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PERFORMANCE ASSESSMENT OF THROUGHPUT IN A 5G SYSTEM

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ABSTRACT

This paper discusses the throughput of a fifth generation (5G) new radio (NR) system. The main goal of this research is to provide and develop a pathway for improving the throughput in the 5G system by investigating and controlling certain effective factors. The studied factors in this paper are the used modulation technique, the used subcarrier spacing in the default Clustered Delay Line (CDL) channel and the existence of a reflector in a custom CDL channel profile. It is found that the performance of the throughput is improved for larger subcarrier spacing and lower-order modulation technique. The existence and position of the reflector located between the transmitter and the receiver will be investigated relative to throughput performance in detail. Both fixed and changeable locations of the reflectors are considered in order to reach an optimal value of throughput. The results show that the existence of the reflector achieves a better throughput value compared to the one with no reflector. In the presence of a reflector and at a subcarrier spacing of 30 kHz, the throughput can reach 100% of throughput at 0 dB of signal to noise ratio (SNR) compared with only 40% at 0 dB for no-reflector case.

KEYWORDS

5G NR, Modulation, Reflector, Subcarrier spacing, Throughput.

1. INTRODUCTION

Challenges are the essential part of the technological development; thus, like all innovations, 5 G still has great challenges to address. As researchers have found, there is a very rapid growth in the advancement of radio technology. The travel is only around 40 years old (1G in 1980 and 5G in 2020) from 1G to 5G (Considering 5G in 2020). However, most of the information and communication technology (ICT)-based industries and consumers have recognized the value of improving the throughput, as the throughput is preferable to be as good as possible for many applications to ensure that the data is received appropriately [1]-[3].

5G has a potential and promises a compatible future, where it will give a much faster, wide range of applications and more reliable systems, without slowing down of running works. Self-driving cars, smart meters that track electricity usage and health-monitoring devices are just a few examples that may all take a big leap from what 5G could provide [4].

As a 5G trial experiment, an experiment was held in 2018 in Indonesia to test a 28 GHz system. This experiment aimed to test the characteristics of 5G mmWave band after implementing some scenarios in that 5G trial network [5]. One of these scenarios was made to determine the optimum coverage of that network and how it would be affected by changing some factors, such as the distance between the equipment of the network, obstacle existence and the reflector distance and angles to TUE (Test User Equipment) and AAU (Active Antenna Unit) [5]. Later, another experiment discussed the passive reflectors and how they can be functioned to enhance the coverage of the system for non-line of sight (NLOS) mmWave links.

Consequently, passive reflectors and some other metallic reflectors have shown significant results in terms of coverage enhancement for a new radio (NR) 28GHz system, as it used two shapes of reflectors, which are the spherical shape and the cylindrical shape and compared the results of both cases. Moreover, further calculations have been made regarding the gain of the reflectors, without ignoring one of the main factors in the reflection which is obviously the reflection angles, in addition to the distances between the reflector and both the transmitter and receiver [6].

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The latest research held regarding the reflectors' effect discussed the possibility of employing reflectors to improve the coverage and to extend the range of the mmWave signal. That experiment introduced the use of ECHO passive reflectors and TURBO active repeaters to achieve an advancement of the coverage for both indoor and outdoor scenarios, taking into consideration the distance between the transmitter and receiver [7].

Accordingly, most of the past studies primarily focused on the whole system performance parameters without putting full focus on the throughput only, as this paper is concerned with. In this regard, the main goal of this research is to provide and develop a pathway to improve the throughput in a 5G system by investigating and controlling some effective factors, such as: modulation technique, subcarrier spacing (SCS) and existence of reflectors (position and location). Therefore, performance assessment will be carried out based on these factors for 3GPP communications standard.

According to the technical standard (TS) from the latest published version of the 3GPP TS 38.101 presented in 3GPP TS 38.101-1 V15.9.0 (2020-3) [8], the subcarrier spacing is not fixed in 5G system. SCS values which are used for the shared channels that carry traffic are 15 kHz, 30 kHz, 60 kHz and 120 kHz; whereas 240 kHz is used only for the synchronization signals. Also, the subcarrier spacing affects directly the number of the used resource blocks (RBs) for a given suggested bandwidth. Thus, it is interesting to investigate the significance of varying the SCS the throughput of the 5G system.

The second tested factor was the modulation technique which varied between the values (QPSK, 16QAM, 64QAM and 256QAM). These values affected the modulation order that is used in a formula which will be mentioned in the transport block size (TBS) in the methodology section.

The third and most important tested factor in this paper is the existence of a reflector. Passive metallic reflectors can be considered as a promising candidate for 5G systems due to many reasons coming from the fact that electromagnetic waves behave similarly to light.

The throughput is evaluated in case of a fixed distance between the transmitter and the receiver and in another case by moving the transmitter or the receiver; for example a driving user, which means that the distance will be changed between any two sides of the transmitter, receiver and reflector.

Table 1. List of abbreviations.

5G	Fifth Generation	HARQ	Hybrid Auto Repeat Request	QPSK	Quadrature Phase Shift Keying
AAU	Active Antenna Unit	ICT	Information and Communication Technology	RB	Resource Block
AoA	Angle of Arrival	IOT	Internet of Things	RTT	Round Trip Time
AoD	Angle of Departure	LOS	Line of Sight	Rx	Receiver
AWGN	Additive White Gaussian Noise	MIMO	Multi-input Multi-output	SCS	Subcarrier Spacing
CDL	Clustered Delay Line	NDI	New Data Indicator	SIB	System Information Block
CP	Cyclic Prefix	NLOS	Non Line of Sight	SNR	Signal to Noise Ratio
CRC	Cyclic Redundancy Check	NR	New Radio	SVD	Singular Value Decomposition
CSI	Channel Status Interference	NRB	Number of Resource Blocks	TBS	Transport Block Size
DL	Downlink	OFDM	Orthogonal Frequency Division Multiplexing	TUE	Test User Equipment
DL-SCH	Downlink Shared Channel	OOB	Out of Band	TX	Transmitter
DM-RS	Demodulation Reference Signal	PDSCH	Physical Downlink Shared Channel	UE	User Equipment
FR	Frequency Range	PRB	Physical Resource Blocks	QAM	Quadrature Amplitude Modulation

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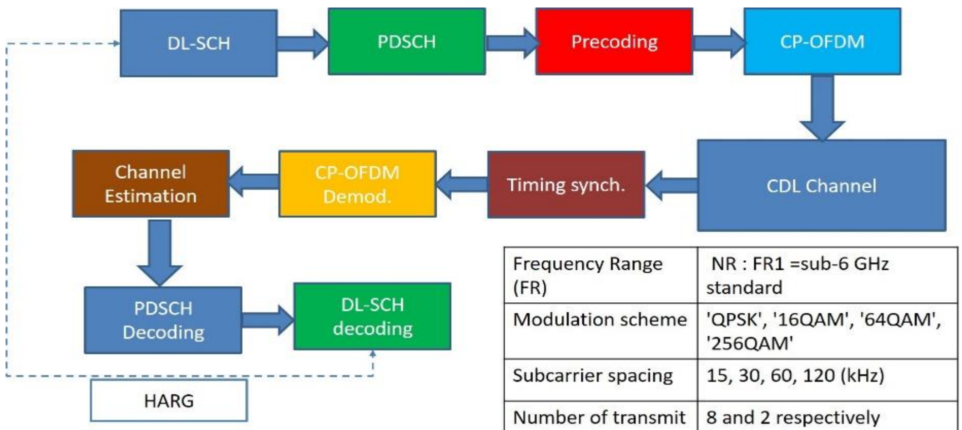
This paper is organized as follows. Following this introduction, methodology is described in Section 2. Then, simulation results are presented and explained in detail in Section 3. Conclusions are then drawn in Section 4.

2. METHODOLOGY

The mechanism of evaluating the throughput of the communication standard 3GPP TS 38.101-1 5G-system went through the following procedure:

1. Setting up the parameters of the physical downlink shared channel PDSCH; this included the number of the resource blocks (RBs), Subcarrier spacing (SCS), the Signal to Noise Ratio (SNR) range, type of cyclic prefix (CP), number of allocated physical resource blocks (PRBs), number of PDSCH layers, the modulation technique, the code rate, the number of Hybrid Auto Repeat Request (HARQ) processes,…etc.
2. Updating the current HARQ process number, where the system will generate new data after checking the CRC of the previous transmission for that specific HARQ process and making sure that there is no need for retransmission.
3. Resource grid generation, in which the new radio downlink shared channel (nrDLSCH) will perform the channel coding, as its operation will be on the provided input transport block, while keeping a copy of the transport block to be retransmitted if needed; then, the precoding operation will be applied only on the resulting signal.
4. Waveform generation, where the generated grid will be OFDM-modulated.
5. Noisy channel modeling, where the waveform will be passed through a CDL fading channel and then the AWGN will be added; the SNR is defined per resource element (RE) for each user equipment (UE) antenna. In this step, for an SNR of 0dB, the signal and noise contribute equally to the energy per PDSCH RE per receive antenna [9].
6. Synchronization is done using the demodulation reference signal (DM-RS) and then, the synchronized signal is OFDM-demodulated.
7. Channel estimation is performed. In this experiment, perfect channel estimation is used. This assumption will be held in order to make the investigation of the tested factors more focused.
8. Calculating of the precoding matrix, which is done for the next transmission using singular value decomposition (SVD).
9. Decoding the PDSCH, where the recovered symbols are demodulated and descrambled by nrPDSCHDecode for all transmit and receive antenna pairs in order to obtain an estimate of the received codewords.
10. Decoding the downlink shared channel (DL-SCH) and storing the block CRC error for a HARQ process; the vector of decoded soft bits is passed to nrDLSCHDecoder which decodes the codeword and returns the CRC error to determine the throughput of the system.



Frequency Range (FR)	NR : FR1 =sub-6 GHz standard
Modulation scheme	'QPSK', '16QAM', '64QAM', '256QAM'
Subcarrier spacing	15, 30, 60, 120 (kHz)
Number of transmit and receive antennas	8 and 2 respectively (uniformly spaced)
SCs in each resource block	12

Figure 1. Flowchart of the simulation steps.

The flowchart in Figure 1 demonstrates the simulation steps mentioned above.

Evaluating the throughput depends basically on a value called the transport block size (TBS), which can be calculated using the guide in [10], as it has different formulae based on some factors affecting the parameters of N_{info} and coding rate, which both are the main factors of calculating the TBS.

$$N_{info} = N_{RE} \cdot R \cdot Q_m \cdot \upsilon \quad (1)$$

where, R is the code rate, Q_m is the modulation order: 2 for QPSK, 4 for 16QAM, 6 for 64QAM and 8 for 256QAM transmissions. υ is the number of layers [10]:

N_{RE} =$N_{RE} = min(156, N'_{RE}) \cdot n_{PRB}$; where, $N_{sc}^{RB} = 12$, which is the number of subcarriers in a physical resource.

$N'_{RE} = N_{sc}^{RB} \cdot N_{symb}^{sh} - N_{DMRS}^{PRB} - N_{oh}^{PRB}$; where, N_{symb}^{sh} : is the number of symbols of the PDSCH allocation within the slot, N_{DMRS}^{PRB}: is the number of REs for DM-RS per PRB in the scheduled duration including the overhead of the DM-RS CDM groups without data and N_{oh}^{PRB}: is the overhead configured by higher layer.

Evaluating the TBS can lead directly to the value of the maximum throughput, by multiplying the value of the TBS by the number of the slots in the system, which varies based on the numerology and the number of frames as in Table 4.3.2-1 in [11].

The procedure mentioned above is generally used for the throughput calculation, with changing the values of the factors that are intended to be investigated.

The third studied factor was the existence of a reflector with the custom delay profile CDL channel, as that mentioned in [12]. In this paper, the impact of the position of the reflector has been studied in case of fixed transmitter and receiver and in case of moving transmitter or receiver, with a reflector design as shown in Figure 2.

Spacing between reflector and both transmitter (Tx) and receiver (Rx) was calculated by assuming a side and angle of the triangle. After that, the remaining needed values were calculated to decide where to locate the reflector in the appropriate position to achieve the best possible performance as will appear in the results.

The reflector type preferred to be used will be the metallic one due to its advantages compared to the other types [13]. Furthermore, the reflection properties of electromagnetic waves are better at higher frequencies because of the smaller skin depth [14] and lower material penetration. Thus, metallic reflectors can act similarly as a communication repeater with the advantage that it can function without electricity in addition to negligible maintenance, with longer life spans and small initial investment costs compared to repeaters consisting of active elements.

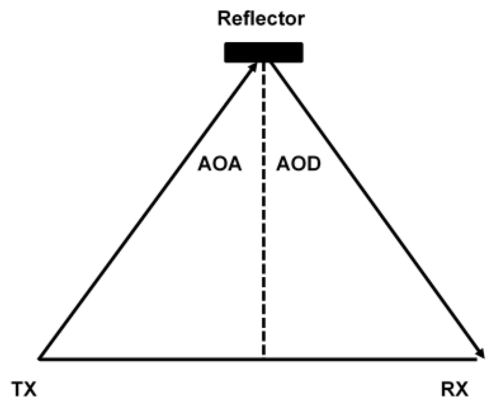


Figure 2. Reflector design.

These metallic reflectors can be part of our everyday objects, such as lamp posts, advertisement boards and street signs. For the characteristics of the metallic reflectors, power can be calculated using the following formula [6]:

$$P = P_{refl}^{(1)} + P_{refl}^{(1)} + P_{olos} + P_s \quad (2)$$

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where $P^{(1)}_{refl}$ and $P^{(2)}_{refl}$ are the received powers due to first- and second-order reflections from the reflectors, respectively, P_{olos} is the power from the obstructed LOS (OLOS) path and P_s is the received power from other surrounding objects.

The transmitted power density at the reflector can be calculated using the following formula [6]:

$$P_{refl}(R_1) = \frac{P_{tx} G_{tx}(\theta_{tx}\,,\ \emptyset_{tx})}{4\pi R_1^2} \quad (3)$$

The transmitted power density at the reflector is denoted as P_{refl} (R_1), at distance R_1 from transmitter, P_{tx} and $G_{tx}(\theta_{tx}, \varphi_{tx})$ are the transmitted isotropic power and gain (directivity) of the transmit antenna at respective azimuth and elevation angles of θ_{tx} and φ_{tx} [6].

3. Results and Discussion

In the following results, the simulations have been conducted using Matlab Platform.

3.1 Subcarrier Spacing

The subcarrier spacing values had varied between 15 kHz, 30 kHz, 60 kHz and 120 kHz, since the subcarrier of 240 kHz was not used, as it is usually used only for the synchronization signals and not for the shared channels which carry traffic. The results of changing the subcarriers were as illustrated in Figure 3.

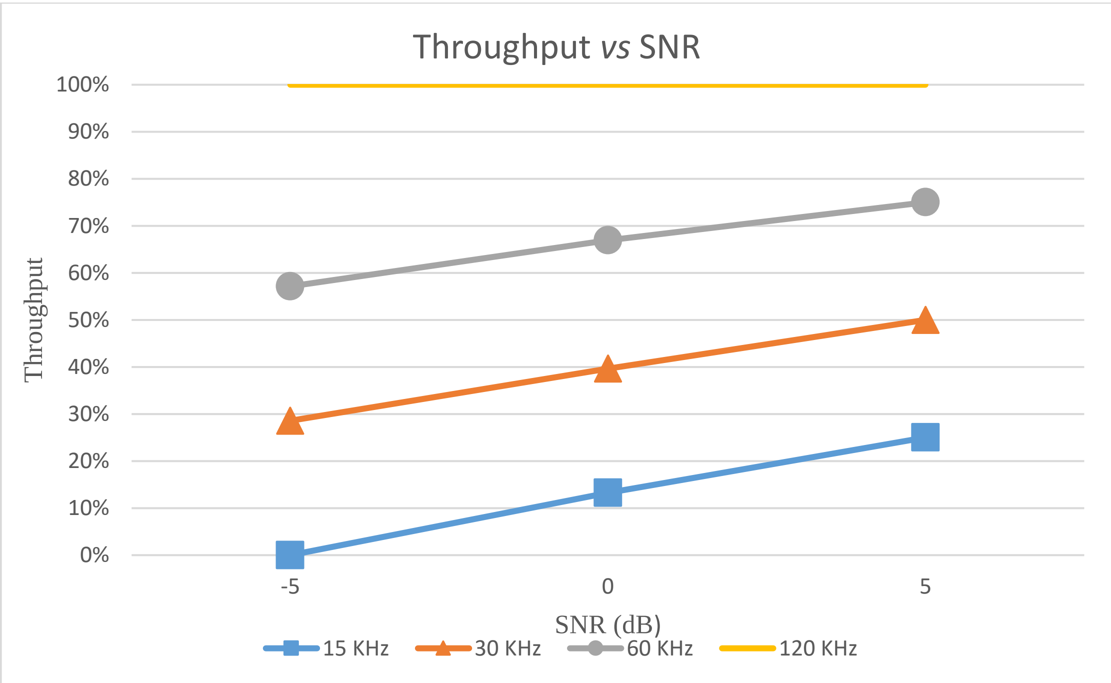


Figure 3. Throughput percentage at different SCS.

It can be noticed from Figure 3 that small subcarrier spacing allows more subcarriers to be available for a given amount of bandwidth, thus increasing the spectral efficiency, since more data is available for a given amount of bandwidth. However, performance degrades as subcarrier spacing decreases due to inter-channel interference [15].

Table 2. Throughput values for different SCS values.

SCS	Throughput (bps) at -5 dB	Throughput (bps) at 0dB	Throughput (bps) at 5dB
15 kHz	0	639520	3197600
30 kHz	639168	1278336	3195840
60 kHz	622976	1284888	3114880
120 kHz	910080	1516800	3033600

The throughput performance evaluation of the system has been varied by changing the applied subcarrier spacing of the system. Different to the previous generations of wireless mobile systems which had a fixed subcarrier spacing (mostly 15 kHz), 5G has the ability to change the subcarrier spacing value, where it can have the value of 15 kHz, 30 kHz, 60 kHz and 120 kHz. Accordingly, the used values of subcarrier spacing in the simulation are varied between 15 kHz and 120 kHz.

Starting from a subcarrier spacing of 15 kHz which produced a value of 12% of throughput at 0dB, the performance of the throughput improved as the values of the subcarrier spacing are increased, as shown by the values of 40%, 68.25% and 100% of throughput for subcarrier spacing's of 30 kHz, 60 kHz and 120 kHz, respectively, as shown in Figure 3. Moreover, for clarity purposes, the values of the throughput shown in Table 2 are calculated by multiplying the value of TBS by the number of slots in each case of SCS.

3.2 Modulation Techniques

For the modulation technique used, QPSK, 16QAM, 64QAM and 256QAM techniques had been tested at 30 kHz SCS and the results are shown in Figure 4. The throughput performance of the system was investigated with the modulation levels applied, where the modulation levels applied were: QPSK, 16QAM, 64QAM and 256QAM, with fixing the subcarrier spacing to 30 kHz.

A comparison between the performance of throughput with different types of modulation shows that the throughput performance can be improved further by using lower level of modulation. However, there is a trade-off between modulation techniques used due to their impact on the spectral efficiency [16]-[17], where using a lower-order modulation technique would improve the throughput performance but it would result in a lower spectral efficiency.

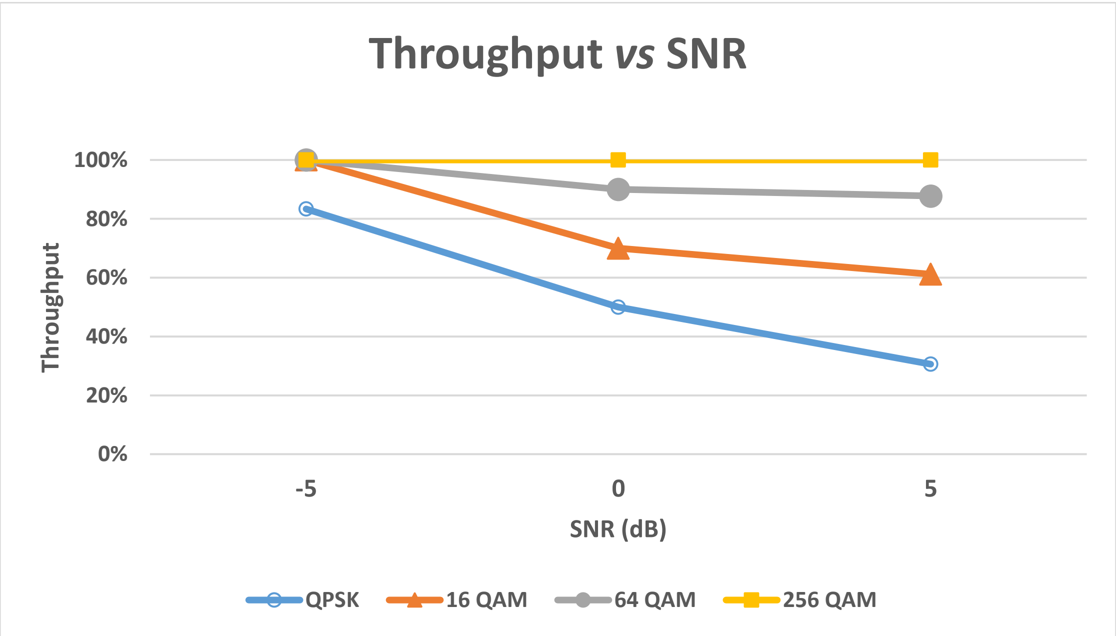


Figure 4. Throughput percentages of different modulation levels.

3.3 Existence of Reflector

Based on the previous results, a trade-off should be made to improve the throughput performance, either by decreasing the data rate and consuming more bandwidth in case of higher SCS, or decreasing the spectral efficiency to have a good throughput performance in case of lower modulation techniques.

Having a reflector could be a solution to have a balanced system. In this subsection, the existence of a reflector and how it can help improve the throughput performance will be discussed.

The default values of the CDL have been stated earlier in the previous results of throughput with changing either the subcarrier spacing or the modulation level, but for the custom values of CDL, the parameters which have been tested were the position and location of the reflector.

The existence of the reflector has shown significant results of throughput, where it could cause a much better performance or a much worse performance depending on the location and position of the reflector.

The existence of the reflector in the 5G system in this paper is investigated for two scenarios. First, a fixed distance between transmitter and receiver is assumed with changing the position of the reflector. Second, different distances between transmitter and receiver are investigated in the existence of a reflector, which might happen as one or more users are moving or driving for example.

In each scenario and for each position and location of the incorporated reflector, the angle of departure (AoD) and the angle of arrival (AoA) will be calculated and used in the simulation. Furthermore, the frequency range used in NR 5G system is FR1 which denotes a sub-6 GHz standard.

Therefore, the procedure for testing the reflector impact on the throughput was carried out through changing some parameters as follows:

1. Angle of Arrival (AoA)
2. Angle of Departure (AoD)
3. Distance from Transmitter to Receiver (Tx-Rx)
4. Distance from Transmitter to Reflector (Tx-Ref)
5. Distance from Receiver to Reflector (Rx-Ref), as will appear in each of the following tables.

In the case of fixed distance between Tx and Rx, this distance was assumed to be 16m and the distances between reflector, Tx and Rx were assumed for the first time and then adjusted closer and further till reaching the best possible scenario.

For the case of varying distance between Tx and Rx, the distances of the first scenario were assumed and then adjusted in different cases to have different scenarios with varied results of throughput performance. It should be noted that throughout this section, the SCS is fixed at 30 kHz and NRB=51.

a) Fixed Distance between Transmitter and Receiver

In this part, the separation between Tx and Rx was fixed to 16m and the position and location of the reflector were varied. The throughput results are shown in Table 3 for five cases and without reflector for comparison purposes.

Table 3. Different reflector positions for fixed 16m distance from Tx to Rx.

	Tx-Rx	**Tx-Ref.**	**Rx-Ref.**	**Throughput % at 0dB**	**Throughput % at 5dB**	**Difference % at 0dB**	**Difference % at 5dB**
No Reflector	-	-	-	42.5	100	-	-
Case 1	16	10	10	15	40	-27.5	-60
Case 2	16	15	15	40	100	-2.5	0
Case 3	16	12	20	97.5	100	55	0
Case 4	16	12	22	100	100	57.5	0
Case 5	16	18	8.5	0	0	-42.5	-100

i. Case 1: Tx-Rx = 16m, Tx-Reflector = Rx-Reflector = 10m

In this case, the throughput performance was below that in the case with no reflector, as the system achieved 15% of throughput at 0dB and 40% at 5dB. Figure 5 (a) and Figure 5 (b) show the reflector position and the throughput performance, respectively.

ii. Case 2, Tx-Rx =16m, Tx-Ref. = Rx-Ref. = 15m

In this case, the throughput performance was still below that in the case with no reflector, as the system achieved 40% of throughput at 0dB and 100% at 5dB, as depicted in Figure 6 (a) and Figure 6 (b), respectively.

iii. Case 3, Tx-Rx = 16m, Tx-Ref. = 12m, Rx-Ref. = 20m

In this case, the throughput performance was much better than in the case with no reflector, as the system achieved 97.5% of throughput at 0dB and 100% at 5dB, as depicted in Figure 7 which shows the reflector position and the throughput performance.

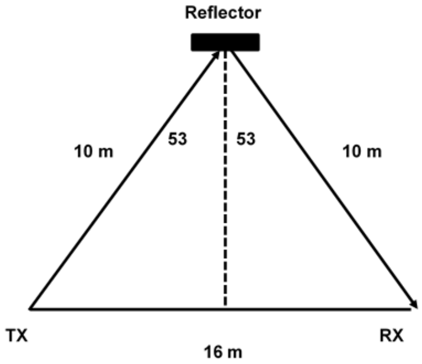
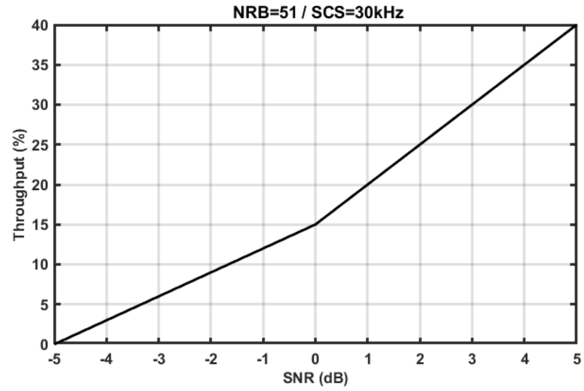


Figure 5 (a). Reflector design of case 1.



(b) Throughput percentage for case 1.

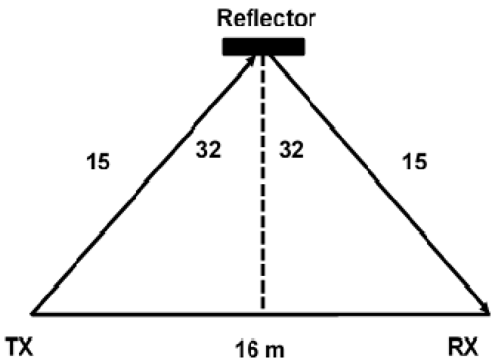
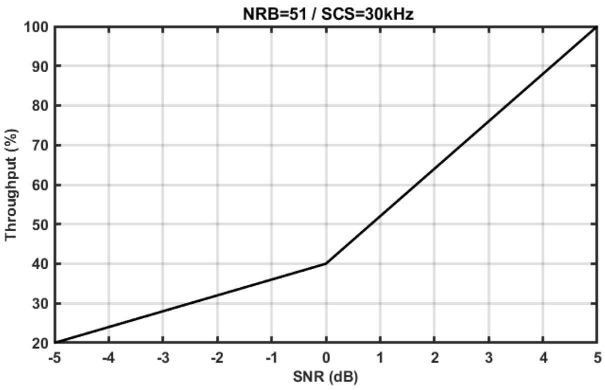


Figure 6 (a). Reflector design of case 2.



(b) Throughput performance for case 2.

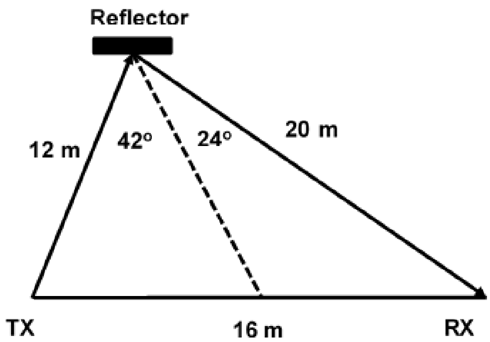
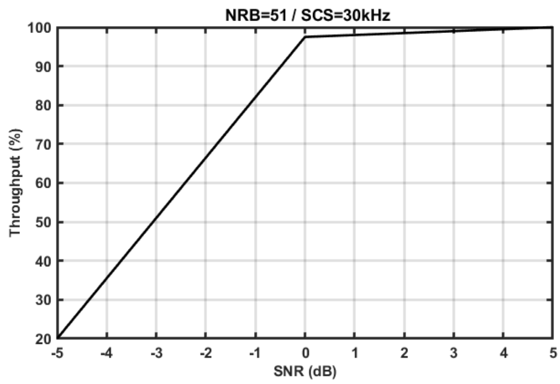


Figure 7. (a) Reflector design of case 3.



(b) Throughput performance for case 3.

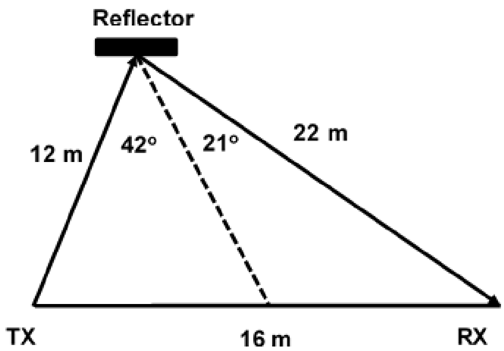
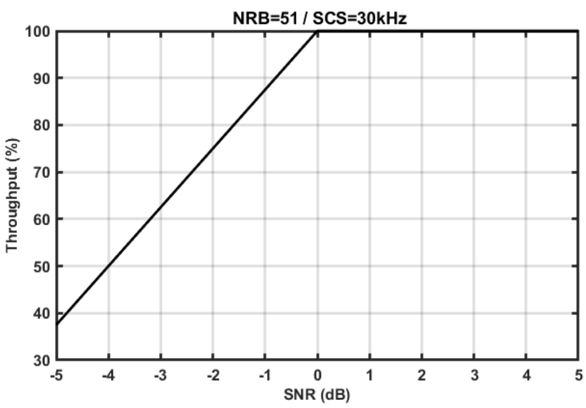


Figure 8 (a). Reflector design of case 4.



(b) Throughput performance for case 4.

iv. Case 4, Tx-Rx =16m, Tx-Ref. = 12m, Rx-Ref. = 22m

In this case, the throughput performance was the best among the different cases, as the system achieved 100% of throughput at 0dB and 100% at 5dB, as shown in Figure 8.

v. Case 5, Tx-Rx = 16m, Tx-Ref. = 18m, Rx-Ref. = 8.5m

In this case, the throughput performance was at its worst case, as the system achieved 0% of throughput at all the points, as shown in Figure 9.

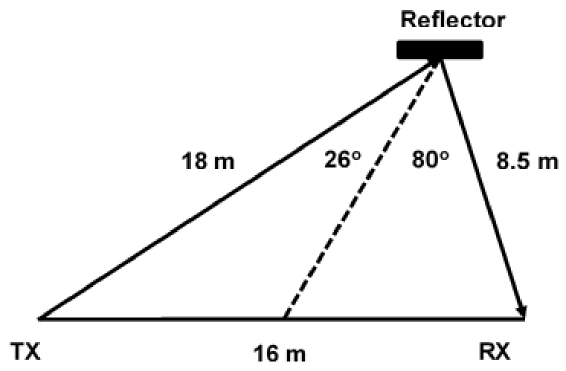
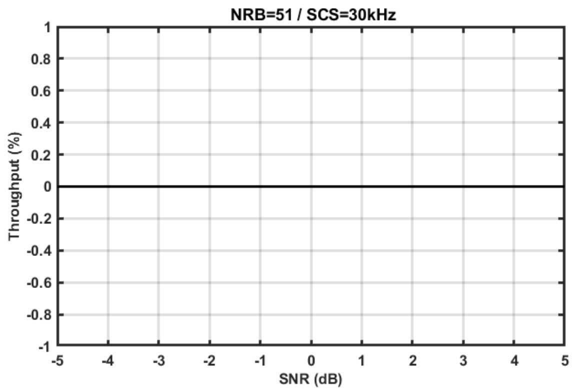


Figure 9 (a). Reflector design of case 5.



(b) Throughput performance for case 5.

Table 4. Different reflector positions moving transmitter or receiver.

	AoA	AoD	Tx-Rx	Tx-Ref.	Rx-Ref.	Throughput % at 0dB	Throughput % at 5dB	Difference at 0dB	Difference at 5dB
No Reflector	0°	0°				42.5	100		
Case 2	30°	22°	7.39	9.23	8.63	100	100	57.5	0
Case 3	10°	30°	6.03	8.12	9.23	80	100	37.5	0
Case 4	40°	35°	10.92	10.44	9.77	40	100	-2.5	0
Case 5	60°	50°	23.4	16	12.44	20	85	-22.5	-15
Case 6	30°	70°	27.32	9.23	22	0	0	-42.5	-100

Comparing the results of the different tested cases, the best case was case 4, where the throughput achieved was 100% when the reflector is spaced 12 meters from the transmitter and 22 meters from the receiver, while the worst case was case 5 when the reflector was spaced 18 meters apart from the transmitter and 8.5 meters apart from the receiver, as shown in Figure 10.

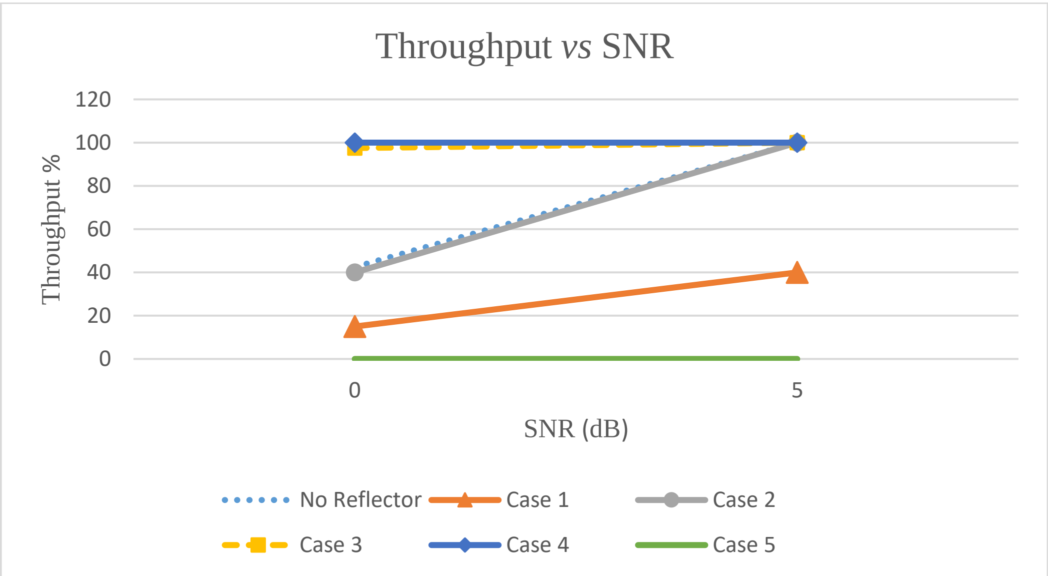


Figure 10. Comparison of different reflector locations with fixed Tx-Rx distance.

b) Moving Transmitter and Receiver

i. Case 1, AoA = AoD = 0° (Default)

For the angle of 0, the throughput percentage reached its maximum at 5 dB and 42.5% of its maximum at 0 dB, as Figure 11 illustrates.

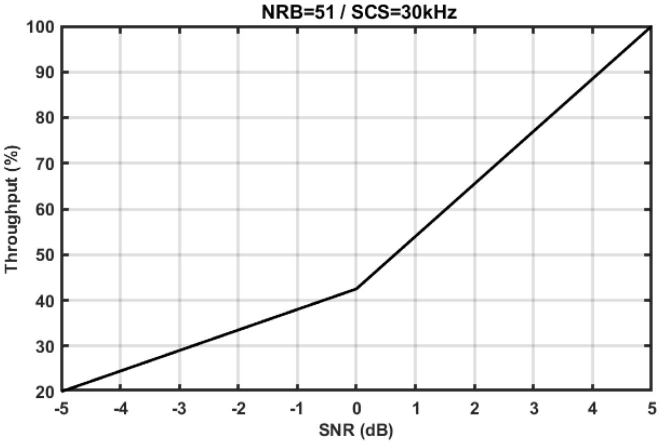
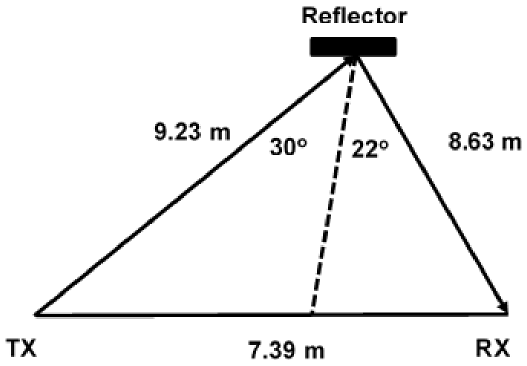


Figure 11. Throughput without reflector.

ii. Case 2, AoA = 30°, AoD = 22°

For this case, the throughput percentage was at its best case which is 100% of throughput all the way from -5 dB to 5 dB (Figure 12 (b)) with an improvement of 57.5% at 0dB compared to the default case (no reflector), with the reflector design shown in Figure 12 (a).



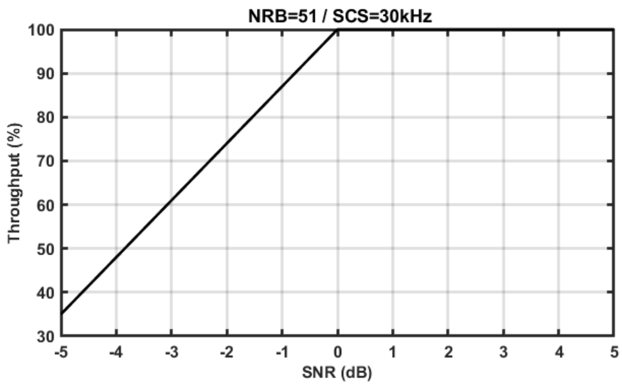
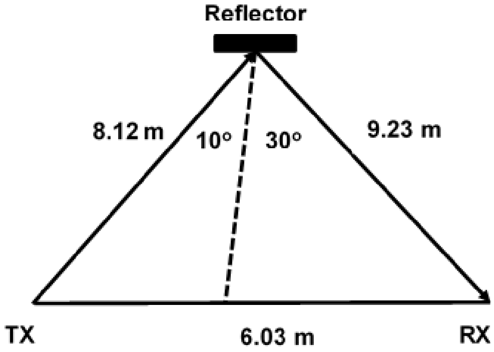


Figure 12 (a). Case 2 reflector design. (b) Throughput for case 2.

iii. Case 3, AoA = 10°, AoD = 30°

For this case, the throughput has improved compared to the default case (no reflector), as the system showed an 80% throughput at 0dB with an improvement of 37.5 % compared to the default case, as shown in Figure 13 (b), while Figure 13 (a) shows the reflector design.



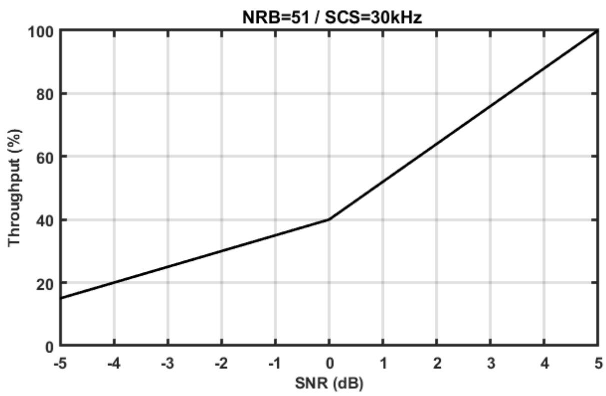


Figure 13 (a). Reflector design of case 3. (b) Throughput for case 3.

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iv. Case 4, AoA = 40°, AoD = 35°

This case shows that the performance decreased when using the reflector, as the system showed 40% of throughput at 0dB, which is lower by 2.5% compared to the case of not using the reflector, as shown in Figure 14 (b), while Figure 14 (a) shows the reflector design.

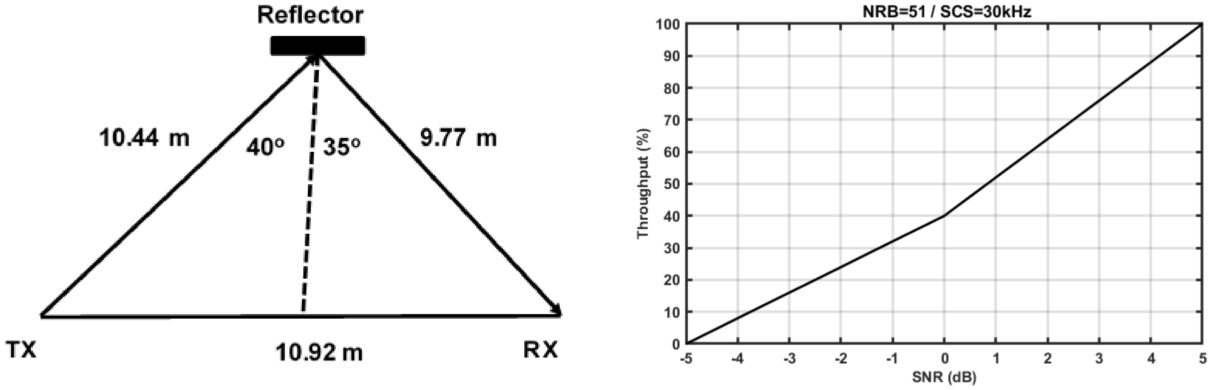

Figure 14 (a). Reflector design of case 4. (b) Throughput for case 4.

v. Case 5, AoA = 60°, AoD = 50

Case 5 shows a significant decrease of throughput percentage compared to the default case (no reflector), with 22.5% decrease at 0dB and 15% decrease at 5dB, as shown in Figure 15 (b).

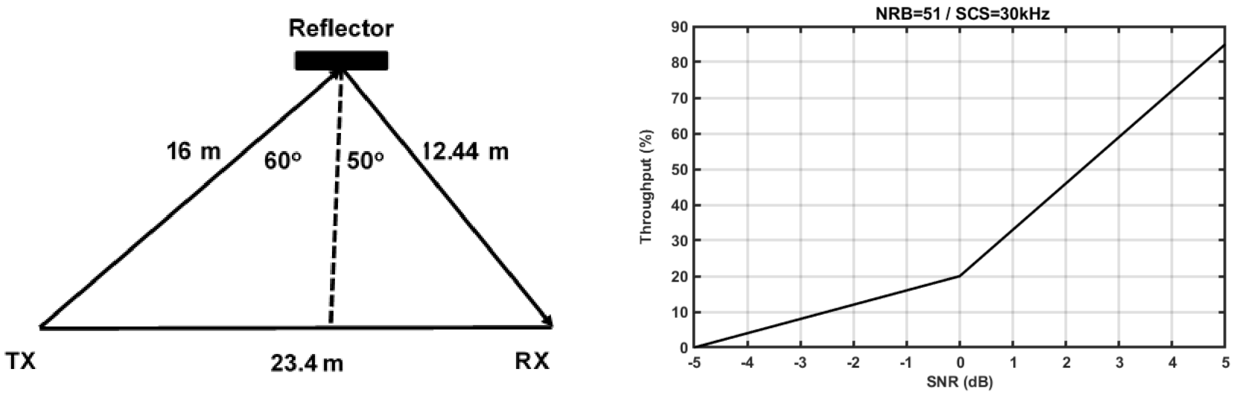

Figure 15 (a). Reflector design of case 5. (b) Throughput for case 5.

vi. Case 6, AoA = 30°, AoD = 70°

The worst case tested in this scenario was when the angle values were 30° for the angle of arrival and 70° and more for the angle of departure, where the throughput resulted in a straight line of 0% for both 0dB and 5dB, which represents a decrease of 42.5% and 100%, respectively, as shown in Figure 16 (b).

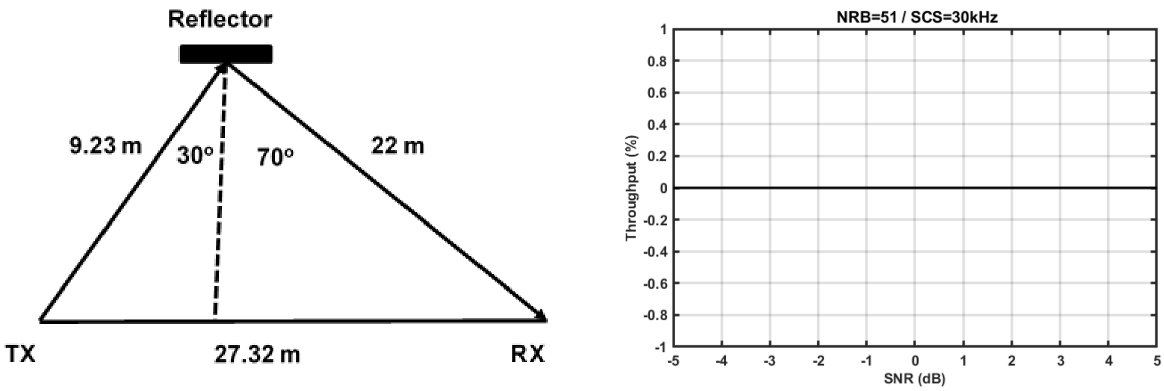

Figure 16 (a). Reflector design of case 6. (b) Throughput for case 6.

As shown in Figure 17, a comparison between the values of throughput in different cases has shown that the throughput performance was at its best in case 2 and at its worst in case 6.

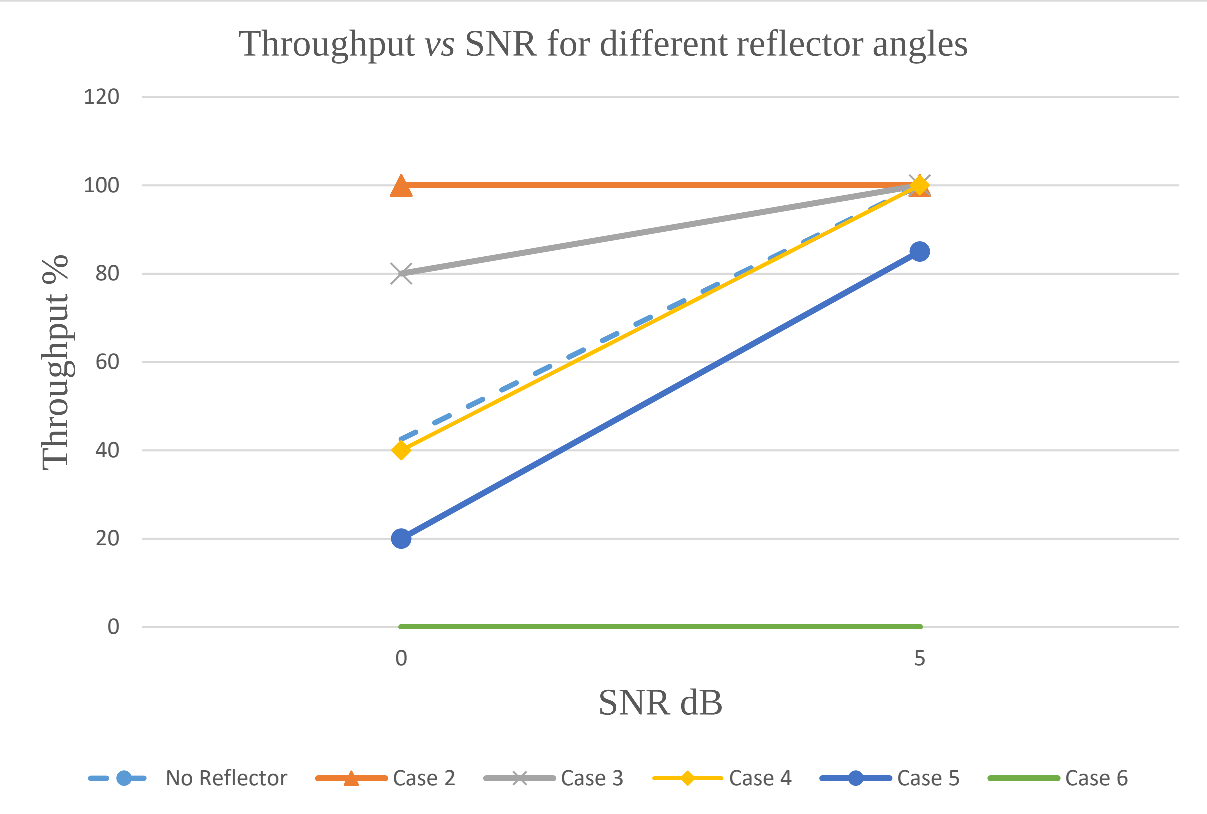

Figure 17. Throughput percentages for different cases of reflector.

4. Conclusion

In this work, an assessment of the throughput performance has been provided based on studying some parameters that might affect it either directly or indirectly. The factors studied were subcarrier spacing, modulation technique in the default CDL channel and the existence of a reflector with two different scenarios. To conclude, it can be argued that using a higher SCS, a greater percentage of throughput can be achieved, whereas for the modulation technique, it is found that higher-order modulation will achieve lower throughput performance and a trade-off should be made to preserve a reasonable spectral efficiency.

Finally, the position of the reflector in case of reflector existence has shown a noticeable effect on the throughput performance for both situations studied; fixed distance and moving users. The results have shown a significant impact of the reflectors in both ways. Further investigation by considering more than one reflector linked with wide coverage milestone can be used in order to improve the performance of system throughput. However, complexity and cost will come into play in this stage. Moreover, investigation of throughput performance using reflectors in mmWave frequency (FR2) in 5G systems could be carried out as well.

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ملخص البحث:

تُناقش هذه الورقة أداء الاجتياز لنظام راديوي جديد من أنظمة الجيل الخامس. والهدف الأساسي منها هو تطوير مسارٍ من أجل تحسين أداء الاجتياز الخاص بالنظام عبر استقصاء عوامل معينة والتحكم بها. العوامل التي خضعت للدراسة في هذا البحث هي: تقنية التعديل المستخدمة، والتباعد المستخدم في الحاملة الفرعية في قناة خط التأخير المجمّعة في غياب عاكس، ووجود عاكس في قناة خط التأخير المجمّعة.

وبينت النتائج أن أداء الاجتياز قد تحسن مع زيادة تباعد الحاملة الفرعية ومع استخدام تقنية تعديل ذات رتبة أقل. وقد تم استقصاء أثر كل من وجود العاكس وموضعه في أداء الاجتياز الخاص بالنظام مع وضع العاكس بين المرسل والمستقبل، بشيء من التفصيل. وأُخذت بعين الاعتبار حالة الموضع الثابت وحالة الموضع المتغير للعاكس؛ من أجل الحصول على القيمة المثلى لأداء الاجتياز.

وقد أسفرت النتائج عن أن وجود العاكس يؤدي الى الحصول على قيمة أفضل لأداء الاجتياز مقارنة بالحالة التي لا يُستخدم فيها عاكس. وبوجود عاكس، وعند تباعُد حاملة فرعية قدرُهُ (30) كيلو هيرتز، يمكن لأداء الاجتياز أن يصل الى (100%) عند نسبة إشارة الى ضجيج مقدارها صفر ديسيبل، مقارنة بـ (40%) عند نسبة إشارة الى ضجيج مقدارها صفر ديسيبل في حالة غياب العاكس.