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| Source(s) | Tim Godfrey  EPRI  Doug Gray TCS | Voice:  E-mail:  \*<<http://standards.ieee.org/faqs/affiliationFAQ.html>> |
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**An Evaluation of Alternative Solutions for 1 MHz Channels for Smart Grid Applications**

**Notes for IEEE 802.16 GRIDMAN WG**

[dgray.tcs@gmail.com](mailto:dgray.tcs@gmail.com)

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Full Spectrum Proposed Solution

In response to a call for contributions, Full Spectrum Inc.[[1]](#footnote-1) has filed a proposed alternative [[[2]](#endnote-1)] to support a 1 MHz channel BW, or less, for Smart Grid networks. My summary includes information in addition to what was contributed, based on a meeting with Full Spectrum staff[[3]](#footnote-2), material received after the meeting and information from their website.

It is important to note that Full Spectrum has been delivering and has extensive deployments in frequency bands below 1000 MHz with channel BWs of 1 MHz and below. The product solutions known as FullMAX use a fast Fourier transform (FFT) of 128. Full Spectrum has also taken overhead (OH) reduction measures to help enhance net throughput.

**Table 1: FullMAX OFDMA Parameters and Data Rate (PHY)**



**Explanatory notes for Table 5:**

* Columns: All of the columns assume AMC permutation, the columns denoted by ‘a’ represent AMC with 2 Bins over 3 symbols, and those denoted by ‘b’, AMC with 1 Bin over 6 symbols resulting in 6 or 12 sub-channels respectively. (5, 10, and 20 ms frame sizes are shown in the table. FullMAX also supports 12.5 ms and 25 ms frame sizes which are not shown in the table)
* Rows numbers in red highlighted in gray are values from information submitted to IEEE, other rows provide additional details
* Row 14: For comparative purposes the TR gap is selected to be 1 symbol for all variations even though it may not be sufficient to support a 40 mi range
* Row 17: Shows the supported range with a single symbol for the TR-Gap
* Row 18: Shows the required number of symbols to support a range ≥ 40 miles (64.4 km) which would generally only be applicable in propagation-friendly environments.
* Rows 32 and 33: The DL and UL data symbols are selected to provide an uplink bias to the direction of traffic in the order 1.6 to 1.7 to 1, as would be typical for Smart Grid applications.
* Row 37: The path loss factor of 4 represents a non-LoS rural environment that is flat with light tree density
* Rows 43 and 44: With several symbols allocated for OH (including TR-Gap) this indicates the impact in per cent for an increased TR-Gap for extended range or a capacity improvement if OH reduction efforts reduced the number of OH symbols from what is assumed here.
* Rows 46 and 47: Columns denoted by ‘a’ assume 2 sub-channels per sector and columns denoted by ‘b’ assume 4 sub-channels per sector for a (1, 3, 3) frequency reuse
* Rows 50 and 51: The Good Put per cell assumes MAC and upper layer OH is 6 %, achieved by the use of packet packing protocols and PHS

The following figure provides a summary of the anticipated UL and DL PHY rate with different frame sizes including 25 ms.

**Figure 1: UL and DL PHY Data Rate for Full Spectrum Solution with AMC Permutation**

The ‘Good Put’ is defined as the effective capacity at the application layer and as described earlier the upper layer OH can be considerable for small sized payloads. With packet packing and payload header suppression (PHS) the upper OH should be manageable with levels of 6% or less. This value is assumed in the following figure.



# Figure 2: Estimated UL and DL Good Put Assuming 6 % Upper Layer OH

## Other Attributes for Full Spectrum Solution

These include:

* Proposed measures to reduce OH requirements
* Preamble On or OFF: When OFF GPS would be used for synchronization,
* Multi-channel operation with non-contiguous channels:
* In addition to Band AMC is PUSC is also supported.

# Runcom Proposed Solution

Runcom[[4]](#footnote-3) offered a proposed solution for 1 MHz channels at the March, 2015 IEEE 802.16 Working Group Meeting. The ODMA parameters for the Runcom proposal is summarized in the following table which has been excerpted from the IEEE submission[[5]](#endnote-2) . This proposed solution has as its starting point a 5 MHz channel BW with a sampling frequency of 5.60 MHz. Cutting the sampling frequency in half to 2.80 MHz and increasing the frame size from 5 ms to 10 ms provides a 2.5 MHz channel BW with a sub-carrier spacing of 5.47 kHz comprising 15 DL subchannels and 18 UL subchannels. To scale to a 1 MHz channel BW an RF filter is employed to pass a reduced number of subchannels, in this case, 6 in the DL and 7 in the UL. The increased frame size maintains the total number of symbols at 48.

The MAP would only allocate data to the subcarriers within the desired 6 DL subchannels and 7 UL subchannels. Similarly the preamble would scaled by 40 % rather than using the entire 2.5 MHz BW.

**Table 2: Runcom Proposed Solution for 1 MHz Channels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Nominal Channel Bandwidth** | | | **1 MHz** |
| Sampling factor | | | 28/25 |
| Sampling frequency (MHz) | | | 2.8 |
| FFT size | | | 512 |
| Subcarrier spacing (kHz) | | | 5.47 |
| Subchannels | | | 6 DL |
| Actual Bandwidth (centered on nominal channel) | | | 918.75 kHz DL |
| Frame Size | | | 10 ms |
| Useful symbol time (µs) | | | 182.86 |
| For CP ratio = 1/8 | OFDMA symbol time (µs) | | 205.72 |
| FDD | OFDMA Symbols per 10 ms frame | n/a |
| Idle time (µs) | n/a |
| TDD | TR Gap Symbols | 1 |
| OFDMA Symbols per 10 ms frame | 47 |
| TTG + RTG (µs) | 331.42 |

A variation on the Runcom proposal was received via e-mail information and discussions on a telephone call[[6]](#footnote-4). For this solution the clock or sampling rate is reduced by a factor of 5 and the frame rate increased from 5 ms to 25 ms compared to a 5 MHz channel BW. The reduced clock frequency reduces the subcarrier spacing to 2.19 kHz. The number DL subchannels is maintained at 15 and the UL subchannels to 18 and, with the 25 ms frame size, the number of symbols is maintained at 48

The following table, which includes parameters for a 5 MHz and 2.5 MHz channel BW for reference purposes, provides a more detailed view of the Runcom proposed solutions with additional details including projections on OTA data capacity using the same methodology as described and used earlier. I use the nomenclature Runcom-10 (or RC-10) to denote the first alternative with the 10 ms frame and Runcon-25 (or RC-25) to denote the second alternative with a 25 ms frame size.

**Table 3: Runcom OFDMA Parameters and Data Rate (PHY)**



**Explanatory notes for Table 3:**

* Column 1: This column simply restates the parameters submitted to the IEEE in March 2015, with the values in red added which were received at a later date[[7]](#footnote-5)
* Row 14: The TR gap is kept at 1 even though it does not ensure a 40 mile range for RC-10, a desirable goal for propagation-friendly rural environments
* Rows 17, 18: Shows the TR gap necessary for a 40 mi range in row 18 shows the achievable range with a 1 symbol gap.
* Rows 30, 31: Number of DL and UL symbols were selected to provide an OTA DL/UL data ratio of approximately 1.6 for a more apples-to-apples comparison with the Full Spectrum proposed solutions.
* Rows 34, 35: As before a propagation environment with n=4 is selected resulting in an average spectral efficiency of 1.80 bps/Hz (see Fig. 5)
* Rows 40, 43: The Phy rate per sector assumes 1/3 of the subchannels are deployed in each sector with the exception of Runcom-10 which supports 7 subchannels. The seventh channel in this case could be deployed in any of the three sectors.
* Rows 41, 44: The cell PHY rate assumes all subchannels are used.
* Rows 43, 44: The net capacity gain for (1,3,1) reuse vs. (1,3,3) reuse is estimated to be 2:1



# Figure 3: UL, DL data rates for RC-10 and RC-25 for UL/DL symbol ratio of 2.0

# Comparing the Full Spectrum and Runcom Solutions and Other Alternatives for Consideration

## PHY Rate Comparison

The following graph provides a comparison of the two proposed solutions. For the comparison the UL and DL PHY rates are combined. For the same reuse, (1,3,3), the FullMAX solution shows a higher throughput than the Runcom solution, driven primarily by the higher efficiency of AMC over PUSC permutation. Obviously the Runcom solution can be implemented with Band AMC and alternatively the FullMAX solution can be implemented with PUSC and similarly, can also be deployed with reuse (1,3,1). That said the two solutions can be considered comparable with respect to the average PHY layer throughput.

F**igure 4:**

## Subcarrier Spacing

A more significant difference lies with the FFT and subsequently the subcarrier spacing. Although mobility is not a high priority requirement for Smart Grid networks, it cannot be ruled out as a longer term requirement. Mobility combined with multipath can contribute to Doppler Spread which in turn can lead to inter-carrier interference. For simplicity just looking at the Doppler shift for a single path can be instructive. In the following the graph on the left shows the Doppler shift in Hertz for different relative velocities between the BS and the SS for carrier frequencies from 500 MHz to 4900 MHz. The graph on the right shows the percentage effect on the subcarrier frequency for a velocity of 100 km/hr for a subcarrier spacing from 10.94 kHz to 2.19 kHz. Using 10.94 kHz as a reference we can assume a value in the range of 3.5 % to 4 % is acceptable to support mobility up to 100 km/hr. This would indicate that a 2.19 kHz subcarrier spacing would support 100 km/hr for carrier frequencies up to 1000 MHz and subsequently 30 km/hr for carrier frequencies up to 3000 MHz.



**Figure 5:**

## Full Spectrum Variations

Following are some variations on the Full Spectrum (FullMAX). One variation I noticed is simply changing the sampling factor from 28/25 to 57/50. The latter, 57/50 is in IEEE Std 802.16 for channel BWs that are a multiple of 2 MHz. This increases the subcarrier spacing from 8.75 kHz to 8.91 kHz and adds 2 symbols per frame for a throughput increase of 3.1 %. I also looked at a PUSC alternative for a more direct comparison to the solution proposed by Runcom. The details are shown in the following table.

**Table 4: Variations on Full Spectrum Solution**



The following shows a comparison with respect to ‘Good Put’ which assumes 6% for the MAC and higher layer OH.



**Figure 6: Variations on Full Spectrum (FullMAX) for 10 ms Frame Size**

The following figure adds the above FullMAX variations to the previous comparisons between the the Runcom and Full Spectrum solutions. It shows more clearly the throughput similarity with similar permutation and reuse options.



**Figure 7: Comparison of Alternative Solutions**

# References

1. [**http://www.fullspectrumnet.com/#welcome**](http://www.fullspectrumnet.com/#welcome) [↑](#footnote-ref-1)
2. DCN 16-15-0035-00-Gcon, FullMAX Air Inetrface Parameters for Upper 700 MHz A Block v1.0, March 23, 2015, By Menashe Shahar, CTO, Full Spectrum Inc. [↑](#endnote-ref-1)
3. Meeting with xxx at Sunnyvale offices on Dec 4, 2015 [↑](#footnote-ref-2)
4. <http://www.runcom.com/products-> [↑](#footnote-ref-3)
5. IEEE 802.16-15-0010-01-Gdoc, March 11, 2015, IEEE 802.16 Working Group, Narrowband Ad-Hoc Meeting Report [↑](#endnote-ref-2)
6. I had the opportunity to discuss the Runcom solution with Zion Haddad, Runcom CEO, on Jan 7, 2016. [↑](#footnote-ref-4)
7. The UL values for ‘subchannels’ and ‘actual bandwidth’ were added by Zion Haddad, Runcom Inc. in E-mail received 1/7/2016. [↑](#footnote-ref-5)