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Cournot Duopoly for Spoofing Attack in MIMO with the Adaptive Antenna System

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Abstract—Wireless communication capacity & performance can be enhanced by Multiple Input Multiple Output (MIMO) technology. The signal transmitted in MIMO technology is affected by path loss, attenuation due to distance and interference. An unauthorized user known as spoofer between transmitter and receiver affects the performance of MIMO technology. An adaptive antenna technology (AAT) is proposed in this work to reduce path loss and attenuation of MIMO technology. A game theoretical approach known as Cournot duopoly is also proposed where an optimum number of transmitter and receiver antenna is used to reduce spoofing in MIMO technology.

Index Terms— AAT, CDMA, MIMO, OSM, Spoofing, Cournot Duopoly.

I. INTRODUCTION

WIRELESS communication performance can be improved by adopting Multiple Input Multiple Output (MIMO) technology, which is also known as spatial diversity [1]. MIMO can handle a large number of users which is in demand of modern wireless communication technology [1]. The major disadvantages of MIMO are interference due to a large number of users and path loss of the medium in which the signals are transmitted. The interference problem can be addressed by adopting Code Division Multiple Access Technology (CDMA) [2]. CDMA uses different codes for different users. However, the problem of path loss, also known as fading is very difficult to remove [3]. The fading is two types' large scale fading (when there is a direct path between transmitter and receiver is known as the Line of Sight or LOS) and small-scale fading (when there is no direct path between transmitter and receiver is known as Non-Line of Sight or NLOS). If the fading is removed then signal quality at the receiver is improved. The interference or fading problem removal is technology is explained in this research work.

MIMO technology can also be affected, by any unauthorized user between transmitter and receiver popularly is known as safer and the unauthorized access of information between transmitter and receiver is known as spoofing effect [4].

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In 1996 Foschini pointed out that significant system capacity will be enhanced [5] with the use of multiple antennas at the transmitter and at the receiver. Large diversity gains are desirable to reduce the effect of fading.

Thus, multipath propagation should be exploited whenever it exists [6]. Adding multipath components does not automatically lead to better performance [7] [8] [9]. For practical receiver designs multipath always lead to serious multiple access and self-interference, reducing the effective system capacity [10].

A general MIMO model which is used by 8 users is considered [11] [12]13]. The information of all the users at the transmitter (TX) are cascaded and transmitted through the medium and a receiver (Rx) their eight numbers of users are considered. A predefined attenuation model is considered in this research work. The path loss in the medium is modelled by the curve fitting method where a set of data is taken in a frequency range of 800-2000 MHz and base station antenna heights 50m over a distance of 5km [14].

The paper is arranged as follows: The system model of the transmitter (Tx) and receiver (Rx) and spoofer are considered in section II. Analysis of performance is described in section III results and discussions are shown in section IV, the conclusion is described in section V.

II. SYSTEMS MODELS

A. *Interference Removal Model*

The transmitter (Tx) is depicted in figure 1, where 8 users are cascaded and transmitted through the medium. The path loss which is known as attenuation or fading is denoted by alpha(α) is introduced in the medium. A different code is used by the individual user which is known as CDMA. Delay spread multipath environments and electromagnetic interference are a very common problem in mobile communication. In a multiuser environment, wireless transmission performance is fundamentally limited by interference due to the presence of signals from other users as well as from multipath.

One of the solutions is the CDMA technology. Scientists have tried to develop a wireless system which can work satisfactorily, even under strong interference condition under CDMA technique. The high-power jamming problem beyond Direct Sequence Spread Spectrum [DSSS] jamming margin is solved by utilizing frequency diversion technique of the carrier frequency. So, the Spread Spectrum technology along with CDMA (code division multiple access) provides a solution for multiple access with its reduced interference level.

But the Co-channel interference is suppressed in the CDMA system satisfactory up to the jamming margin level above which it is prone to interference. This may be the situation when the cars stop at the crossing of roads and the mobile units at the cars face infinite dwell time. Additionally, the limitations of data rate arise from the different speed of the user. The higher data rate is well supported for the user under low mobility condition like walking etc. But while moving in a high-speed vehicle, the multipath fading is accentuated, again at high data rate multipath distortion is more disturbing at a high data rate which in turn degrades the quality of service.

The model which is considered in this research work direct path between the transmitter (Tx) and receiver (Rx) is considered as direct path carry more power and less attenuation due to less reflection and refraction.

The receiver is described in figure 2 where a replica of the transmitted signal is received by eight receivers and multiplied by a weight which is the inverse matrix of attenuation matrix was calculated by the existing standard model. This method is named as Adaptive Antenna Technology (AAT).

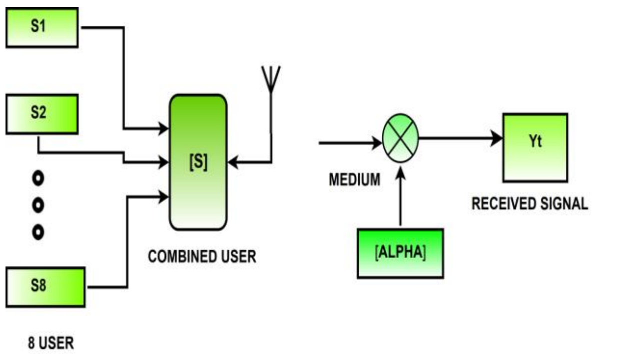

Fig. 1. Transmitter Model of the System

The path loss also can be reduced by another technology where the negative slope of frequency to distance is maintained a constant ratio which is named Optimization Slope Method (OSM)

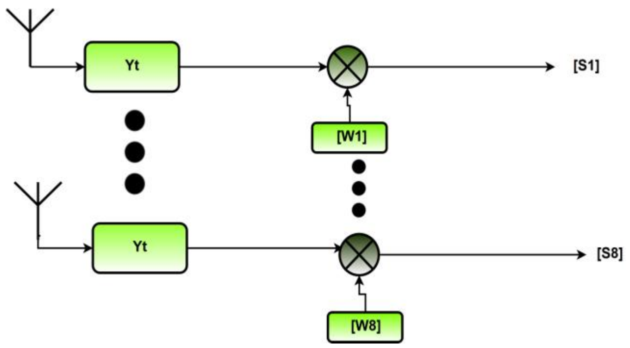

Fig. 2. Receiver Model of the System

B. Spoofing Model of the System

Spoofing is an unauthorized user contains an equal number of antennas as a transmitter and transmit the same power as a transmitter. The receiver can't detect the spoofer and assumes it as a transmitter and starts communicating with the spoofer. The spoofer takes advantage of this problem and transmits false information to the receiver [15]. The spoofer can be detected by comparing with a threshold value [4].

The spoofing attack can be reduced by enhancing the number of antennas at the transmitter as well as in the receiver [4].

However, the number of optimum numbers is not discussed by any of them. A game theoretical approach which is known as Cournot duopoly game is discussed in this work to detect a number of transmitting and receiver antennas.

The spoofing model is shown in Figure (3) where A is known as the transmitter of the system contains N_t number of transmit antennas, B is known as rea ceiver of the system contains N_r number of antennas and E is known as the spoofer which behaves same as the as transmitter.

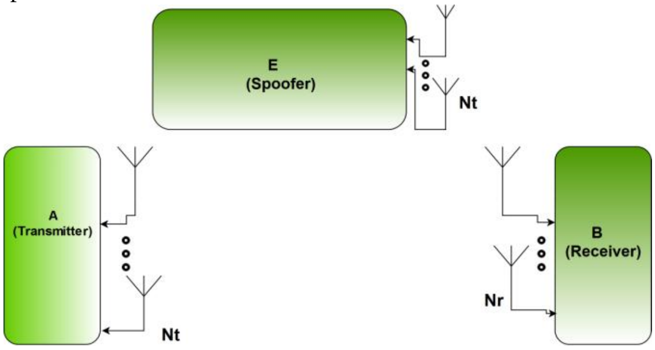

Fig. 3. Spoofing Model of the System

III. ANALYSIS OF PERFORMANCE

A. Interference Removal Model

Adaptive Antenna Technology (AAT) system plays an important role in the mitigation of multipath effects. The capacity improvement of the wireless network has drawn considerable attention to multiple-input-multiple-output (MIMO) system. Multiple antenna arrays at both the transmitter and receiver side of a communication link significantly improve the capacity over the single antenna system. A smart antenna is used widely to mitigate CCI.

An important research area for the antenna system is the processing block which consists of weight. In this work, the weights are calculated and multiplying with the incoming signal to get only the desired signal.

In this work, the weights are calculated and multiplying with the incoming signal to get only the desired signal. Here 8 mobile units and 8 antennas are considered at the receiver (Rx) station. In order to substantiate our present model, the cell size of the 1km radius and the transmitting power of 1watt are considered.

For unity gain the free space loss (α) expressed in dB as

α=(32.4 + 20*log(d) + 20*log(f))… ……………………..(1)

Where d is the distance in kilometre and f is the carrier frequency in MHz Here at the 900 MHz frequency band is considered, however, it can be calculated for 2.4 GHz also. However, for different areas, this equation will deviate from the present form.

The signal matrix is considered as below

S= $[S_1\ S_2\ S_3\ S_4 S_5\ S_6\ S_7\ S_8]$

=[29.8 30.0 31.2 28 30.7 29.4 29 30.6] ……………………………………………………………….(2)

The corresponding distance matrix is d is given by d=the corresponding attenuation matrix is calculated from equation 1.

So, the transmitted signal is given by as shown in figure 1 is

$[Y_t]=[S]_{1\times8}*[\alpha]_{8\times8}$ ……………………(3)

The weight W is calculated by the inverse of matrix α

$[W]_{8\times8}$=inverse (α)

$=[W_i]$ …………………………………(4)

Where i is varied from 1 to 8 and each W_i is an 8×1 matrix

So, at the receiver signals are received by

$S_i=[S]_{1\times8}*[\alpha]_{8\times8}*[W_i]_{8\times1}$ …………………………(5)

Now to calculate the slope for zero attenuation derivative of equation (1) with respect to d is given by

$\frac{d\alpha}{dd}=\frac{20}{\ln(10)}[\frac{1}{d}+\frac{1}{f}*\frac{df}{dd}]$ ………………………………(6)

Now if zero is equated with equation (6), then $\frac{df}{dd}$ is given by

$\frac{df}{dd}=-(\frac{f}{d})$ ……………………………………………..(7)

Hence from the equation (7), it is clear that for zero attenuation the slope value must be maintained.

B. Spoofing Model of the System

The number of optimum antennas can be detected by using the Cournot duopoly game theoretical approach. Where S_1 is the number of transmit antennas at the transmitter and at the spoofer terminal,S_2 is the number of antennas at the receiver, A is the power of the spoofer, C is the power at the transmitter and at the receiver,B is the average power at the transmitter and receiver=½(C+C)=C.

The power of spoofer can de be defined as follows

$P(S_1,S_2)$=Power of spoofer-Transmit power×Total number of antennas

$=A-B\times(S_1+S_2)$……………………………………(8)

The spoofer also contains S_1 Number of antennas. Hence the total payoff of the spoofer is given by

=(Spoofing Attack Power) × Number of antennas of the spoofer

$=(A-B\times(S_1+S_2))\times S_1$……………………………..(9)

The spoofing attack for the transmitter reduces with the number of antennas at the transmitter and with total power=CS_1 .

Hence total payoff for the spoofer with respect to the transmitter (Tx) is given by

$U_1(S_1,S_2)=(A-B\times(S_1+S_2))\times S_1-CS_1$………………(10)

$=S_1(A-B\times(S_1+S_2)-C)$……………………………….(11)

Similarly, the total payoff for the spoofer with respect to the receiver (Rx)is given by

$U_2(S_2,S_1)=S_2(A-B\times(S_1+S_2)-C)$……………………(11)

Now to find the best response derivative is performed of equation (11) with respect to S_1.

$\frac{\partial U_1}{\partial S_1}=A-C-2BS_1-BS_2=0$…………………………………(12)

Thus the optimum value of S_1 is given by from the equation(12)

$S_1^*=\frac{A-C-BS_2}{2B}$……………………………………………(13)

Thus, the optimum value of S_2 is given by

$S_2^*=\frac{A-C-BS_1}{2B}$……………………………………………(14)

Now replacing the value of S_2 at the equation (13) is given by

$S_1^*=\frac{A-C}{2B}$ - ½× S_2^*

$=\frac{A-C}{2B}$ - ½×($\frac{A-C}{2B}$ - ½× S_1^*)

$S_1^*=\frac{A-C}{3B}$……………………………………………..(15)

Similarly, S_2^* is given by

$S_2^*=\frac{A-C}{3B}$………………………………………………(16)

So the Nash Equilibrium of the game theoretical approach is given by

$=(\frac{A-C}{3B},\frac{A-C}{3B})$…………………………………………(16)

Now if the Transmitter (Tx) and Receiver (Rx) is transmitting pilot symbol which contains information of the number of transmitter and receiver antenna, then the utility function of the spoofer is given by

$U_t(S_1,S_2)=U_1(S_1,S_2)+U_2(S_2,S_1)$

$=(S_1+S_2)\times(A-C-B\times(S_1+S_2))$……………………………(17)

Now=$S_1+S_2=S_t$(Say)

Equation (17) becomes

$U_t(S_t)=(A-C)S_t-B\times S_t^2$……………………………….(18)

Now to find the optimum value of number antennas a differentiation is performed of equation (18) with respect to S_t

$\frac{\partial U_t}{\partial S_t}=(A-C)-2BS_t=0$……………………………………(19)

So, $S_t^*=\frac{A-C}{2B}$……………………………………………(20)

So the number of optimum number of transmitting and receive antennas are given by

$S_1^{**}=S_2^{**}=\frac{A-C}{4B}$……………………………………….(21)

So, the Nash Equilibrium is given by as follows

$(\frac{A-C}{4B},\frac{A-C}{4B})$…………………………………………….(22)

Table 1: Comparison Table of Two Equations

Equation Number	No. of Tx Antennas	No. of Rx Antennas	Comments
(15)	$\frac{A-C}{3B}$	---------------	The Number transmit antennas in the second equation is less, Hence It's Better
(21)	$\frac{A-C}{4B}$	---------------	
(16)	----------- -	$\frac{A-C}{3B}$	The Number receiving antennas in the second equation is less, Hence It's Better
(21)	----------- -	$\frac{A-C}{4B}$	

IV. RESULTS AND DISCUSSION

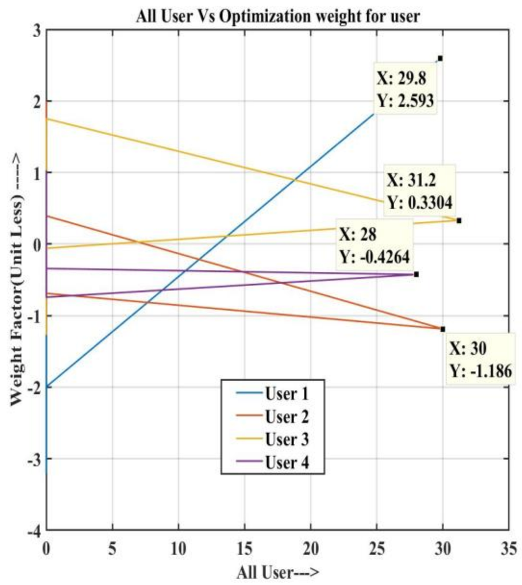

Fig. 4. Optimization Weight for User 1,2,3,4

The optimized weight value for user 1,2,3,4 is given by: W_1=[2.5929;-1.9960;-0.5079;-.1150;1.5548;1.2178;0.4298; -3.2061]; W_2= [-0.6892; -1.1864;0.3935;0.6711; -1.1515; -0.4686;0.4988 1.9951]; W_3= [-1.1521;1.7516;0.3304; -0.0592;-1.2698;-0.4183;-0.3213;1.1577]; W_4= 1.0298;0.6927; -0.7433; -0.4264 -0.3422 -0.4006 -0.4942 0.6519].

It's the inverse matrix of the attenuation thus cancel the attenuation matrix (which can be predicted from standard model value) of the medium and the optimum weight across the user 1,2,3,4 is given by 2.593,-1.186, 0.3304, -0.4264 respectively then there is no attenuation and exact information of the user can be detected across the receiver.

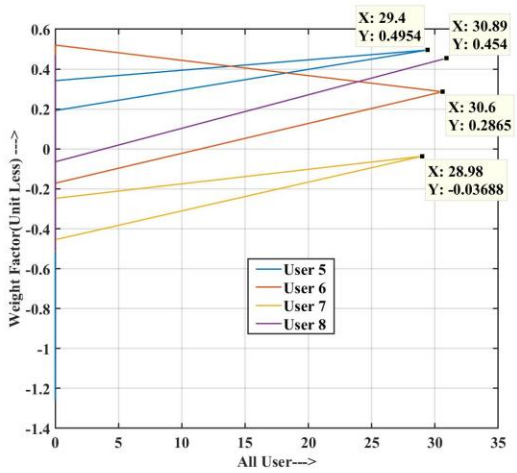

Fig. 5. Optimization Weight for User 5,6,7,8

The optimized weight value for user 1,2,3,4 is given by: W_5=[-1.2599;0.3586;-0.0050;0.1923;0.4954;0.3420;0.1751; -0.2737]; W_6= [0.1181; -0.4887;0.1374;0.1195;0.5203;0.2865; -0.1719;-0.5139]; W_7=[-0.2549;0.4329;0.2768;-.0014;0.2929; -0.4550; -0.0369 -0.2477]; W_8= [-0.5093;0.4707;0.2005; -0.3614; -0.1090; -0.0664; -0.0647 0.4540]

The inverse matrices of the attenuation thus cancel the attenuation matrix (which can be predicted from standard model value) of the medium and the optimum weight across the user 1,2,3,4 is given by 4954, 0.2865, -0.03688, 0.454 respectively then there is no attenuation and exact information of the user can be detected across the receiver.

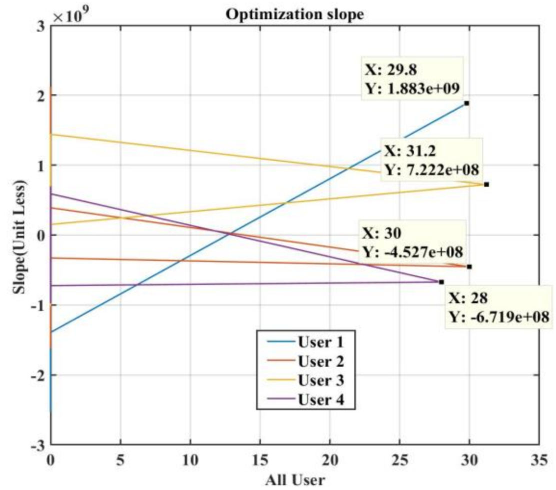

Fig. 6. Optimization Slope for User 1,2,3,4

The optimization slope for user 1,2,3,4 is given by: 1.0e+09 * [1.8830 -1.3924 -1.0959 -0.7456 0.9860 1.7713 0.5554 -2.5283]; 1.0e+09 *[-0.3284 -0.4527 0.3898 1.2389 -1.6131 -1.3750 0.7992 2.1181]; 1.0e+09 *[-0.7307 1.4412 0.7222 0.1515 -1.0184 -0.4470 -0.4221 0.7544]; 1.0e+08 *[6.9928 3.7850 -7.2303 -6.7193 5.8994 1.5807 -9.7658 3.6077]; It's the value of slope(frequency/distance) which is maintained to cancel attenuation due to distance and the optimum value across user 1,2,3,4 is given by 1.0e+09 *1.883, 1.0e+09 *(-4.527), 1.0e+09 *(7.222), 1.0e+09 *(--6.719) respectively then there is no attenuation and exact information of the user can be detected across the receiver.

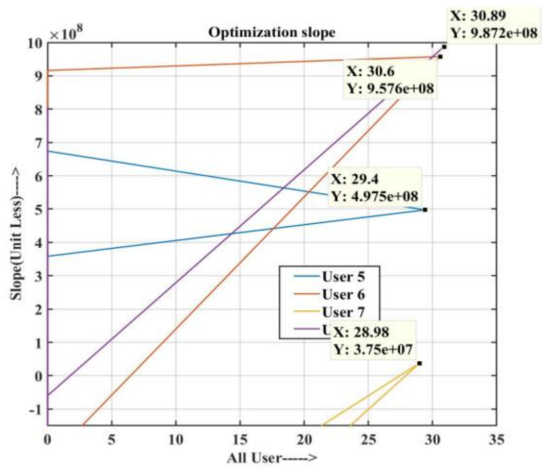

Fig. 7. Optimization Slope for User 5,6,7,8

The optimization slope for user 5,6,7,8 is given by: 1.0e+09 *[-1.3301 0.4060 -0.7427 0.3583 0.4975 0.6740 0.6222 -0.1546]; 1.0e+09 *[0.7022 -1.4523 -0.0868 0.3972 0.9158 0.9576 -0.2570 -1.2214]; 1.0e+08 *[-0.4809 3.7952 7.9389 0.9829 5.2416 -9.7088 0.3750 -6.7441]; 1.0e+08 *[-7.9284 7.1136 8.0680 -7.2688 -1.3786 -0.5292 -0.6024 9.8721]

It's the value of slope(frequency/distance) which is maintained to cancel attenuation due to distance and the optimum value across user 5,6,7,8 is 1.0e+09 *4.975, 1.0e+09 *9.576, 1.0e+09 *3.75, 1.0e+09 *9.872 then there is no attenuation and exact information of the user can be detected across the receiver.

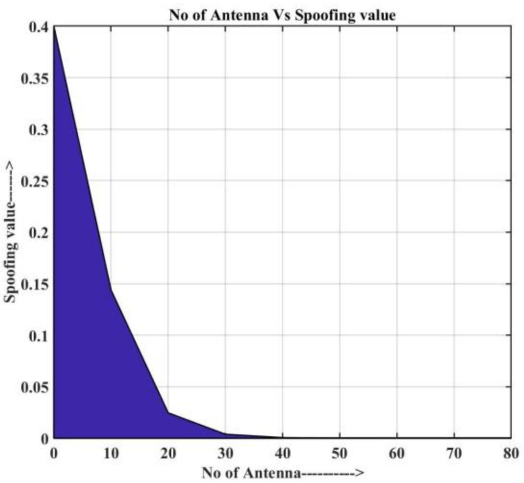

Fig. 8. Spoofing Value Vs No of antennas

It can derive from [4] that increasing no antennas reduces spoofing effect which is shown in the figure (8).

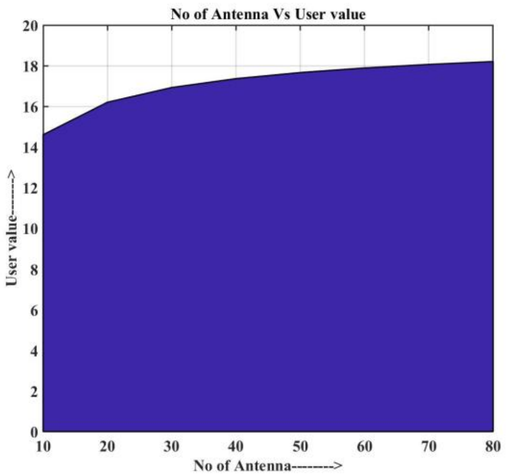

Fig. 9. User Value Vs No of antennas

The user value at the transmitter & receiver is enhanced if the number of antennas is increased which is shown in [4]

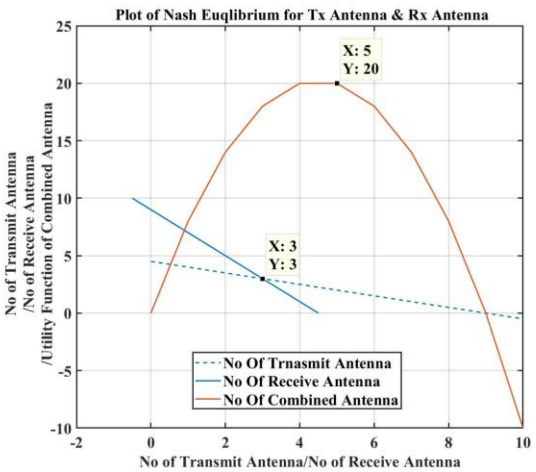

Fig. 10. Game Theoretical Model Plot

If A=10 milliwatt and B=C=1 milliwatt and put the values in the equation in (15), (16), (21) respectively, then it can be derived that S_1^*=S_2^*=3 and S_t^*=5 no of antennas. Obviously, it can be concluded that the second method is efficient as less number of antennas are required to nullify the effect of spoofing.

Table 2: Cross-Tick Table of Two Equations

Name of The Parameters	Q-Learning	Game Theoretical Approach	Path Loss Removal	Dyns-Ps
[4]	√	√	×	√
Proposed Model	×	√	√	×

V. CONCLUSION

The proposed model, it can be concluded that Adaptive Antenna Technology (AAT) & Orthogonal Slope Method (OSM) technology will be a good solution for Multiple Input & Multiple Output (MIMO) technology. The AAT and OSM technology are used to reduce the path loss or attenuation to a much low level where the inverse matrix of the medium is calculated at the receiver and multiplied with attenuation matrix so that attenuation of the medium is reduced. AAT and in OSM technology a slope value(frequency/distance) is maintained so that attenuation due to distance is reduced, if optimum weight or slope value is maintained across individual user then there is no attenuation due to the distance which improves the performance of communication system. The number of an optimum number of antennas can be derived using game theoretical model for spoofing reduction.

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