Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Proposal for Incorporating Single-carrier FDMA into 802.16m**
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Re:	IEEE 802.16m-07/047 - Call for Contributions on Project 802.16m System Description Document, on Multiple access and multi antenna techniques
Abstract	Due to its lower CM/PAR and larger cell coverage compared with OFDM, it is proposed to incorporate single-carrier FDMA into 802.16m specification.
Purpose	To incorporate the proposals into the 802.16m SDD.
Notice	
Release	
Patent Policy	

Proposal for incorporating single-carrier FDMA into 802.16m

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Motivations

In the current WiMAX system, OFDMA is used in both UL and DL as the access technique. However, the single-carrier FDMA with cyclic prefix (CP) provides additional advantages [1][2][3]. It is well known that, compared to OFDMA, one of the main benefits provided by single-carrier transmission is the significantly lower peak-to-average power ratio (PAPR) or cubic metric (CM). The PAPR/CM reduction provides corresponding improvements in power-amplifier efficiency and coverage area. Another problem with OFDMA in mobile environment is resulting from the inevitable frequency offset in the frequency references among different terminals [3]. It is already demonstrated in research literature that using SC-FDMA can overcome this disadvantage, also.

Principle of SC-FDMA

SC-FDMA with cyclic prefix, which utilizes the single carrier modulation and frequency domain equalization, can be regarded as a variant of OFDMA, similar to which the information symbols are modulated on different orthogonal subcarriers. However, in SC-FDMA the data is passed through a DFT operation before the subcarrier mapping (see Figure 1). With this change, compared to OFDMA, SC-FDMA can reduce significantly the envelope fluctuations in the transmitted waveform.

From Figure 1 it is noticeable that the SC-FDMA can be easily integrated in the current 802.16e framework, with the exception of the *N*-DFT block all the subsequent blocks are the same as in the OFDMA case.

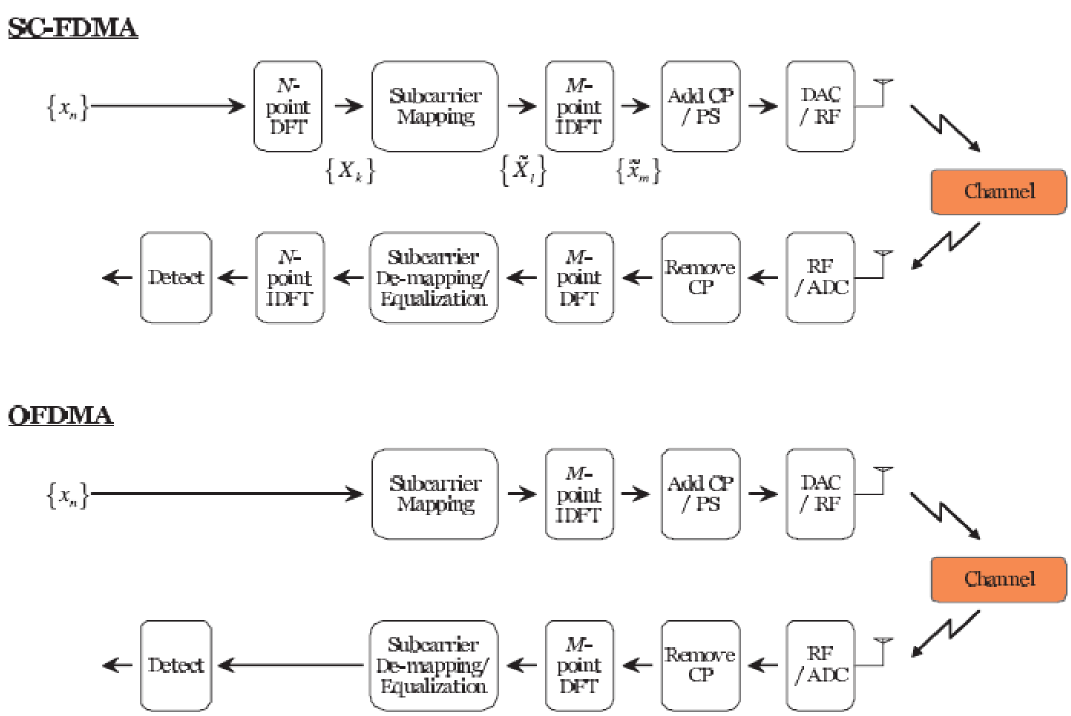

Figure 1 Comparison of transmitter and receiver structure (SC-FDMA vs. OFDMA) [2]

Performance comparison between SC-FDMA and OFDMA

Performance comparison between OFDMA and SC-FDMA has been carried out in [5]-[6]. Figure 2 from [6] presents the block error rate (BLER) performance for SC-FDMA and OFDMA with HARQ in the SIMO case. Ideal channel estimation with typical urban 6 paths channel model is assumed. Chase combining (CC) and incremental redundancy (IR) are used in HARQ. The performance for the two schemes is very similar with gaps usually less than 0.5 dB, for some MCSs.

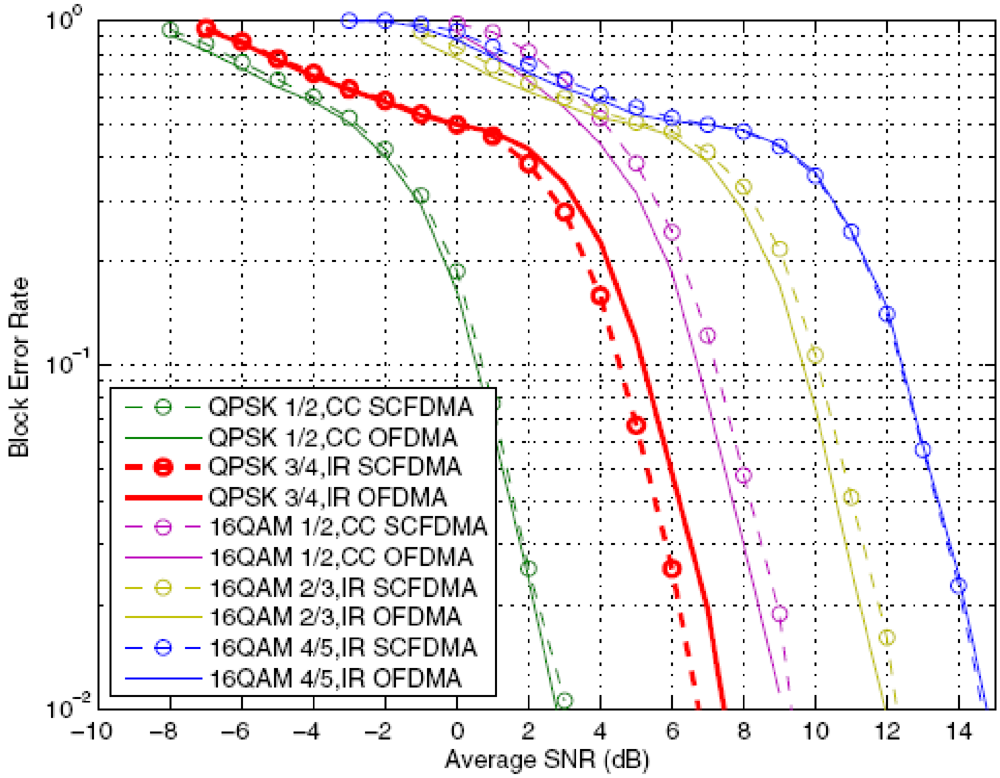

Figure 2 SC-FDMA versus OFDMA for various modulation and coding sets.

As pointed out in [7], the cubic metric is a more effective measurement of a typical power amplifier in a mobile handset, [see Appendix]. Similar to PAR, the higher the CM is, the lower the transmitter efficiency. The cubic metrics of SC-FDMA and OFDMA with different roll-off factors and for different modulations are shown in Figure 3 [5], where the CM of SC-FDMA shows a consistent lower value than their corresponding OFDM system.

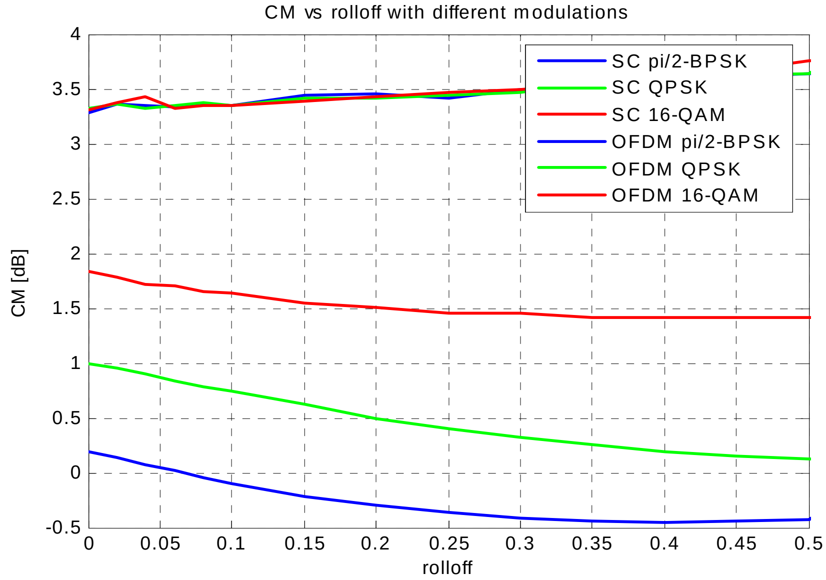

Figure 3 Cubic metrics as function of roll-off

Some results with respect to coverage area are shown in Figure 4 [4]. Here, the typical-urban channel is used in the simulation. Other simulation assumptions could be found in [4]. From the figure, it is clear that SC-FDMA provides a consistent higher data rate for the same coverage than OFDMA.

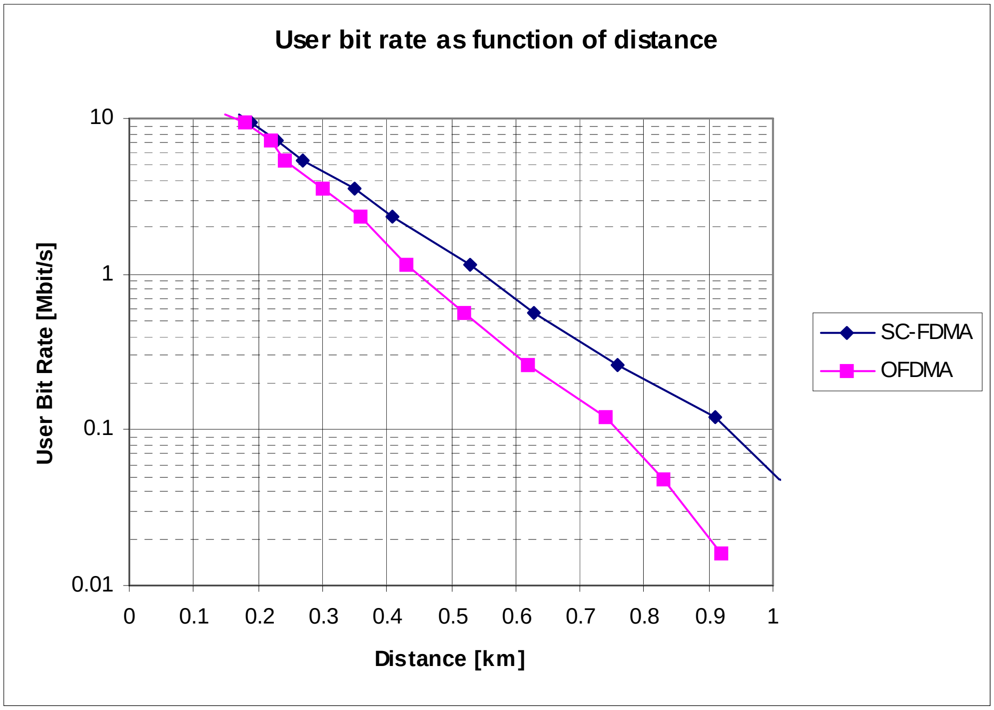

Figure 4 User bit rate at 90 % availability as function of distance

Multiplexing method for single carrier users

Considering the legacy support, there are basically two methods to multiplex single carrier users with 16/16e users, i.e. time division multiplexing (TDM) and frequency division multiplexing (FDM). Of course, the combination of these two is one option as well.

In TDM mode, by definition, the conventional OFDMA users and SC-FDMA users will be separated by time. That is to say, the data from SC-FDMA and OFDMA users are time-division multiplexed in the uplink frame, as shown in Figure 5. Thus a new zone will be defined as SC-FDMA zone which is exclusively reserved for SC users. This is the easiest and obvious way which should be a viable solution as well. By using TDM method, the backward compatibility can be easily achieved due to the complete isolation between OFDMA MSs and SC-FDMA MSs in time domain.

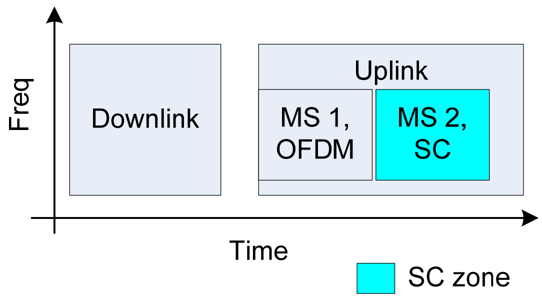

Figure 5 TDM method of multiplexing SC-FDMA into 802.16m

On the other hand, the principle of FDM is shown in Figure 6, in which the data from SC-FDMA users and OFDMA users are mapped onto different sub-carriers.

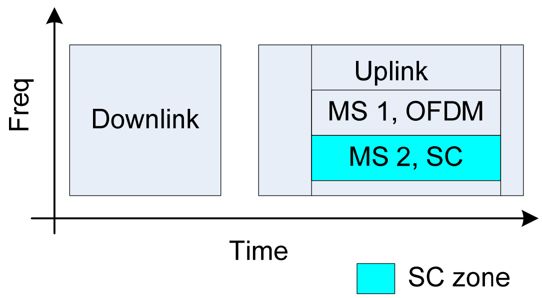

Figure 6 FDM method of multiplexing SC-FDMA into 802.16m

Conclusion

Based on the performance comparison shown above, we propose to incorporate the single-carrier FDMA into 802.16m.

Appendix

The Cubic Metric (CM) calculation is as follows [7]:

$$CM = \frac{20\log_{10}\left\{rms\left[v_{norm}^{3}(t)\right]\right\} - 20\log_{10}\left\{rms\left[vref_{norm}^{3}(t)\right]\right\}}{K} \quad dB$$

Where $20\log_{10}\{rms[v_{norm}^{3}(t)]\}$ is the called *raw cubic metric* (in dB) of a signal

to clarify: $rms(x)=\sqrt{\frac{(x'x)}{N}}$, and $v_{norm}(t)=\frac{|v(t)|}{rms[v(t)]}$

And the values of $rms[vref_{norm}(t)]$ and K could be found in [7] as well.

References

[1] *SC-FDMA website: http://hgmyung.googlepages.com/scfdma. .*

[2] *H. G. Myung, J. Lim and D. J. Goodman, Single Carrier FDMA for Uplink Wireless Transmission, IEEE Vehi. Tech. Mag., vol. 1, no. 3, pp. 30-38, Sept.2006.*

[3] *Z. Wang, X. Ma and G. B. Giannakis, OFDM or Single-carrier block transmissions?, IEEE Trans. on Comm., vol. 52, no. 3, March 2004*

[4] *Nokia, 3GPP TSG RAN WG1, R1-051088, Coverage comparison between UL OFDMA and SC-FDMA, October 10-14, 2005.*

[5] *Nokia, 3GPP TSG RAN WG1, R1-050639, Impact of the transmitter back-off to the uplink range, June 20-21, 2005.*

[6] *B.E. Priyanto, H. Codina; S. Rene; T. B. Sorensen; P. Mogensen, Initial performance evaluation of DFT-spread OFDM based SC-FDMA for UTRA LTE uplink, Proc. of IEEE 65th Vehicular Technology Conference, 2007. VTC2007-Spring, April 2007, pp. 3175 – 3179.*

[7] *3GPP, R1-060023, Motorola, Cubic Metric in 3GPP-LTE, Jan 2006.*

Proposed changes

[Insert in the ToC in the PHY layer in the appropriate sections (like Multiple Access Scheme, PHY Processing, Subcarrier Allocation, etc) provisions for SC-FDMA.]

x.x.x.x Single Carrier FDMA