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| Abstract | This paper proposes a method for using non-square QAM constellations with independent I&Q. This method is based in the creation of non-separable I and Q constellations by combining constituent separable I and Q constellations. |
| Purpose | To be used by TGa for discussion and to help preparing the draft document. |
| Notice |  |
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# Method to use non-squared QAM constellations

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## Proposal

This paper proposes a method for using non-square QAM constellations with independent I&Q. This method is based in the creation of non-separable I and Q constellations by combining constituent separable I and Q constellations.

## Discussion

The way to obtain this objective has the following steps:

1. Draw the square constellation that has double number of points ($2^{n+1}$ points) than the non-square constellation that we want to use ($2^n$ points) (i.e. if we want to use a 32 QAM we start with the constellation for 64 QAM with independent I&Q Gray mapping).

2. Delete every other point in each dimension such that every row keeps half of the points and every column keeps half of the points and that the constellation points that remains have the same distance between them.

3. Assign to each remaining point, a number formed from the bits of the I value and bits of the Q value of the original constellation mapping, where one bit position of the I value or one bit position of the Q value have been removed. The first number is from the I dimension, called I-value, and the second number is from the Q dimension, called Q-value.

4. Decoded the resulting signal using two subset square constellations with independent I and Q and reducing the processing power because of factor that appear in the decoding process.

When one bit in one dimension is removed, the resulting n-1 bits of the n bit constellation-value have independent I and Q.

## Application of the method to the 8 QAM case.

The design of an 8 QAM constellation with independent I&Q property, using Gray mapping has 4 possible combinations or cases. The first 2 steps are common all 4 cases. Steps 3 and 4 are unique for each case.

Step1. Draw the square constellation that has double number of points ($2^{n+1}$ points) than the non-square constellation that we want to use ($2^n$ points). For 8 QAM, n=3, the square constellation is 16 QAM with independent I&Q Gray mapping.

Figure 1 shows the 16 QAM constellation with Gray Mapping. The first number represent the Q dimension and the second number represents the I dimension.

```
I     { 0 { 0 { 1 { 1
        0}  1}  1}  0}
                                   Q
       00 01 03 02    (00)
       10 11 13 12    (01)
       30 31 33 32    (11)
       20 21 23 22    (10)
```

Figure 1. 16 QAM constellation with Gray Mapping.

Step 2. Delete every other point in each dimension such that each row keeps half of the points and every column keeps half of the points and that the constellation points that remains have the same distance between them.

Figure 2 shows the constellation after removing half of the points.

The technique produces similar constellations if we decide to keep the points that had been removed from Figure 2.

```
   01    02
10    13
   31    32
20    23
```

Figure 2. Second step of the method.

Step 3. Assign to each remaining point, a number formed from the bits of the I value and bits of the Q value of the original constellation map, where one bit position of the I value or one bit position of the Q value have been removed.

Case 1. Remove the most protected bit in I. Figure 3 shows the region created in this case.

```
      Remove the most protected bit of I

   I-value {}      I    { 0}{ 1}{ 1}{ 0}
   Q-value ()                            Q
                          01    00       (00)
                        10    11         (01)
                          31    30         (11)
                        20    21           (10)
```

Figure 3. 8 QAM case 1.

The previous case the resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 4.

```
                          01----00
                        10--|-11  |
                         | 31--|-30
                        20----21
```

Figure 4. Subset constellation of 8 QAM case 1

Case 2. Remove the least protected bit in I. Figure 5 shows the region created in this case.

```
      Remove the least protected bit of I

   I-value {}      I    { 0}{ 0}{ 1}{ 1}
   Q-value ()                             Q
                          00    01        (00)
                        10    11          (01)
                          30    31          (11)
                        20    21            (10)
```

Figure 5. 8 QAM case 2.

The previous case the resulting non-square constellation is the superposition of two square constellations, one of those had been shifted. This is shown in Figure 6.

```
                          00----01
                        10--|-11  |
                         | 30--|-31
                        20----21
```

Figure 6. Subset constellation of 8 QAM case 2

In this case 2 it is important to note that the OX values of the two subset square constellations are the same 0 for the first column and 1 for the second column. This fact is very helpful to the decoding process, reducing considerably the computational requirements.

Case 3. Remove the most protected bit Q. Figure 7 shows the region created in this case.

```
Remove the most protected bit of Q

I-value {}      I    { 0 { 1 { 1 { 0
Q-value ()            0}  0}  1}  1}              Q

                             02    01              (0)
                          10    13                 (1)
                             12    11              (1)
                          00    03                 (0)
```

Figure 7. 8 QAM case 3

The previous case the resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 8.

```
   02----01
10--|-13  |
 | 12--|-11
00----03
```

Figure 8. Subset constellation of 8 QAM case 3

Case 4. Remove the least protected bit Q. Figure 9shows the region created in this case.

```
Remove the least protected bit of Q

I-value {}      I    { 0 { 1 { 1 { 0
Q-value ()            0}  0}  1}  1}              Q

                             02    01              (0)
                          00    03                 (0)
                             12    11              (1)
                          10    13                 (1)
```

Figure 9. 8 QAM case 4.

Also in this case it is interesting to note that in the previous case the resulting non-square constellation is the superposition of two square constellations, one of those had been shifted. This is shown in Figure 10.

```
   02----01
00--|-03  |
 | 12--|-11
10----13
```

Figure 10. Subset constellation of 8 QAM case 4

In this case 4 it is important to note that the OY values of the two subset square constellations are the same 0 for the first row and 1 for the second row. This fact is very helpful to the decoding process, reducing considerably the computational requirements.

## Application of the method to the 32 QAM case.

Here it is illustrate the use of the method for a 32 QAM constellation with Gray mapping for the 6 possible combinations.

Step1. Draw the square constellation that has double number of points ($2^{n+1}$ points) than the non-square constellation that we want to use ($2^n$ points). For 32 QAM, n=5, the square constellation is 64 QAM with independent I&Q Gray mapping.

Figure 11 shows the 64QAM constellation with Gray Mapping. The first number represent the Q dimension and the second number represents the I dimension.

```
0  0  0  0  1  1  1  1
0  0  1  1  1  1  0  0
0  1  1  0  0  1  1  0

00 01 03 02 06 07 05 04 (000)
10 11 13 12 16 17 15 14 (001)
30 31 33 32 36 37 35 34 (011)
20 21 23 22 26 27 25 24 (010)
60 61 63 62 66 67 65 64 (110)
70 71 73 72 76 77 75 74 (111)
50 51 53 52 56 57 55 54 (101)
40 41 43 42 46 47 45 44 (100)
```

Figure 11. 64 QAM Constellation with Gray Mapping.

Step 2. Delete every other point in each dimension such that each row keeps half of the points and every column keeps half of the points and that the constellation points that remains have the same distance between them.

Figure 12 shows the constellation after removing half of the points.

The technique produces similar constellations if we decide to keep the points that had been removed from Figure 12.

```
   01    02    07    04
10    13    16    15
   31    32    37    34
20    23    26    25
   61    62    67    64
70    73    76    75
   51    52    57    54
40    43    46    45
```

Figure 12. Second step of the method for the 32 QAM case.

Step 3. Assign to each remaining point, a number formed from the bits of the I value and bits of the Q value of the original constellation map, where one bit position of the I value or one bit position of the Q value have been removed.

Case 1. Remove the most protected bit in I. Figure 13 shows the region created in this case.

```
     Remove the most protected bit of I

I-value {}      I   { 0 { 0 { 1 { 1 { 1 { 1 { 0 { 0
Q-value ()            0}  1}  1}  0}  0}  1}  1}  0}          Q

                              01    02    03    00    (000)
                           10    13    12    11       (001)
                              31    32    33    30    (011)
                           20    23    22    21       (010)
                              61    62    63    60    (110)
                           70    73    72    71       (111)
                              51    52    53    50    (101)
                           40    43    42    41       (100)
```

Figure 13. 32 QAM case 1.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 14.

```
  01----02----03----00
10--|-13----12----11  |
 | 31    32    33  | 30
20  | 23    22    21  |
 | 61    62    63  | 60
70  | 73    72    71  |
 | 51----52----53--|-50
40----43----42----41
```

Figure 14. Subset constellation of 32 QAM case 1

Case 2. Remove the second most protected bit in I. Figure 15 shows the region created in this case.

```
     Remove the second most protected bit of I

I-value {}      I   { 0 { 0 { 0 { 0 { 1 { 1 { 1 { 1
Q-value ()            0}  1}  1}  0}  0}  1}  1}  0}          Q

                          01    00    03    02   (000)
                       10    11    12    13      (001)
                          31    30    33    32   (011)
                       20    21    22    23    (010)
                          61    60    63    62   (110)
                       70    71    72    73      (111)
                          51    50    53    52   (101)
                       40    41    42    43      (100)
```

Figure 15. 32 QAM case 2.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 16.

```
  01----00----03----02
10--|-11----12----13  |
 | 31    30    33  | 32
20  | 21    22    23  |
 | 61    60    63  | 62
70  | 71    72    73  |
 | 51----50----53--|-52
40----41----42----43
```

Figure 16. Subset constellation of 32 QAM case 2.

Case 3. Remove the least bit in I. Figure 17 shows the region created in this case.

```
Remove the least protected bit of I

I-value {}      I   { 0 { 0 { 0 { 0 { 1 { 1 { 1 { 1
Q-value ()            0}  0}  1}  1}  1}  1}  0}  0}          Q

                         00    01    03    02   (000)
                      10    11    13    12      (001)
                         30    31    33    32   (011)
                      20    21    23    22      (010)
                         60    61    63    62   (110)
                      70    71    73    72      (111)
                         50    51    53    52   (101)
                      40    41    43    42      (100)
```

Figure 17. 32 QAM case 3.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 18.

```
   00----01----03----02
10--|-11----13----12  |
 | 30    31    33  | 32
20  | 21    23    22  |
 | 60    61    63  | 62
70  | 71    73    72  |
 | 50----51----53--|-52
40----41----43----42
```

Figure 18. Subset constellation of 32 QAM case 3.

Case 4. Remove most protected bit in Q. Figure 19 shows the region created in this case.

```
Remove the most protected bit of Q

I-value {}        I    { 0 { 0 { 0 { 0 { 1 { 1 { 1 { 1
Q-value ()               0   0   1   1   1   1   0   0
                         0}  1}  1}  0}  0}  1}  1}  0}        Q

                            01    02    07    04        (00)
                         10    13    16    15           (01)
                            31    32    37    34        (11)
                         20    23    26    25           (10)
                            21    22    27    24        (10)
                         30    33    36    35           (11)
                            11    12    17    14        (01)
                         00    03    06    05           (00)
```

Figure 19. 32 QAM case 4.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 20.

```
  01----02----07----04
10--|-13----16----15  |
 | 31    32    37  | 34
20  | 23    26    25  |
 | 21    22    27  | 24
30  | 33    36    35  |
 | 11----12----17--|-14
00----03----06----05
```

Figure 20. Subset constellation of 32 QAM case 4.

Case 5. Remove the second most protected bit in Q. Figure 21 shows the region created in this case.

```
     Remove the second most protected bit of Q

  I-value {}     I   { 0 { 0 { 0 { 0 { 1 { 1 { 1 { 1
  Q-value ()           0   0   1   1   1   1   0   0
                         0}  1}  1}  0}  0}  1}  1}  0}          Q

                            01    02    07    04    (00)
                         10    13    16    15       (01)
                            11    12    17    14    (01)
                         00    03    06    05       (00)
                            21    22    27    24    (10)
                         30    33    36    35       (11)
                            31    32    37    34    (11)
                         20    23    26    25       (10)
```

Figure 21. 32 QAM case 5.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 22.

```
   01----02----07----04
10--|-13----16----15  |
 | 11    12    17   | 14
00  | 03    06    05  |
 | 21    22    27   | 24
30  | 33    36    35  |
 | 31----32----37--|-34
20----23----26----25
```

Figure 22. Subset constellation of 32 QAM case 5.

Case 6. Remove the least protected bit in Q. Figure 23 shows the region created in this case.

```
     Remove the least protected bit of Q

I-value {}      I   { 0 { 0 { 0 { 0 { 1 { 1 { 1 { 1
Q-value ()            0   0   1   1   1   1   0   0
                        0}  1}  1}  0}  0}  1}  1}  0}          Q

                           01    02    07    04    (00)
                        00    03    06    05       (00)
                           11    12    17    14    (01)
                        10    13    16    15       (01)
                           31    32    37    34    (11)
                        30    33    36    35       (11)
                           21    22    27    24    (10)
                        20    23    26    25       (10)
```

Figure 23. 32 QAM case 6.

The resulting non-square constellation is the superposition of two square constellations; one of those had been shifted. This is shown in Figure 24.

```
   01----02----07----04
00--|-03----06----05  |
 | 11    12    17  | 14
10  | 13    16    15  |
 | 31    32    37  | 34
30  | 33    36    35  |
 | 21----22----27--|-24
20----23----26----25
```

Figure 24. Subset constellation of 32 QAM case 5.