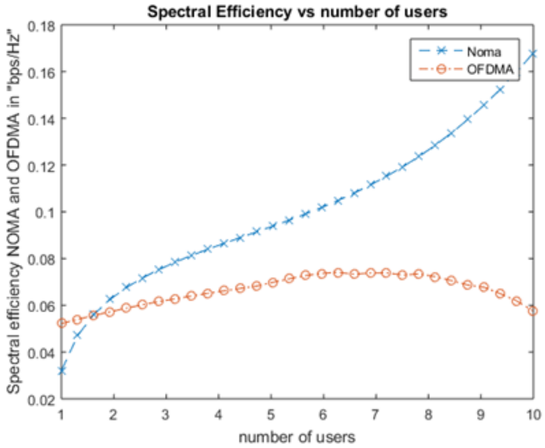

Figure 7. SE trade off vs number of users

Conclusion

In this proposition, we have studied the comparison between two multiple access schemes namely NOMA and OFDMA. The former technique is proven to be superior in comparative analysis of the two techniques in terms of spectral efficiency, energy efficiency and sum rate. The sub-channel assessment in the OFDMA is based on single user multiplexing while the NOMA can accommodate more but to avoid higher complexity in implementing SIC at the receiver end, we have focused on incorporating atmost two users in a sub-channel. Further, we have implemented fractional power allocation algorithm to assign different power levels to each user in each of the sub-channel based on the corresponding distance from the base station. Thus, the proposed algorithms including sub-channel assignment, power allocation and power assignment to a pair of user in the sub-channel all have positively outperformed previously deployed OFDMA technique to satiate the need for an alternative in fifth generation mobile communications.

Statement of authorship:

The author contributed intellectually in the work, meet the conditions of authorship and approved the final version of it.

Aakarsh Dhariwal: conception and design of the study, analysis and interpretation of data, final approval of the version to be submitted Aakarsh Dhariwal: analysis and interpretation of data, final approval of the version to be submitted.

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