Intercarrier Interference of Multiple Access UFMC with Flexible Subcarrier Spacings

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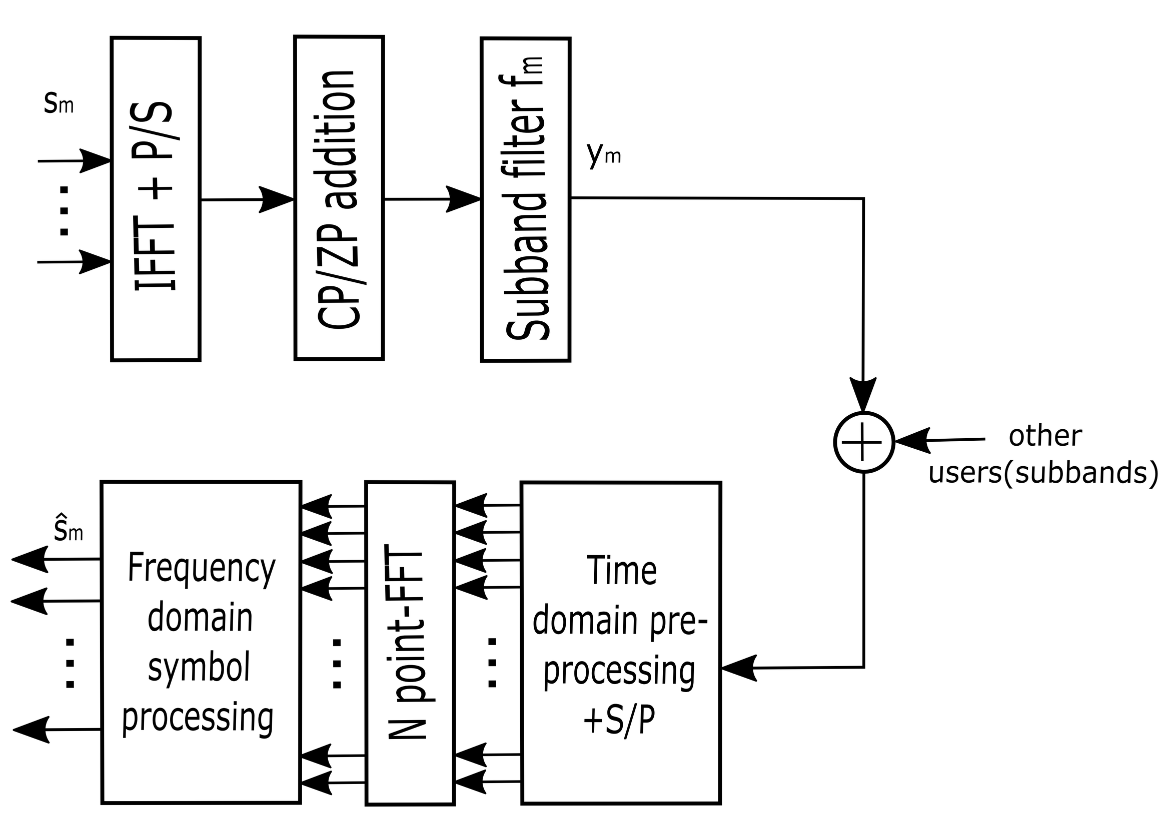
Contributions

- Investigation of Intercarrier Interference (ICI) between two users with different subcarrier spacings in a Universal Filtered Multicarrier System (UFMC)
- Analytical form of ICI functions of both users validated with simulation results
- ICI power and appropriate time-frequency efficiency in terms of filter lengths and number of guard subcarriers

System Model



- The signal after the IFFT is denoted as:

$$\mathbf{x}_m = \mathfrak{F}^{-1}\{\mathbf{s}_m\}. \quad (1)$$

- After subband filtering with filter $\mathbf{f}_m$, the transmit signal is:

$$\mathbf{y}_m = \mathbf{x}_m * \mathbf{f}_m. \quad (2)$$

- After an ideal channel without noise the received signal is

$$\mathbf{r} = \sum_m \mathbf{y}_m. \quad (3)$$

- The received vector is transformed into:

$$\hat{\mathbf{r}} = \mathbf{r}_b + \left[\mathbf{r}_t^T \quad \mathbf{0}_{[1\times N-L+1]}\right]^T, \quad (4)$$

with

$$\mathbf{r}_b = \left[r_0 \ \ r_1 \dots r_{N-1}\right]^T$$
$$\mathbf{r}_t = \left[r_N \ \ r_{N+1} \dots r_{N+L-2}\right]^T. \quad (5)$$

- Recovered signal is:

$$\hat{\mathbf{s}} = \mathfrak{F}\{\hat{\mathbf{r}}\}. \quad (6)$$

ICI Description

Since User 2 employs twice the subcarrier spacing of User 1, two short symbols of User 2 correspond to one symbol of User 1:

$$\mathbf{x}_1^{(1)} = \left[x_1^{(1)}(0), x_1^{(1)}(1), \dots x_1^{(1)}(N_1-1)\right]^T,$$
$$\mathbf{x}_2^{(1,2)} = \begin{bmatrix}\mathbf{x}_2^{(1)}\\ \mathbf{x}_2^{(2)}\end{bmatrix} = \begin{bmatrix}\left[x_2^{(1)}(0), x_2^{(1)}(1), \dots x_2^{(1)}(N_2-1)\right]^T\\ \left[x_2^{(2)}(0), x_2^{(2)}(1), \dots x_2^{(2)}(N_2-1)\right]^T\end{bmatrix} \quad (7)$$

Applying N_1 - FFT at Receiver 1 the recovered signal is:

$$\hat{\mathbf{s}}_1^{(1)} = \mathfrak{F}(\mathbf{y}_{total}) = \mathbf{x}_1^{(1)} + \mathbf{x}_2^{(1,2)} = \mathbf{s}_1^{(1)} + \underbrace{\mathfrak{F}\left\{\mathbf{x}_2^{(1,2)}\right\}}_{\text{ICI}}, \quad (8)$$

$$\text{ICI}(k) = \sum_{n=0}^{N_1-1} \mathbf{x}_2^{(1,2)}(n) e^{\frac{-j2\pi kn}{N_1}} = \sum_{n=0}^{N_2-1} \mathbf{x}_2^{(1)}(n) e^{\frac{-j2\pi kn}{N_1}} + \sum_{n=N_2}^{N_1-1} \mathbf{x}_2^{(2)}(n) e^{\frac{-j2\pi kn}{N_1}}$$
$$= \sum_{k'=0}^{N_2-1} \mathbf{s}_2^{(1)}(k') \sum_{n=0}^{N_2-1} e^{\frac{-j2\pi n}{N_2}\left(\frac{k}{2}-k'\right)} + \sum_{k'=0}^{N_2-1} \mathbf{s}_2^{(2)}(k') \sum_{n=N_2}^{N_1-1} e^{\frac{-j2\pi n}{N_2}\left(\frac{k}{2}-k'\right)} \quad (9)$$

ICI in UFMC

- User 2 employs twice the subcarrier of User 1
- Mathematical form of the ICI at Receiver 1 is obtained from the spectrum of User 2.

$$ICI_{[dB]}(\omega) = 10\ \log_{10}\left[\sum_{k'=0}^{K_m-1}\left|\text{sinc}\left((k'+1)\frac{\pi}{2}+\frac{\omega}{2q}\right)\right|^2 |f(\omega)|^2\right], \quad (10)$$

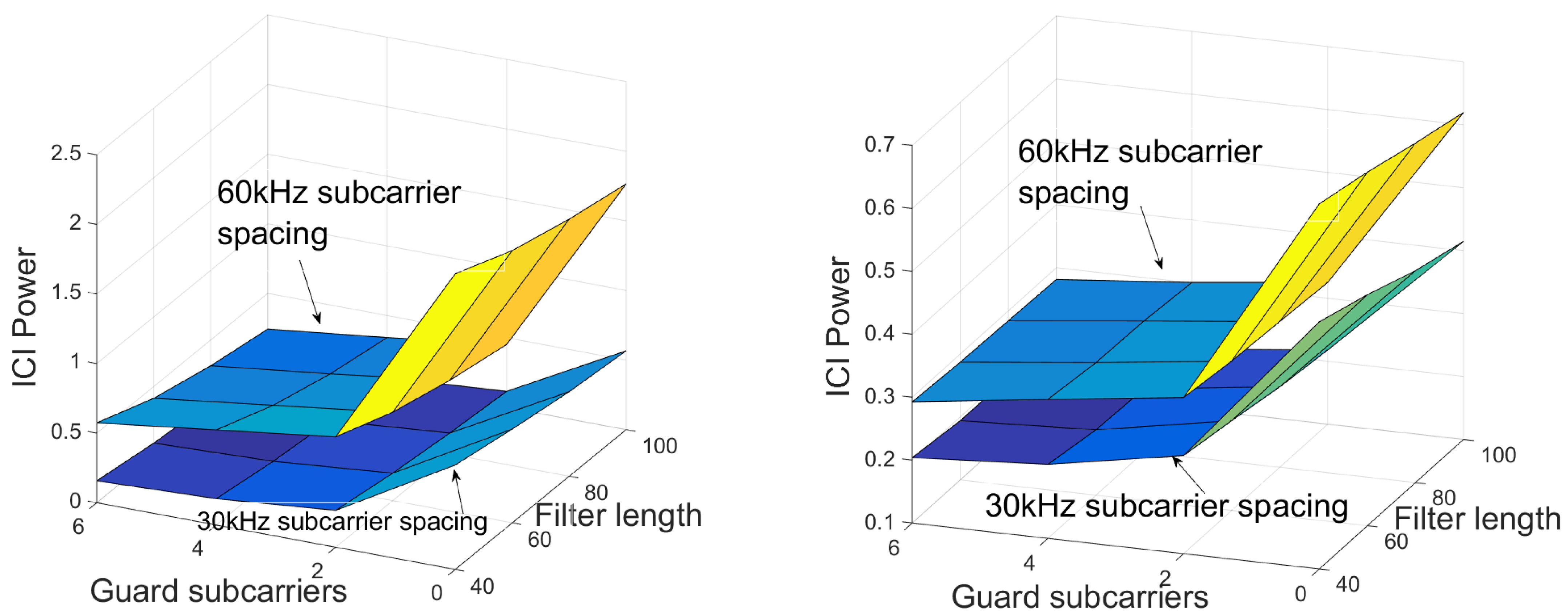
The filter function $f(\omega)$ is characterized by the amplitude function:

$$A(\omega, N_2, L_2) = \frac{c_1(N_2,L_2)\pi^2}{c_2(N_2,L_2)\pi + \omega^2}. \quad (11)$$

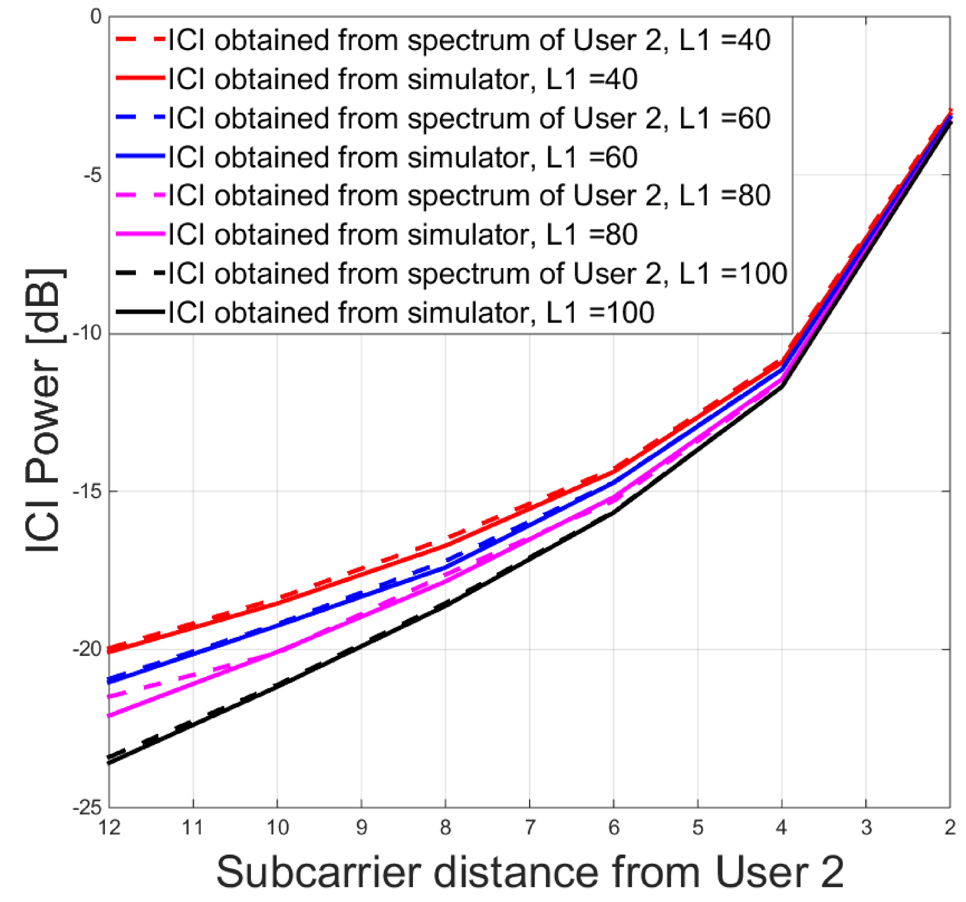
- Mathematical form of the ICI at Receiver 2 is obtained as vector-valued input-output relationship:

$$ICI_{[dB]}(k) = 10\ \log_{10}\left[\frac{|\hat{\mathbf{s}}_1^{(1)}(k)|^2 + |\hat{\mathbf{s}}_1^{(2)}(k)|^2}{2}\right]. \quad (12)$$

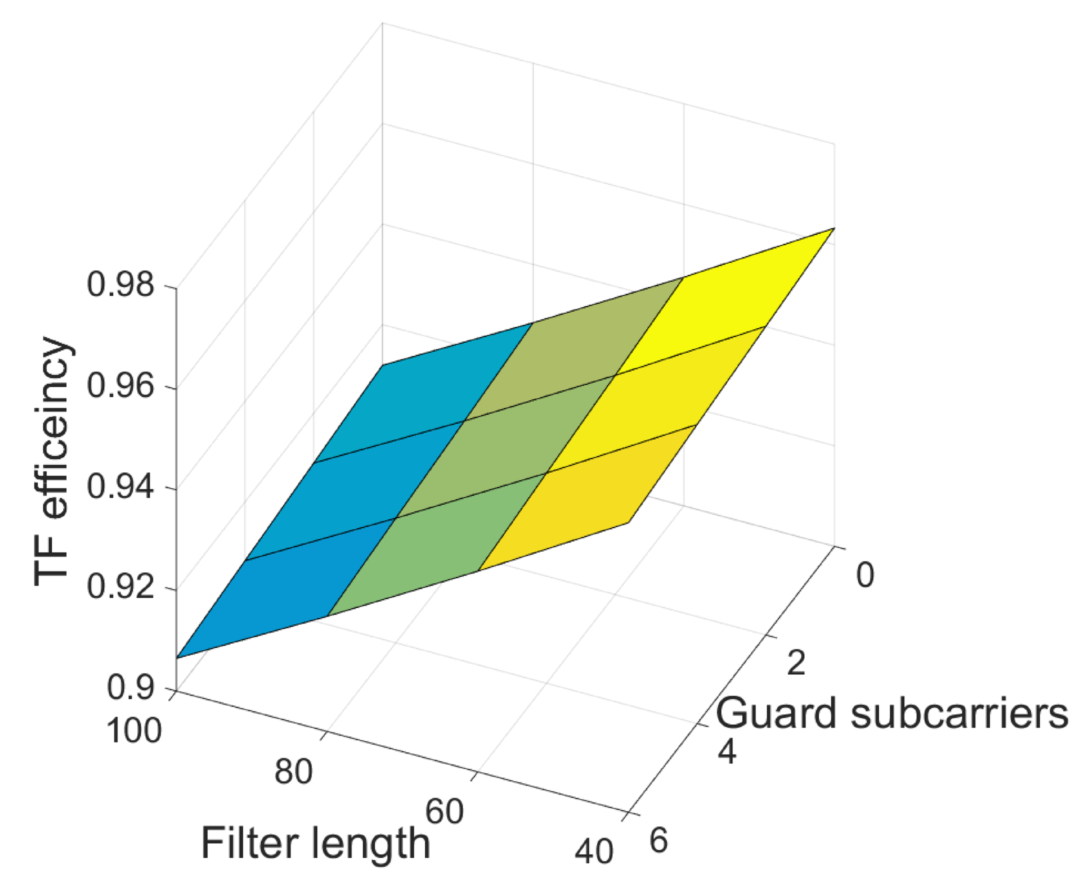
Simulated ICI Power



Analytical vs. Simulation Results



Time-Frequency Efficiency



Conclusion

- Closed form of ICI expression at Receiver 1 derived from the spectrum of User 2
- Closed form of ICI expression at Receiver 2 is not available due to the convolution with *sinc* function
- Largest ICI with small filter lengths and without guard subcarriers at the same time
- Increasing the subcarrier spacing of one user additionally increases ICI
- With smaller bandwidth frequency efficiency will be decreased