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Source(s)	Tal Kaitz, Ran Yaniv **Alvarion Ltd.** Voice:+972-37674583 tal.kaitz@alvarion.com ran.yaniv@alvarion.com Adam Kerr, Paul Petrus **ArrayComm Inc.** adam@arraycomm.com petrus@arraycomm.com
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Frequency Diversity in AMC

Tal Kaitz, Ran Yaniv
Alvarion Ltd.

Adam Kerr, Paul Petrus
ArrayComm Inc.

1 Introduction

The objective of this contribution is to introduce frequency diversity in the AMC zone over a configurable subset of its bands. The motivation is to make the AMC mode optimal for AAS use.

This contribution is arranged as follows: section 2 states the problem and discusses the need for frequency diversity in the AMC mode. Section 3 outlines the proposed changes. Section 4 presents an overview of the required text changes.

2 Problem Statement

In AMC mode, transmissions occur over a group of contiguous bins, where a bin is a contiguous group of 9 contiguous subcarriers. This makes the AMC mode particularly useful for AAS use, because the continuity in the frequency domain allows for improved channel estimation, a critical feature for AAS operation.

It is important to note that AMC transmissions occur, by design, over a *single* contiguous frequency band and thus provide no frequency diversity. This feature allows the MAC layer to select, for each SS, the optimal frequency band for operation. This scheme was shown to provide a significant performance advantage. However for this scheme to operate, the channel needs to remain relatively static over periods of time equivalent to the MAC layer latency and processing time. In medium to high vehicular velocities, the MAC layer will not accommodate the fast channel variations.

It can be argued that other modes, such as the PUSC and FUSC modes provide ample frequency diversity. However, these modes are less suitable for AAS operation since training signals are shared among all the subchannels. As a consequence, beamforming cannot be done separately for each subchannel, but rather for each major group in PUSC mode, and over the entire bandwidth in FUSC mode.

Another argument that can be made is that spatial diversity, typically provided in AAS systems, compensates for the lack of frequency diversity. In the next subsection it is shown that even when spatial diversity is present, frequency diversity can significantly reduce the required fade margin.

2.1 The importance of frequency diversity

In this section we analyze interaction of frequency diversity and spatial diversity.

In the following we shall use the notation suggested in [4]. Consider the system described in Figure 1. The BS is located at the origin of the coordinate system. The BS consists of two antennas located at x=±d/2. The SS is located at a distance D from the BS. The line joining the SS with the BS makes an angle Φ_0 with the x-axis. The SS is surrounded by a scattering region of radius σ_s. A precise definition of σ_s will be provided later on. Note that σ_s is not restricted to be smaller than D, and the scattering region may encompass the BS.

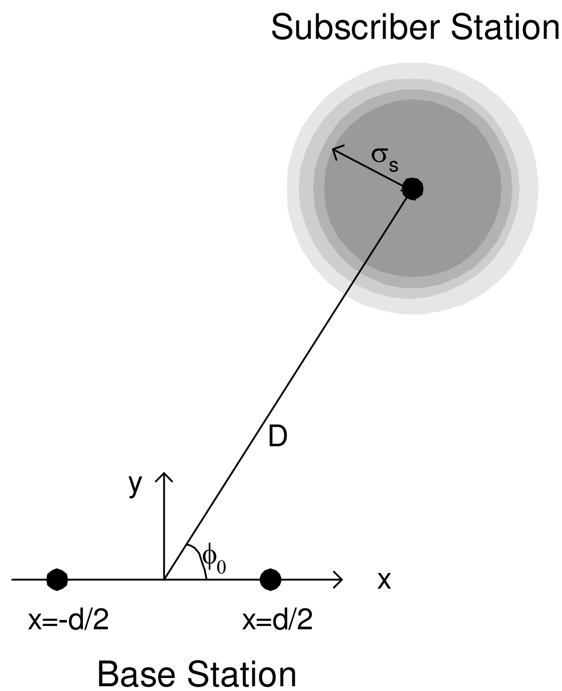


Figure 1 System model

Let $P_{AS}(\Phi)$ denote the power azimuth spectrum associated with the scattering region. The correlation between the signals received at base station antennas is given by

$$\rho_s(d) = \int \exp\left(jkd\cos\phi\right)P_{AS}(\phi)d\phi \qquad (1)$$

where $k = 2\pi/\lambda$ and λ is the wavelength of the RF carrier.

Let $P_{DS}(\tau)$ denote the delay spread spectrum associated with the scattering region. The correlation between the signal received at frequencies f_1 and f_2 is given by

$$\rho_f(\Delta f) = \frac{1}{2\pi}\int \exp\left(j2\pi\Delta f\cdot\tau\right)P_{DS}(\tau)d\tau \qquad (2)$$

with $\Delta f = f_1 - f_2$.

Next we make use of a Geometrically Based Single-Bounce (GBSB) statistical channel modeling approach (see [1] for an overview of spatial channel models) where the propagation between the SS and the BS are assumed to take place via single scattering from obstacles in the scattering region. This region is characterized by the probability density function of the scattering obstacles.

In particular we make use of a Gaussian Scattering Model (GSM). The GSM was proposed in [2] and [3]. The obstacle probability density of the GSM is given by

$$p(x_m, y_m) = \frac{1}{2\pi\sigma_s^2} \exp\left(-\frac{x_m^2 + y_m^2}{2\sigma_s^2}\right) \qquad (3)$$

Here, x_m and y_m denote the coordinate of the obstacle relative to the SS.

In [4], Janaswamy derived closed form expressions for the power azimuth spectrum (PAS) and the power delay spread spectrum (PDS) for the GSM. Using expressions for PAS and PDS, he showed agreement to the measurement results provided by Pedersen, [5].

Although close form analytical expressions exist, we have used Monte Carlo techniques to compute the spatial and frequency correlations given in (1) and (2). We used the following conditions

- Carrier frequency $f_{RF} = 2.6$GHz
- Frequency separation Δf=5MHz.
- Spatial separation d=10 λ.
- 30 obstacles were generated fro each simulation round, 10000 simulation rounds were performed.

The value of D was varied in the range of 100m to 4km.The value of σ_s was varied from 10m to 200m. (For reference, the values found by Pederson corresponded to D=1.5Km, σ_s = 162m)

The results are shown in Figure 2 where the spatial (solid lines) and frequency (dashed lines) correlation are shown. As can be seen, for large distances, the frequency correlation depends mostly on the scattering radius. The spatial correlation depends both on the scattering radius and BS-SS distance. (Actually it depends on the ratio of the two).

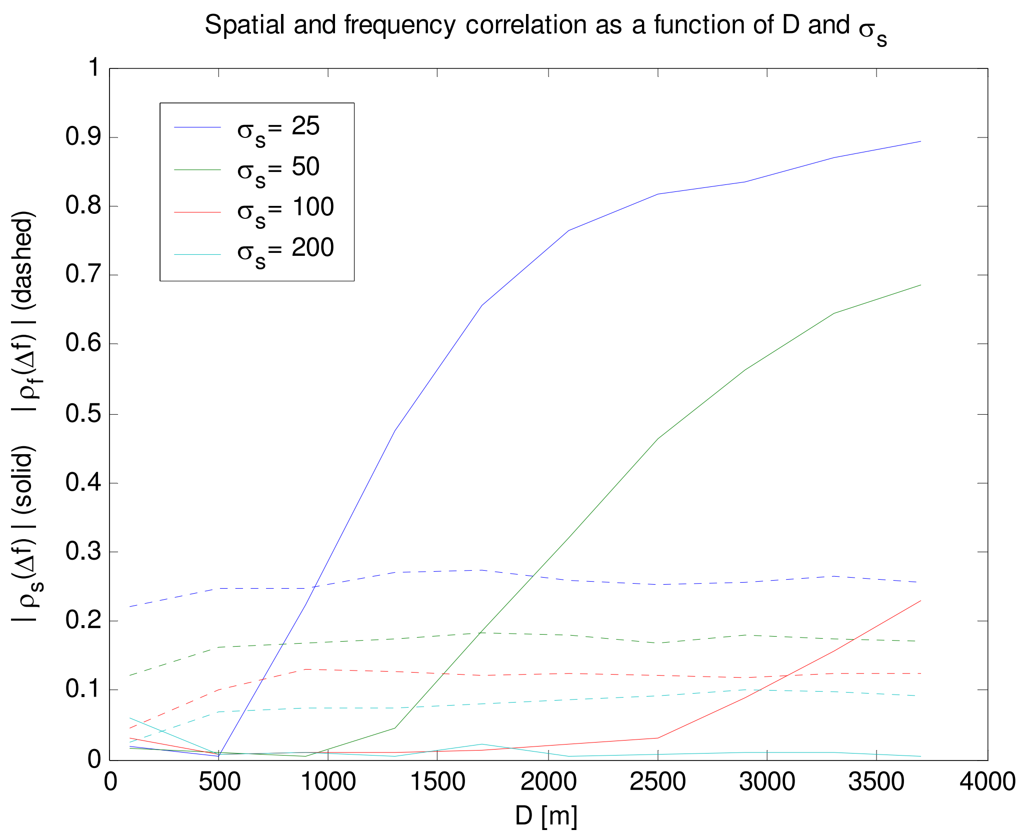


Figure 2 Spatial and frequency correlation

For large scattering radius, both correlations are low. As the scattering radius is reduced, both spatial and frequency correlations increase. For large angular spreads, (i.e. large ratios of σ_s/D), spatial correlation is lower than the frequency correlation. However for small angular spreads, frequency correlation is smaller. For the lowest angular spreads simulated, the antennas became completely correlated.

As a general conclusion, it seems that frequency diversity is important for macro-cell environment, where the distances are high and the angular spreads are small. For the microcell and picocell environments, where the angular spreads are high, spatial diversity is more important.

To evaluate the impact on system performance, we look at the required fade margin for a 1% outage probability, for the case of σ_s=25m. The fade margin is computed for the case of two antennas (d=10) and a single frequency (Δf=0Hz), and for the case of two antennas and two frequencies. (d=10 λ Δf=5MHz). The results are shown in Figure 3. For this simulation, 50000 trials were run.

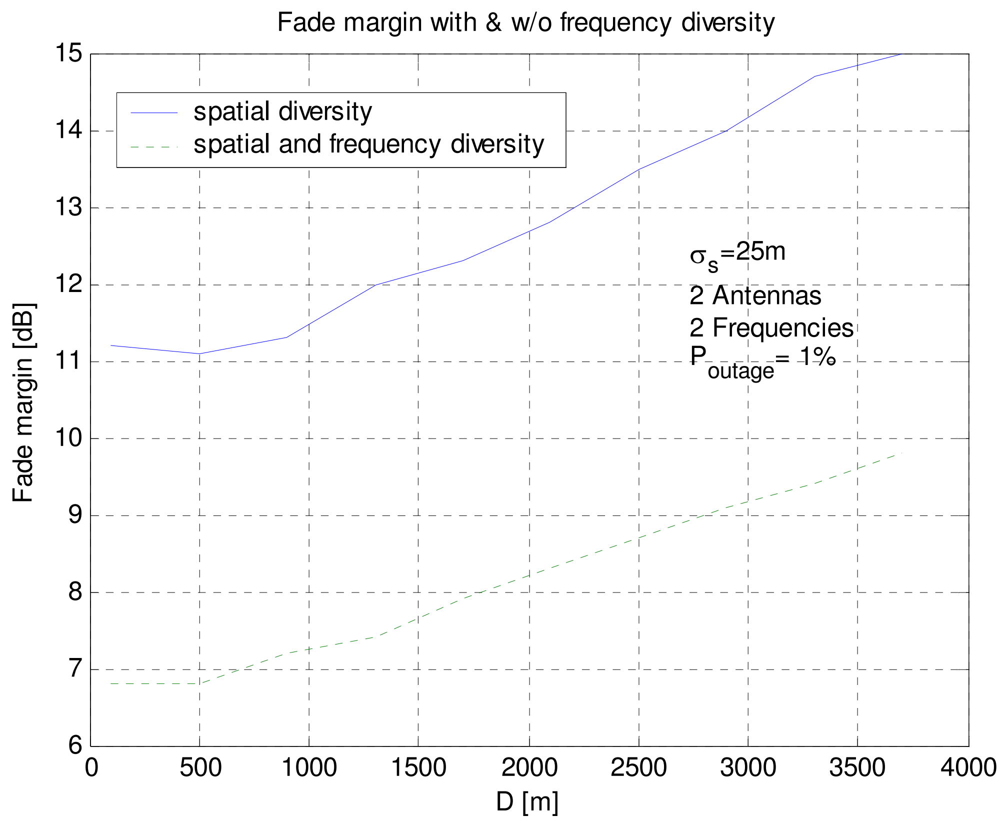
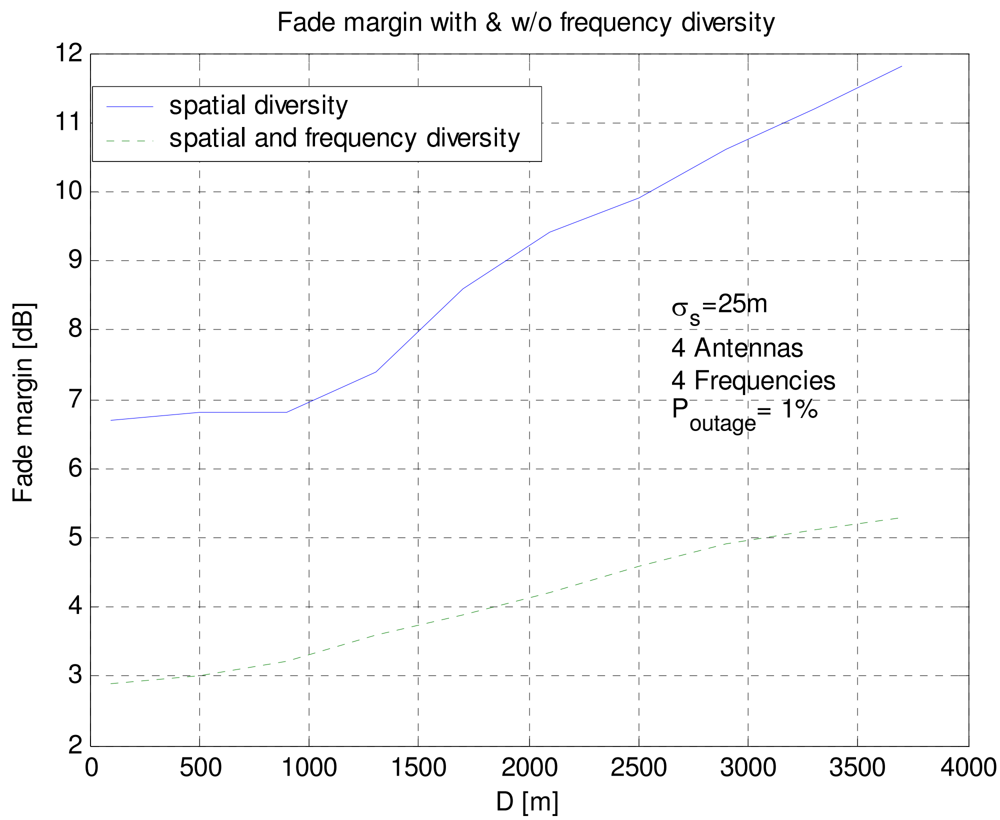


Figure 3 Fade margin

In the case of high angular spreads (low D), frequency diversity provides a reduction in fade margin of 5dB. In this case the antennas are uncorrelated, and frequency diversity increases diversity order to about 4. When D is increased the antennas become correlated but the response across frequencies remains uncorrelated. The effective diversity order is reduced to 2. In this case the improvement in fade margin is about 6dB.

Finally we look at the case of 4 antennas and 4 frequency points. The antenna spacing and frequency spacing remain the same (10λ and Δf=5MHz respectively). In this case, the improvement at low D is only about 4 dB, but at high D it is about 6.5dB.



3 Proposed solution

3.1 Solution outline

It is proposed to define an extended AMC zone (called 'DAMC' zone) that supports frequency diversity over a configurable subset of its bands. The concept presented maintains backward compatibility with [6], as will be discussed in more detail later on. Note that the solution does not apply to HARQ over AMC; hence any reference to AMC implies non-HARQ transmission.

The DAMC zone allocates some of its physical bands as DAMC (*diversity-AMC*) bands. The bins of these bands are then allocated to subchannels through a permutation formula that maintains subchannel frequency diversity. DAMC zones may differ in the number of bands allocated to the frequency diversity scheme. For the downlink, a DAMC subchannel is comprised of 6 bins. In the uplink, a DAMC subchannel is comprised of 3 bins. Note that the bins are not contiguous in frequency.

As an example, consider a DL sub-frame with both AAS and non-AAS AMC zones, as depicted in Figure 4 for FFT-1024. The non-AAS portion includes one legacy AMC zone and one DAMC zone with only DAMC bands. The AAS portion is comprised of a DAMC zone with both ¾ DAMC and ¼ regular bands.

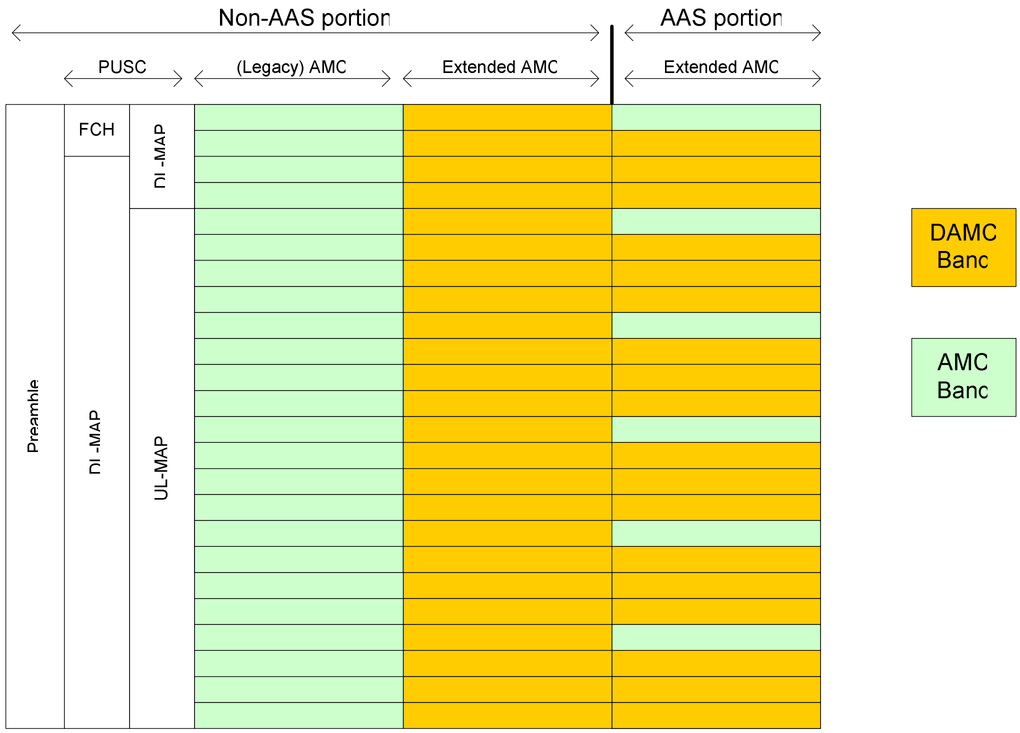


Figure 4 – Example of a DL subframe consisting of PUSC, legacy AMC, and DAMC zones.

3.2 DAMC Zone Structure

Each DAMC zone is subdivided along the frequency dimension to regular-AMC and DAMC bands. Regular AMC subchannels are allocated in the AMC bands as is defined in the AMC section. DAMC subchannels are allocated as follows:

1. The zone's physical bands are first split into $N_{superbands}$ super-bands, each comprised of M bands. In each super-band, the first $(M\text{-}L)$ bands are specified as regular AMC bands, and the remaining L bands are assigned to DAMC (L is a configurable zone parameter). The total number of DAMC bands is therefore $N_{superbands}*L$. The following table specifies the values of these parameters for the various FFT sizes:

FFT size	Number of super-bands ($N_{superbands}$)	Number of bands per super-band (M)	Number of DAMC bands in each super-band (L)
2048	6	8	2, 4, 6, or 8
1024	6	4	1…4
512	6	2	1…2
128	3	1	1

2. The bins of all DAMC bands are then renumbered consecutively in ascending frequency order from 0 to $N_{DAMCbins}\text{-}1$.

3. DAMC subchannels are allocated by assigning 6 non-adjacent bins to a subchannel in the downlink or 3 non-adjacent bins to a subchannel in the uplink; hence the DAMC slot dimensions are 6 bins x 1 symbol for the downlink, and 3x2 for the uplink. The number of DAMC subchannels per FFT size and *L* for DL and UL are shown in the following table:

FFT size	Number of DAMC bands in each super-band (*L*)	Number of DAMC subchannels ($N_{subchannels}$)	
		DL	UL
2048	2	8	16
	4	16	32
	6	24	48
	8	32	64
1024	1	4	8
	2	8	16
	3	12	24
	4	16	32
512	1	4	8
	2	8	16
128	1	2	4

4. Frequency diversity is achieved by using a permutation formula for allocating the (reordered) DAMC bins to subchannels. The permutation formula first assigns bins to "clusters"[1], each cluster containing 6 non-adjacent bins:

$$Bin(k, c) = (N_{DAMCbins}/6)*k + (P[(c+k) \bmod (N_{DAMCbins}/6)] + IDcell) \bmod (N_{DAMCbins}/6) \quad (1)$$

   where k is the bin index and c is the cluster index, $k = 0, \ldots, 5$; $c = 0, \ldots, (N_{clusters}-1)$. $N_{clusters}$ is equal to the number of DL subchannels, and P is a permutation sequence dependent on FFT-size and L. P is TBD.

5. Subchannels are then formed from the clusters. For the downlink, each cluster simply corresponds to one subchannel. In the uplink, each cluster corresponds to two subchannels: bins 0, 2, 4 of the cluster are assigned to the 1st subchannel and bins 1, 3, 5 of the cluster are assigned to the 2nd subchannel.

Figure 5 depicts the allocation scheme.

[1] Not to be confused with "clusters" used in downlink PUSC permutation.

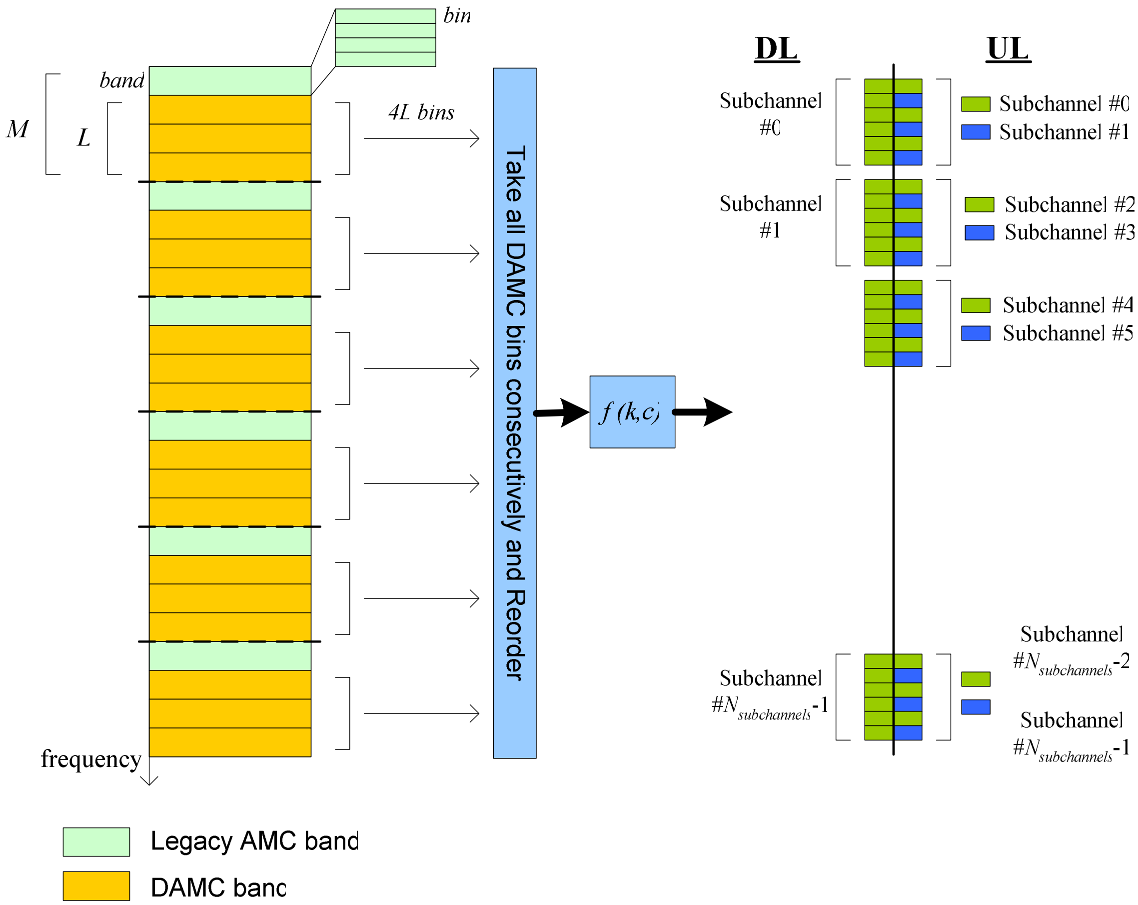


Figure 5 –DAMC subchannel allocation scheme for FFT-1024 with L = 3.

3.3 Burst Allocation and Maps

1. Separate zone switch IEs are defined in the UL and DL (via extended DIUC/UIUC) for DAMC zones. The number of DAMC bands per super-band is configurable through this zone switch IE.

2. Subchannels in a DAMC zone are renumbered as follows: The numbering shall start from 0 with the regular non-diverse AMC subchannels (in ascending frequency order) and then continue on to the DAMC subchannels.

3. A burst will not span both regular and DAMC subchannels.

3.4 AAS Diversity map scan

AAS diversity-map-scan shall be supported by the DAMC zone using the same physical bins specified in [6]. Therefore, the SS's DLFP search mechanism remains unchanged. This is accomplished by first allocating the AMC and DAMC subchannels according to the specification in section 3.2, and then switching bins that are allocated over the AAS-DLFP's expected physical location to other locations. Consider two scenarios:

1. The DAMC zone is comprised of only DAMC bands (no legacy bands).
2. The DAMC zone also contains legacy AMC bands.

For the first scenario, switching is done simply by exchanging the 6 bins allocated on the DLFP's expected physical location with the 6 bins of the last DAMC subchannel (# $N_{subchannel}$-1). This last subchannel shall not be allocated through maps.

For the second scenario, the first DLFP 3x2 slot occupies the first physical band which is a legacy AMC band, while the 2nd DLFP 3x2 slot occupies the last physical band, which is a DAMC band. The first physical band (a legacy AMC band) is exchanged with the first DAMC band in its super-band, and then the switching defined for scenario 1 can be applied.

The AAS-DLFP should additionally include a parameter that specifies the number of bands in the super-band (*L*) used in the DAMC zone to which the UL/DL allocation IE in the DLFP points. This single parameter will apply to both UL and DL using DAMC.

Note that the AAS SS searching for the AAS-DLFP need not be aware of this band switching. The switching of bins occurs for any DAMC zone that exists in the downlink AAS zone, regardless of whether an AAS-DLFP is actually transmitted in the zone.

3.5 Co-existence with H-ARQ

The H-ARQ mechanism will regard the AMC zone with DAMC as a zone with 'normal subchannels' and not as a 'Band-AMC' zone. The 'Band-AMC' H-ARQ mode will not apply to an AMC zone with DAMC subchannels.

3.6 Backward Compatibility

It is proposed that the diversity-AMC enhancement be mandatory for 802.16e systems supporting adjacent subcarrier permutation. Backward compatibility with [6] is maintained by adding a new capability to negotiate DAMC support.

An 802.16e BS will not schedule allocations intended for an 802.16d SS in a DAMC zone. An 802.16e SS supports legacy AMC zones and can therefore seamlessly work with an 802.16d BS.

4 Detailed Text Changes

The following is an overview of the required text changes. The exact modifications are currently being refined.

1. **Modify section 8.4.4.6:**

   Explain bin-switching for accommodating the AAS-DLFP in the DAMC zone at its original physical location.

2. **Modify section 8.4.5.3.3:**

   Add additional AAS DL IE to specify transition to AAS traffic over a DAMC zone. Configuration parameters are:
   - *Number of DAMC bands per super-band (at least 1),*
   - *IDcell.*

3. **Add new section 8.4.5.3.19:**

   Add new DAMC DL zone switch IE. Configurable parameters are Number of DAMC bands per super-band (at least 1) and IDcell.

4. **Modify section 8.4.5.4:**

   Specify that in a DAMC UL zone, an allocation will not span over both regular and DAMC bands.

5. **Modify section 8.4.5.4.6:**

   Add additional AAS UL IE to specify transition to AAS traffic over a DAMC zone. Configurable parameters are Number of DAMC bands per super-band, and IDcell.

6. **Add new section 8.4.5.4.21:**

   Add new DAMC UL zone switch IE. Configurable parameters are Number of DAMC bands per super-band (at least 1), and IDcell.

7. **Add new section 8.4.6.4 "Diversity-AMC (DAMC) Zone":**

   Define structure of DAMC zone, bin permutation, and subchannel numbering.

8. **Modify section 11.8.3.7.5 "OFDMA SS Permutation Support":**

   This field indicates the different optional OFDMA permutation modes (optional PUSC, optional FUSC and AMC) supported by a WirelessMAN-OFDMA SS. The DAMC support bit is specified for backward compatibility to IEEE Std 802.16-2004 and its value shall equal that of the AMC support bit; DAMC support is mandatory for an SS that supports AMC. A bit value of 0 indicates "not supported" while 1 indicates "supported."

Type	Length	Value	Scope
154	1	Bit# 0: Optional PUSC support Bit# 1: Optional FUSC support Bit# 2: AMC support Bit# 3: DAMC support Bits# ~~3~~4–7: *Reserved*, shall be set to zero	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

5 Acknowledgement

The authors would like to acknowledge Dr. Jack Cohen for his assistance in preparing the analysis and simulation in section 2.1.

6 References

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[6] IEEE P802.16-2004.

[7] IEEE P802.16e-D4.