Chapter Four

Simulation Results and Discussion

4.1 Simulation Environments

This chapter discusses the simulation results based on different variables. It is interested only on the nodes that active on D2D session and plotted in the cell, also the cellular and D2D communication are assumed to be not interact directly on each other. Subsequently idle nodes and nodes communicating with the BS are not shown. It is especially interested in the number of groups that are created to give an assured SINR requirement.

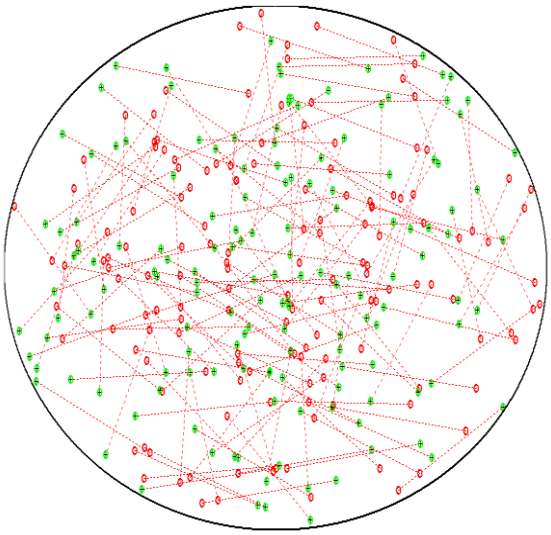
The figures 4.1 and 4.2 explain how the nodes are distributed inside the cell, also two variables nodes have been taken and the cell assumed as a circular shape for this study.

The first variables are 300 nodes with 150 links. In the case shown in figure 4.1, it is observed that the cell has been distributed with 150 links with different distance such as 500, 250, 100, 50 in (a), (b), (c) and (d) respectively. When the distance between D2D links decreased and became close to each other, then SINR requirement has been satisfied.

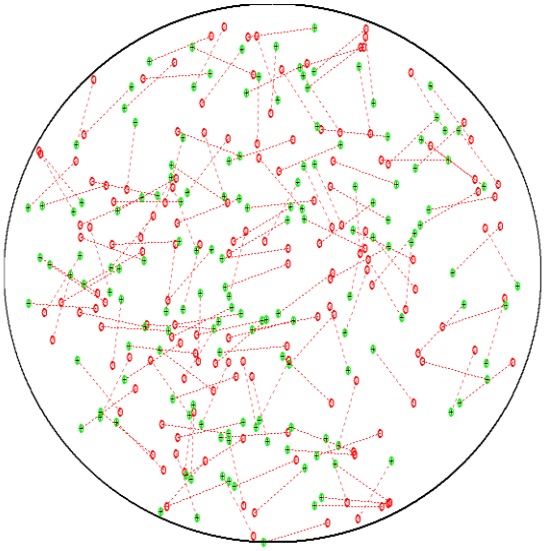
The second variables are 100 nodes with 50 links as shown in figure 4.2. The cell has been populated with 50 links the same as in figure 4.1. Therefore, the number of D2D in the cell has been decreased, compared to the results shown in figures 4.1 and 4.2. As observed from the simulation result the first case has give best result than the second case when D2D nodes are applied with greedy grouping algorithm because more links can be combined to the same group due to high density links.

There are four scenarios (indoor, free space, urban area and sub urban area) have been implemented and the results are analyzed and compared. all these scenarios are applied to 150 links and 50 links with greedy grouping algorithm.

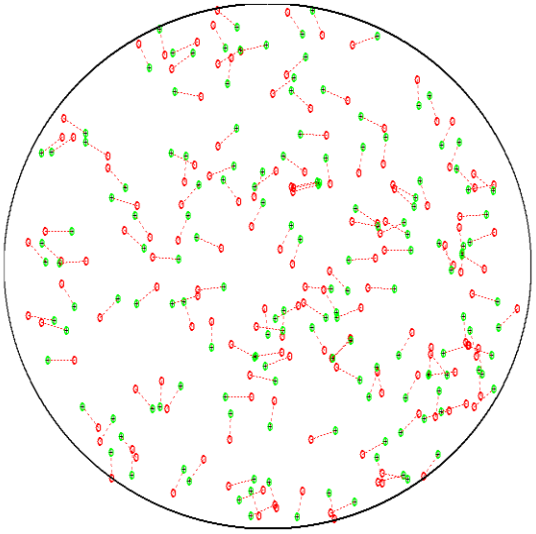
The bar plots shown in figures (4.3 - 4.10) , explain the number of necessary groups such as minimum ,mean and maximum respectively (Min (M), Mean (M) and Max (M)) from the total number of links for all simulated scenarios and SINR requirements.



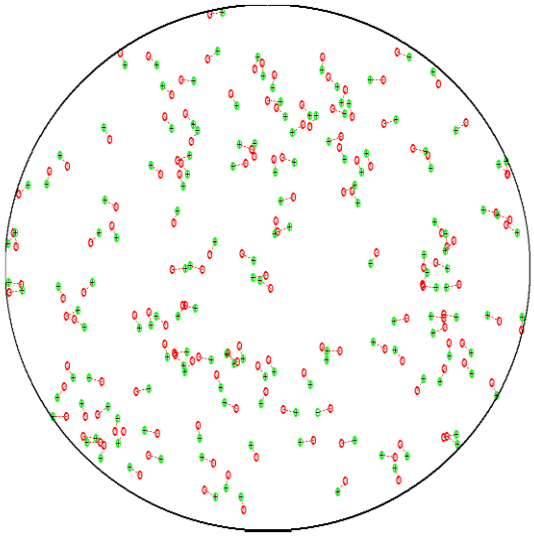
(a) 500 meter links



(b) 250 meter links

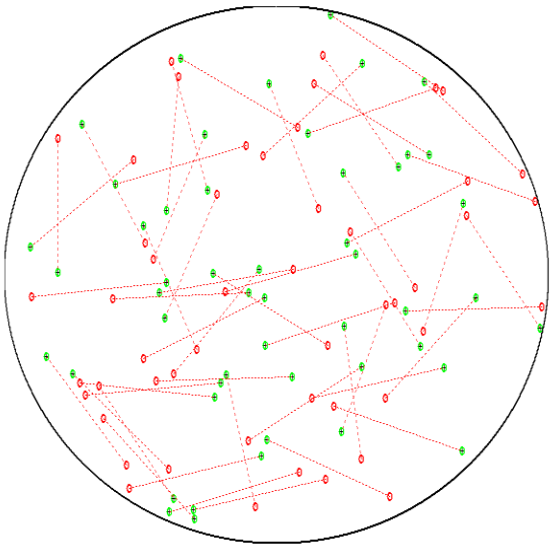


(c) 100 meter links

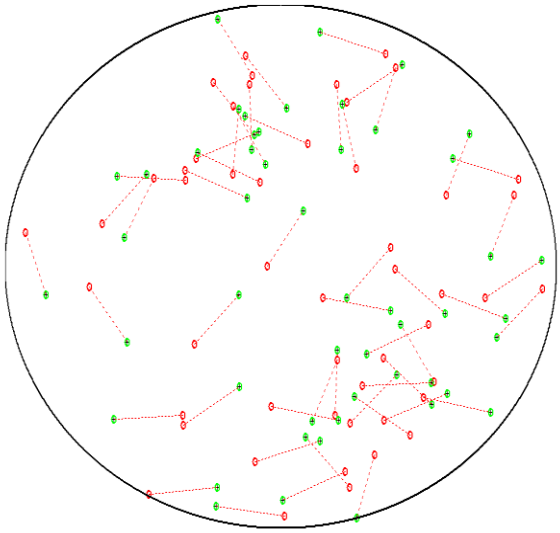


(d) 50 meter links

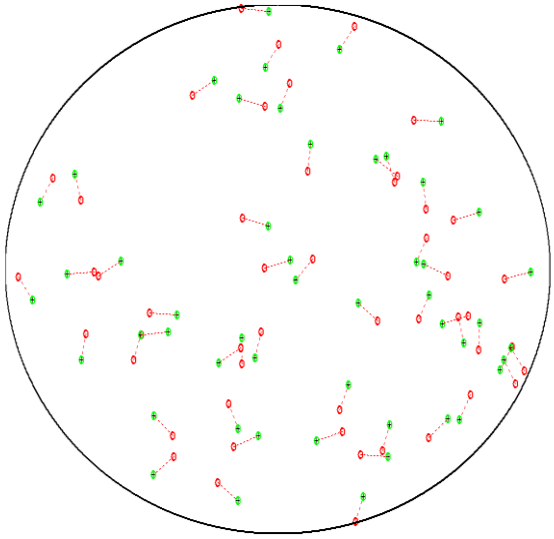
Figure 4.1: cell scenarios with fixed D2D link lengths (300 nodes)



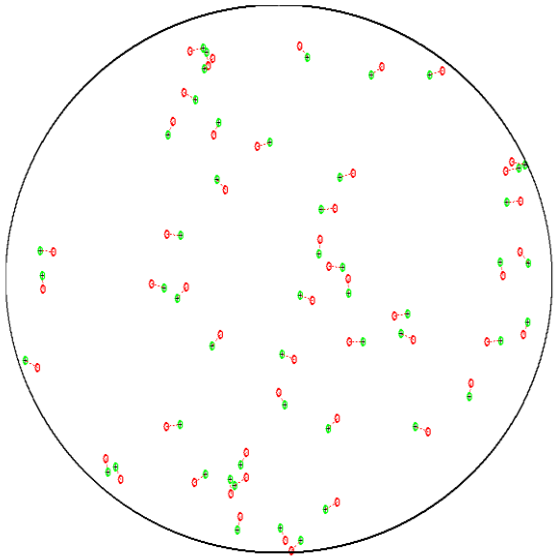
(a) 500 meter links



(b) 250 meter links



(c) 100 meter links



(d) 50 meter links

Figure 4.2: cell scenarios with fixed D2D link lengths (100 nodes)

(a) Scenario1: Indoor

In figure 4.3, 300 nodes with fixed links distributed over the cell, as observed for a very long links eg. 500 and 250 meters, no links can be combined in a group. It has been seen that for every link, a single group is created and because of that a minimum distance requirement d_{min} for maximum D2D link length became 3233.3, 4854.2, 7287.7 and 2427.1 and 3643.8 meters as shown in table 4.1 for minimum SINR 6dB, 9dB and 12dB respectively.

Based on the radius of cell R, the diameter was 2000 meter. Therefore, due to this assumption no links have been combined in the same group, and the minimum SINR in the simulation has been achieved as infinite value, and that means no noise is presented or the noise level was low. When the link distances were decrease, more links are placed in the same group and also fewer groups are needed to accommodate all links. Also when the link lengths have been decreased a higher SINR guaranteed at a lower cost.

The scenario shown in figure 4.4 is approximately the same as shown in figure 4.3; but 50 D2D links are distributed randomly in the cell and the number of groups relative to the total number of links is plotted.

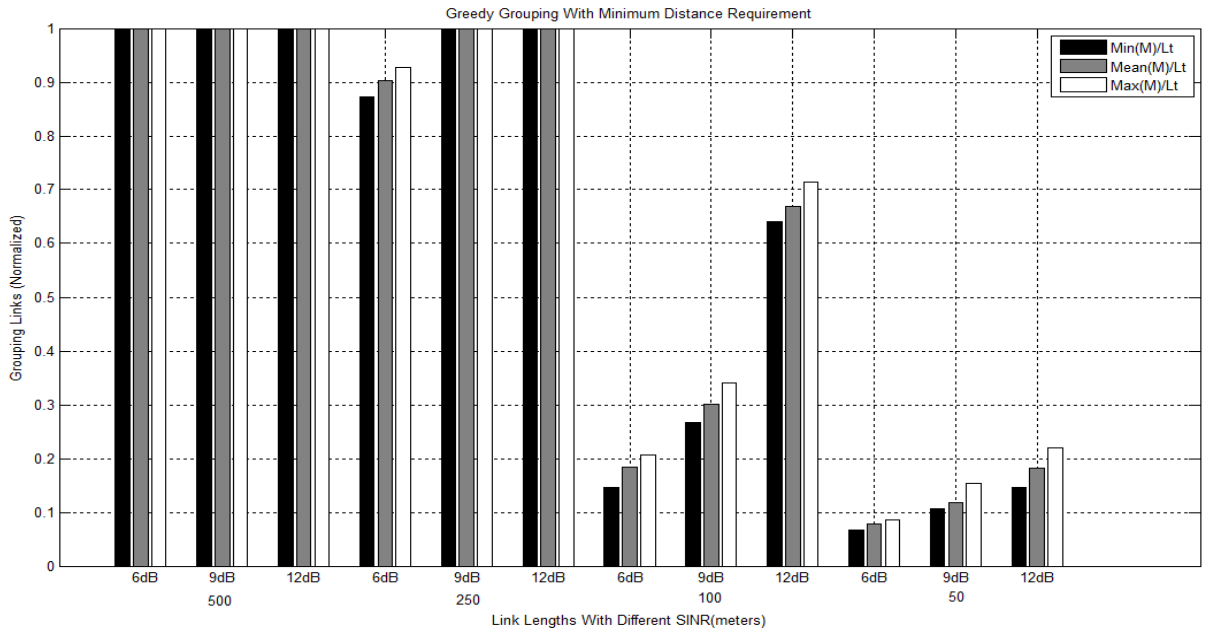


Figure 4.3: number of groups formed with 150 links in indoor scenario

Table 4.1: scenario 1 with 150 links and fixed link lengths Indoor

150 link link length (m)	**$SINR_{min}$(dB)**	**d_{min} (m)**	**Min (M)**	**Mean (M)**	**Max (M)**
500	6	3233.3	150	150	150
	9	4854.2	150	150	150
	12	7287.7	150	150	150
250	6	1616.7	132	134	138
	9	2427.1	150	150	150
	12	3643.8	150	150	150
100	6	646.6618	17	21.8	26
	9	970.8403	37	48.2	61
	12	1457.5	89	96.2	102
50	6	323.3309	7	11.2	17
	9	485.4201	14	17	20
	12	728.7665	25	29	32

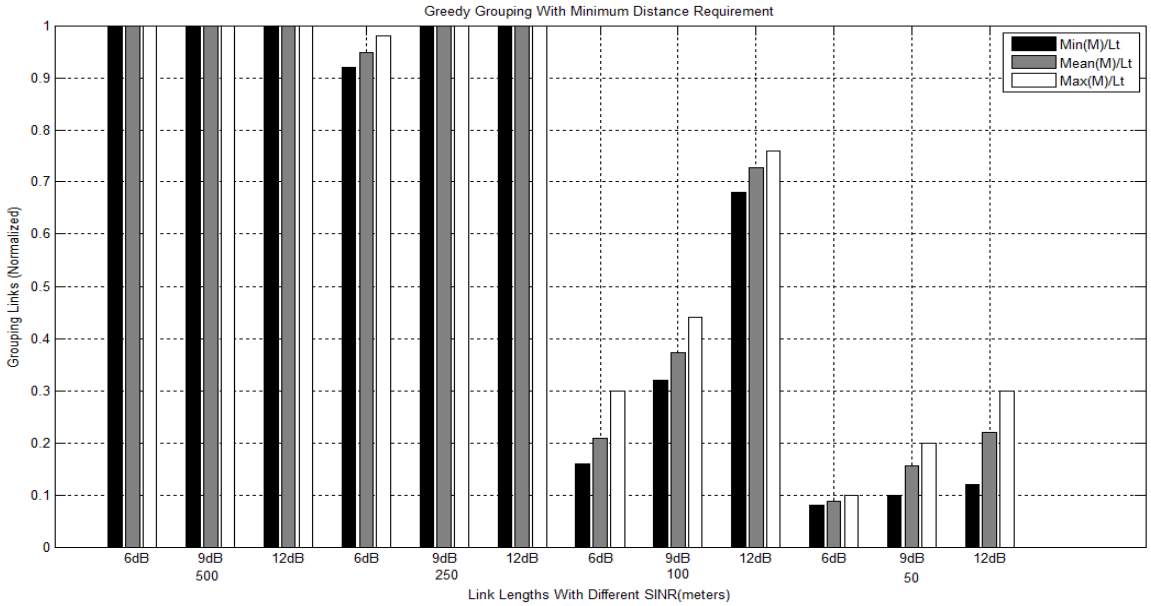


Figure 4.4: number of groups formed with 50 links in indoor scenario

Table 4.2: scenario 1 with 50 links and fixed link lengths Indoor

50 link link length (m)	$SINR_{min}$(dB)	d_{min} (m)	Min (M)	Mean (M)	Max (M)
500	6	3233.3	50	50	50
	9	4854.2	50	50	50
	12	7287.7	50	50	50
250	6	1616.7	45	48	49
	9	2427.1	50	50	50
	12	3643.8	50	50	50
100	6	646.6618	8	11	13
	9	970.8403	15	20.8	26
	12	1457.5	33	35.2	38
50	6	323.3309	5	6	8
	9	485.4201	5	7.6	11
	12	728.7665	10	13.8	16

(b) Scenario 2: Free space

In figure 4.5, the 150 links are distributed over the cell, for very long links with a length of 500,250 meters the minimum distance 2443.7, 3451.8, 4875.8, and 1725.9, 2437.9. Figure 4.6 scenario is approximately the same as shown in figure 4.5; but 50 D2D links.

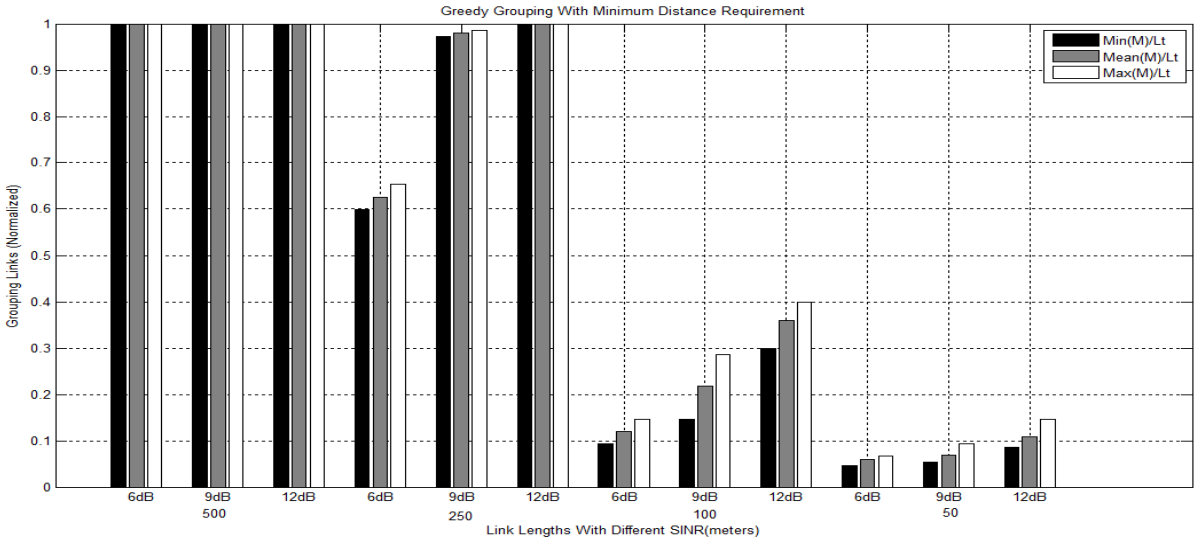


Figure 4.5: number of groups formed with 150 links in free space scenario

Table 4.3: scenario 2 with 150 links and fixed link lengths free space

150 link link length (m)	$SINR_{min}$(dB)	d_{min} (m)	Min (M)	Mean (M)	Max (M)
500	6	2443.7	150	150	150
	9	3451.8	150	150	150
	12	4875.8	150	150	150
250	6	1221.8	87	92.8	100
	9	1725.9	144	146.4	150
	12	2437.9	150	150	150
100	6	488.7375	13	17	18
	9	690.3600	28	29.6	32
	12	975.1594	44	52.6	65
50	6	244.3687	5	8.6	11
	9	345.1800	9	12.6	16
	12	487.5797	11	15	20

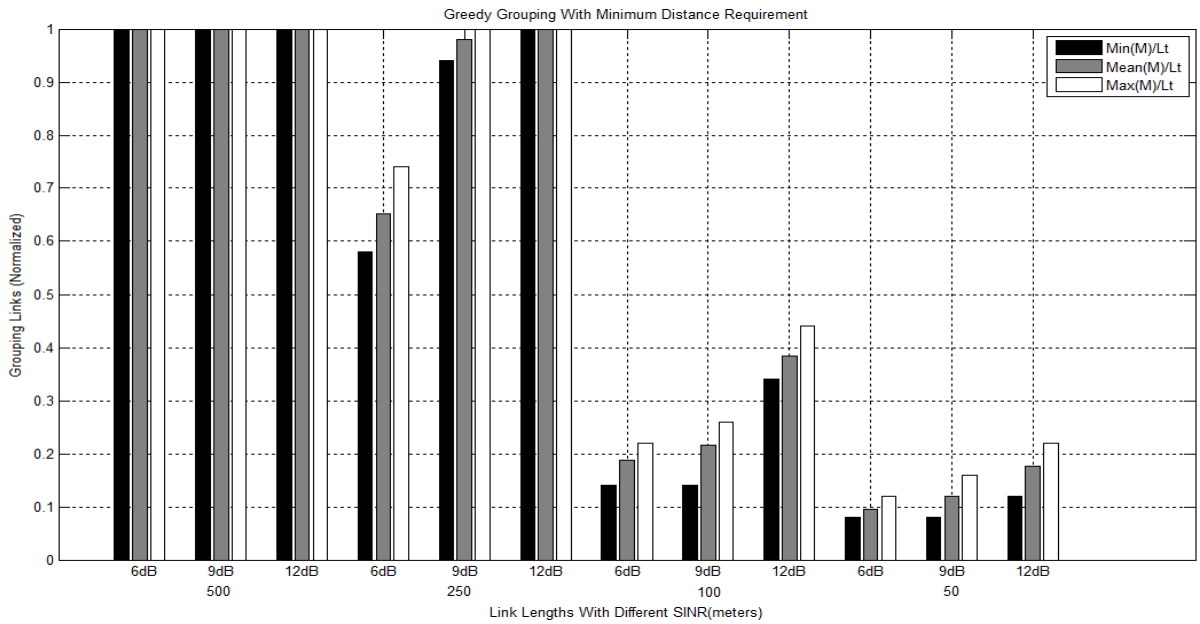


Figure 4.6: number of groups formed with 50 links in free space scenario

Table 4.4: scenario 2 with 50 links and fixed link lengths free space

50 link link length (m)	$SINR_{min}$(dB)	d_{min} (m)	Min (M)	Mean (M)	Max (M)
500	6	2443.7	50	50	50
	9	3451.8	50	50	50
	12	4875.8	50	50	50
250	6	1221.8	31	35.2	39
	9	1725.9	48	49.6	50
	12	2437.9	50	50	50
100	6	488.7375	6	8.4	11
	9	690.3600	8	11.8	14
	12	975.1594	12	16.8	23
50	6	244.3687	4	4.4	5
	9	345.1800	6	6.4	7
	12	487.5797	6	8.2	11

(c) Scenario 3: Urban Area

In figure 4.7, the 150 links with fixed link lengths are distributed over the cell, for very long links with a length of 500 meters, it has been seen that for every link, more groups are created Because the minimum distance requirement d_{min} for maximum D2D link length being 1238.0 1508.1 and 1837.2 meters respectively like as shown in table 4.5 for 6dB, 9dB and 12dB as the minimum SINR.

The figure 4.8 scenario has been approximately the same such as the figure 4.7; but 50 D2D links are distributed randomly in the cell and the number of groups relative to the total number of links is plotted, so more links can combined in the same group.

The difference between scenarios in figures 4.8 and 4.7, were when the link density is high, the different simulations are more similar to each other than when the link density is low, it is also observed that for a high link density, the relative efficiency is slightly better compared to the low density simulations. The reason for this it has been became more probable to fill groups more densely when there are more links distributed over the cell, because there are more links to choose from.

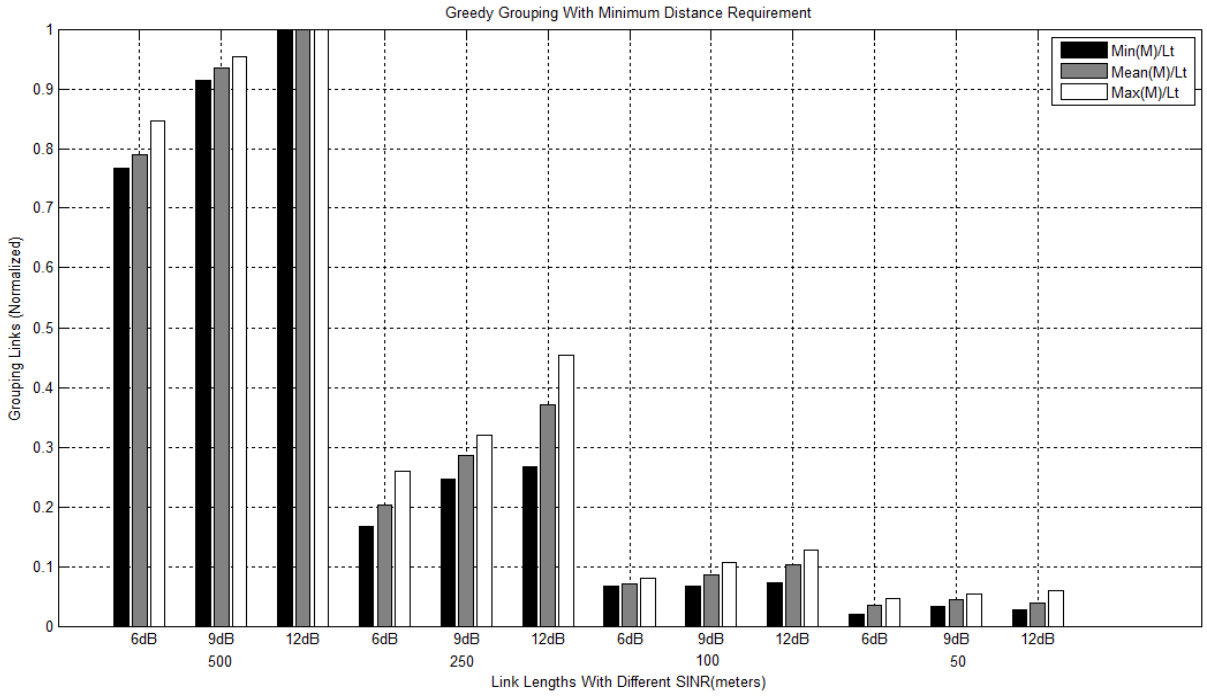


Figure 4.7: number of groups formed with 150 links in Urban Area scenario

Table 4.5: scenario 3 with 150 links and fixed link lengths urban area

150 link link length (m)	$SINR_{min}$(dB)	d_{min} (m)	Min (M)	Mean (M)	Max (M)
500	6	1238.0	110	120.2	127
	9	1508.1	136	139.6	142
	12	1837.2	150	150	150
250	6	619.0098	26	32.4	36
	9	754.0702	34	40	45
	12	918.5992	50	53.8	57
100	6	247.6039	9	10.4	11
	9	301.6281	10	12	16
	12	367.4397	11	12	14
50	6	123.8020	4	5.6	6
	9	150.8140	5	6.4	8
	12	183.7198	5	7.2	9

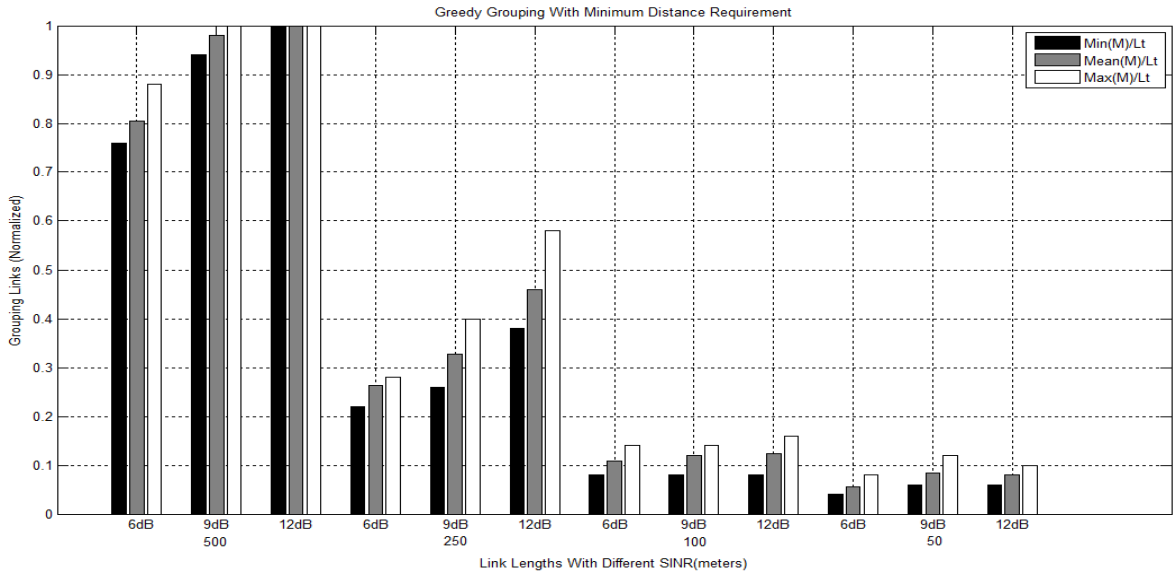


Figure 4.8: number of groups formed with 50 links in Urban Area scenario

Table 4.6: scenario 3 with 50 links and fixed link lengths urban area

50 link link length (m)	$SINR_{min}$(dB)	d_{min} (m)	Min (M)	Mean (M)	Max (M)
500	6	1238.0	36	39.8	42
	9	1508.1	46	48.4	50
	12	1837.2	50	50	50
250	6	619.0098	10	11.4	15
	9	754.0702	12	16	19
	12	918.5992	21	26	28
100	6	247.6039	3	5.2	7
	9	301.6281	3	5.6	7
	12	367.4397	6	6.8	9
50	6	123.8020	2	2.6	3
	9	150.8140	3	3.8	4
	12	183.7198	3	4	5

(d) Scenario 4: Sub Urban Area

For very long links with a length of 500 meters, all links are placed in the same group because the minimum distance requirement d_{min} for maximum D2D link length being 943.1923, 1082.9 and 1243.4 shown in tables 4.7 and 4.8.

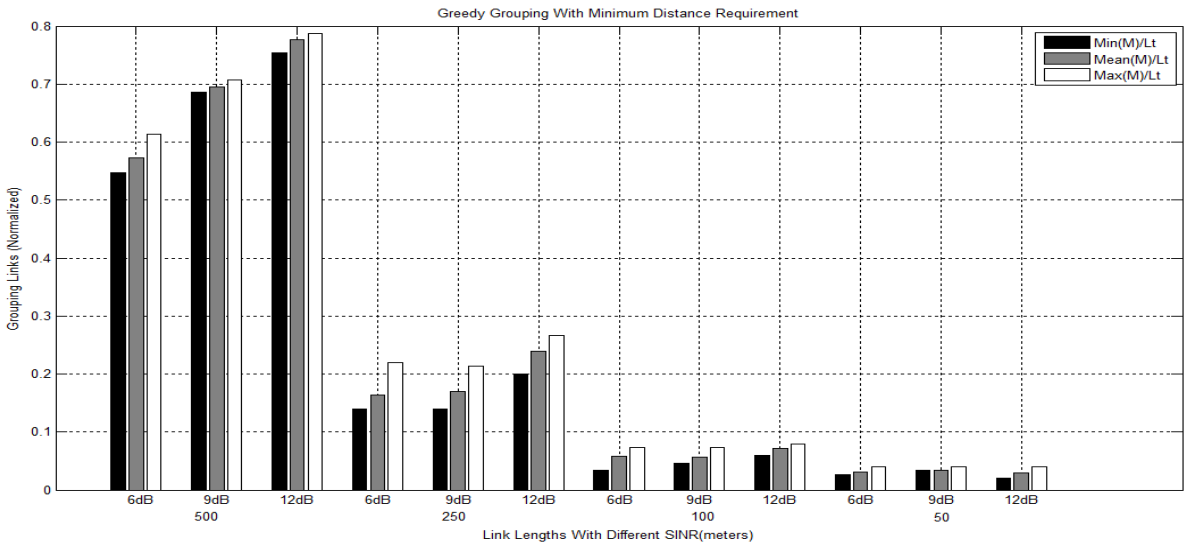


Figure 4.9: number of groups formed with 150 links in Sub Urban scenario

Table 4.7: scenario 4 with 150 links and fixed link lengths sub urban area

150 link link length (m)	**$SINR_{min}$(dB)**	**d_{min} (m)**	**Min (M)**	**Mean (M)**	**Max (M)**
500	6	943.1923	83	86.4	92
	9	1082.9	101	105	108
	12	1243.4	112	118.4	124
250	6	471.5962	21	22.2	26
	9	541.4648	18	25.2	31
	12	621.6848	30	36	42
100	6	188.6385	5	7.2	9
	9	216.5859	7	9	11
	12	248.6739	7	9.4	13
50	6	94.3192	4	5	7
	9	108.2930	3	3.8	5
	12	124.3370	4	4.6	6

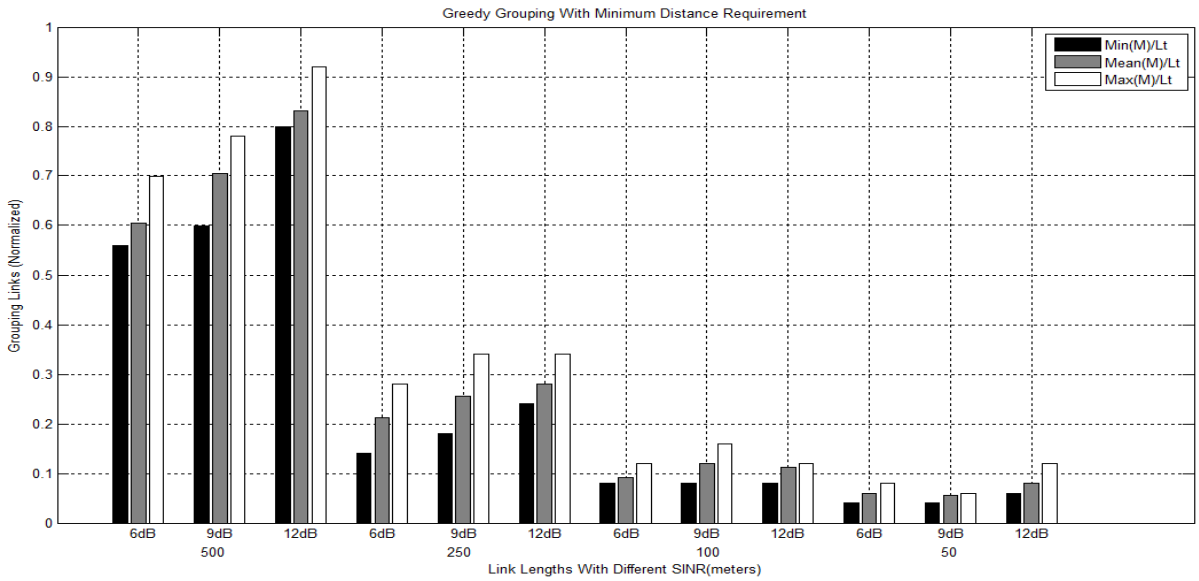


Figure 4.10: number of groups formed with 50 links in Sub Urban scenario

Table 4.8: scenario 4 with 50 links and fixed link lengths sub urban area

50 link link length (m)	**$SINR_{min}$(dB)**	**d_{min} (m)**	**Min (M)**	**Mean (M)**	**Max (M)**
500	6	943.1923	23	30.6	36
	9	1082.9	31	36.6	41
	12	1243.4	38	41.4	46
250	6	471.5962	9	11.4	13
	9	541.4648	10	11.8	14
	12	621.6848	9	13.8	19
100	6	188.6385	4	4.8	6
	9	216.5859	4	5.2	6
	12	248.6739	5	5	5
50	6	94.3192	2	2.8	4
	9	108.2930	3	3.2	4
	12	124.3370	2	3.6	5

4.2 Summery

The difference between scenarios in figures 4.3, 4.5, 4.7, 4.9 and figures 4.4, 4.6, 4.8 and 4.10 with 150 and 50 links lengths are explain as follow, When the link density is high, the different simulations are more similar to each other than when the link density is low, it is also observed that for a high link density, the relative efficiency is slightly better compared to the low density simulations because there are more links to choose from.

In scenario 1 for very long link lengths, no links can be combined to the same groups due to large distance between D2D nodes according to the numerical results in tables 4.1 and 4.2, this causes severe interference to other devices.

In scenario 2, for very long link lengths, few links can be combined to the same group compared to the scenario 1 and the grouping increase when the link lengths decrease.

In scenario 3, for lengthy links, more links can be combined to the same group and the necessary groups to accommodate all links have been decreased compare to previous scenarios.

In scenario 4 for very long link lengths all links have been combined to the same group because the minimum distance requirement is less than the diameter of the cell and the SINR is guaranteed and when the link lengths decrease all links can be accommodate in less necessary group.

Comparing the scenarios, it is founded that scenario 4 is the best one with greedy grouping algorithm to guarantee the SINR requirement for minimum distances, and the level of interference has been low compared to other scenarios.