Unveiling Myths about SC-FDMA in TGm

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IEEE 802.16m-07/047, “Call for Contributions on Project 802.16m System Description Document (SDD)”.
Target topic: “Multiple access and multi antenna techniques, specifically as related to frame structure”

Base Contribution:
None

Purpose:
To be discussed and adopted by TGm for the 802.16m SDD

Unveiling Myths about SC-FDMA in TGm

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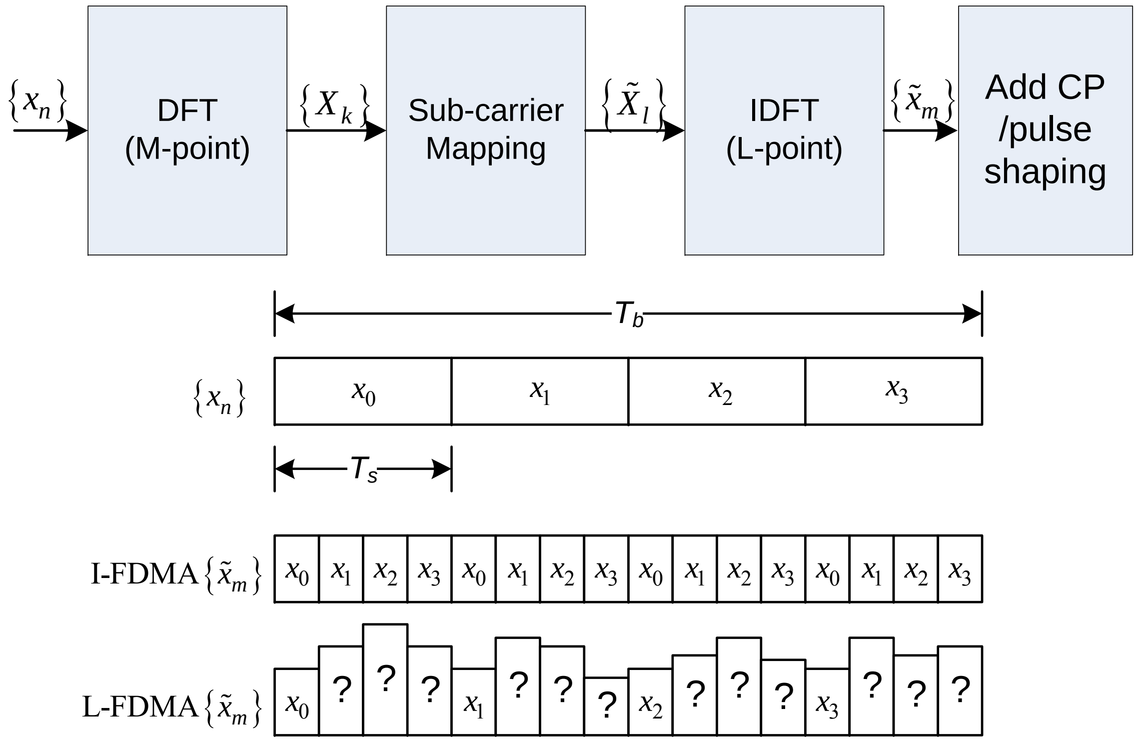
Outline

- Introduction of SC-FDMA
- Key Considerations for TGm
  - Complexity
  - Out of Band Emissions
  - Link Level Performance
  - Multiplexing
  - Pilot Tone Insertion
- System Level Preliminary Evaluations
- Conclusions & Proposal

Introduction of SC-FDMA

SC-FDMA Transmitter

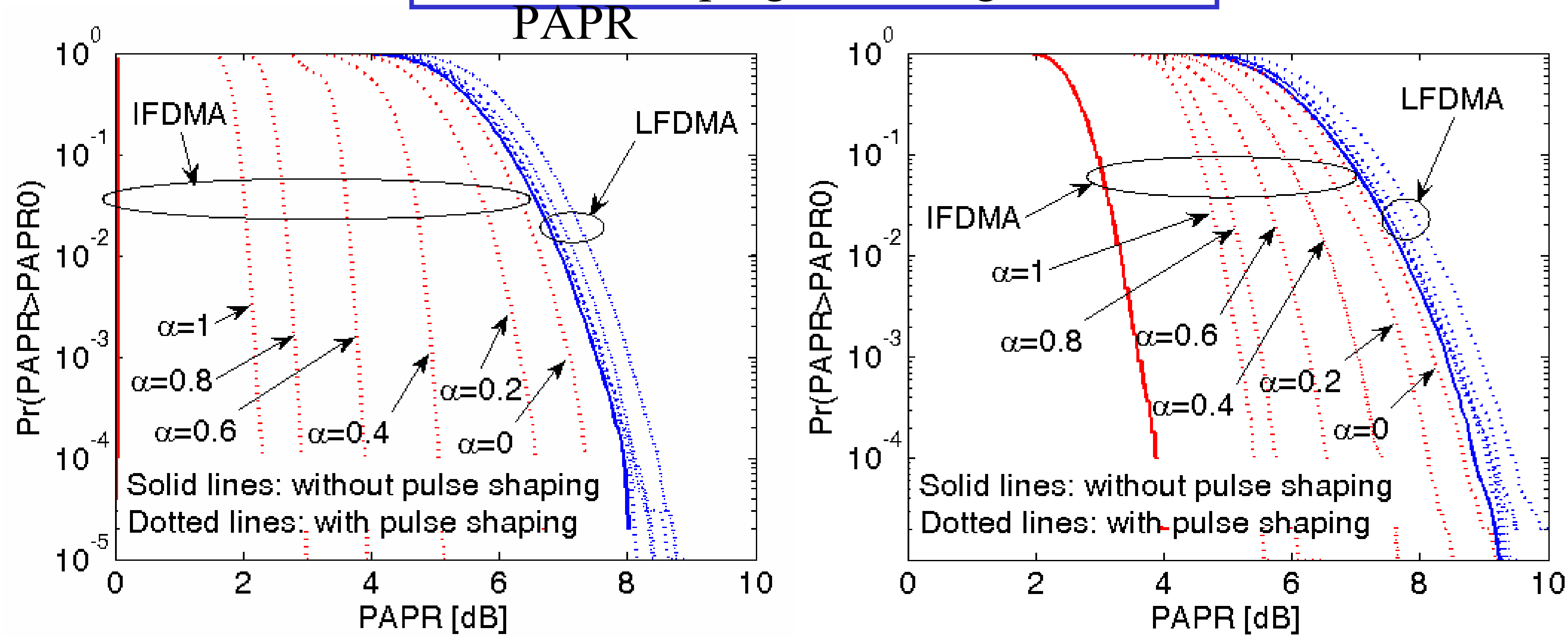
- Properties of SC-FDMA Tx
  - Single carrier transmission due to DFT spreading
  - Lower PAPR at the cost of out of band emission
  - Need pulse shaping filter : Back to high PAPR



An example of SC-FDMA transmit symbols in the time domain for M=4, Q=4, and L=16.

SC-FDMA Transmitter - PAPR

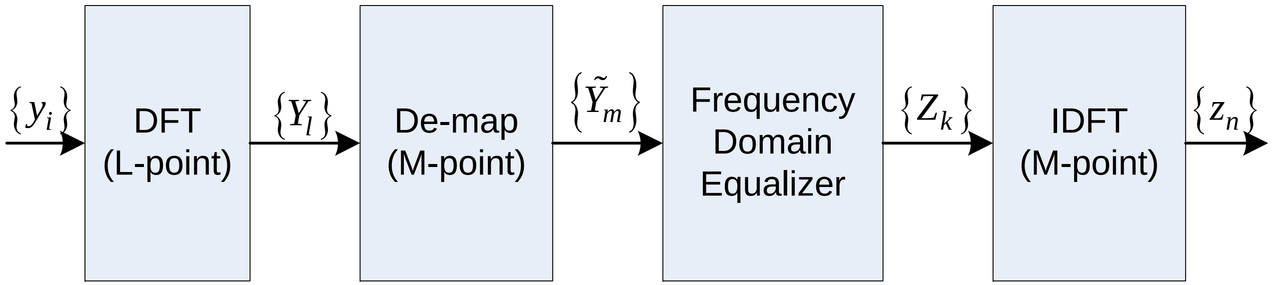
Pulse shaping incurs higher PAPR



Comparison of CCDF of PAPR for IFDMA and LFDMA with M = 256, N = 64, and roll off factor(α) of 0, 0.2, 0.4, and 0.6, 0.8, and 1. (a) QPSK. (b) 16-QAM.

SC-FDMA Receiver

- Properties of SC-FDMA Rx
  - Vulnerable to severe frequency selective fading
    - Lower post-SINR than OFDMA
  - 1-tap frequency domain equalization per subcarrier
    - A block of input symbols experiences same distortion.
    - One severe FDE loss is detrimental to a block information
      → Should be taken into account for cell edge user



Key Considerations for TGm

Complexity

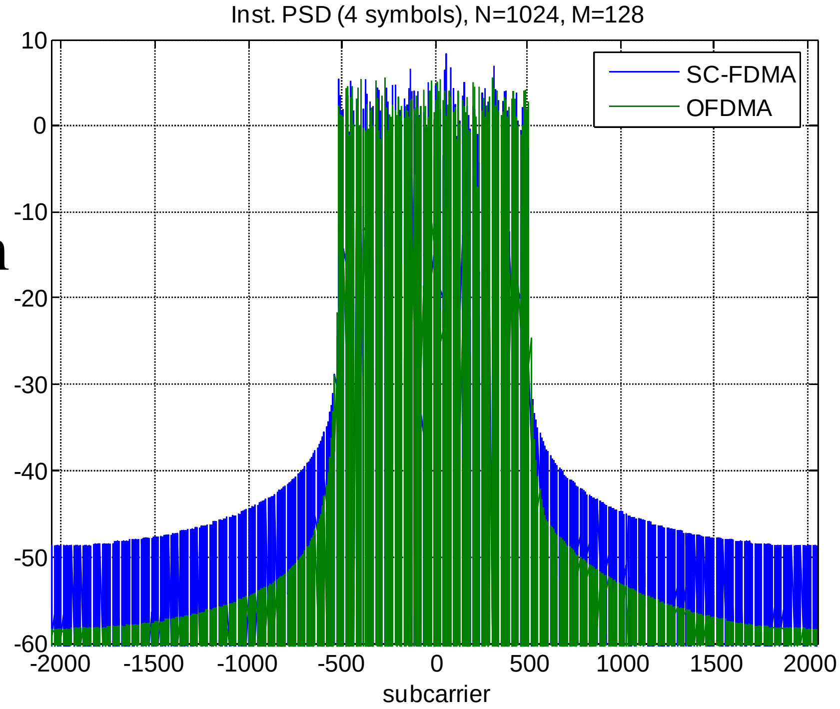
- Transmitter (MS side)
  - Require additional DFT process with dynamic DFT size relying on number of allocated subcarriers.

- Receiver (BS side)
  - Additional IDFT processing
  - High complexity frequency domain equalizer
  - Impractical implementation for ML receiver

- Consequently,
  - Increase burden for detection and decoding.
  - Additional power consumption
  - Additional processing delay is prohibitive to handset.

Out of Band (OOB) Emissions

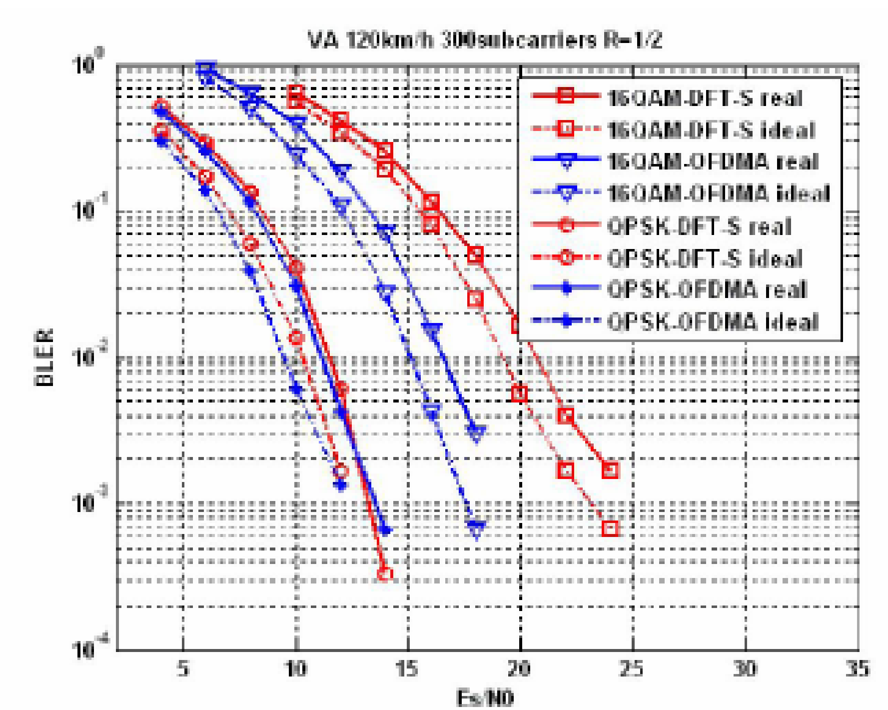
- SC-FDMA: Higher instantaneous out of band emission
  - Interfere to adjacent channels
  - OOB can be compensated with pulse shaping at the cost of PAPR.
  - Waste of resource increasing guard band

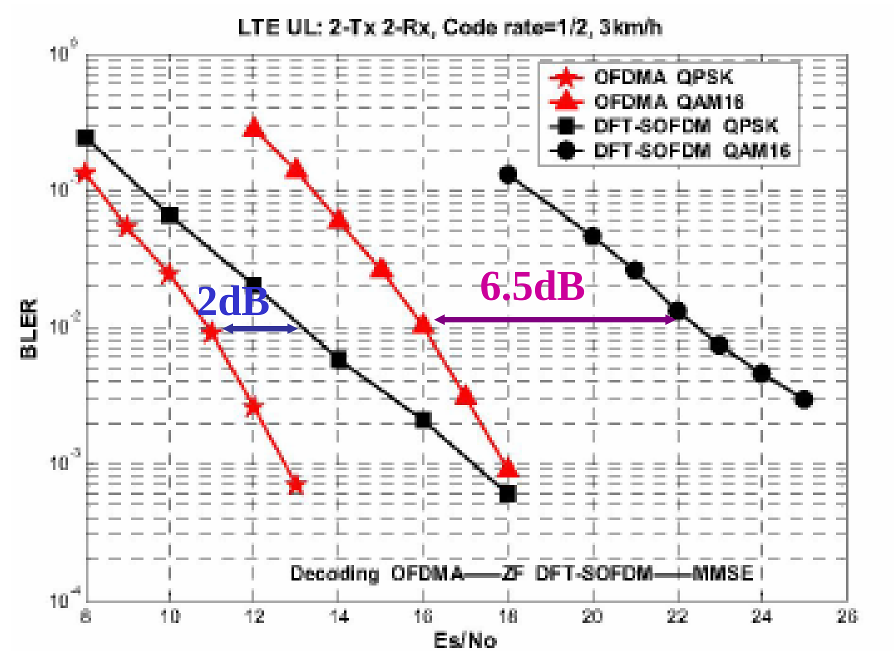


*Intel Corp. Ref. Alamouti presentation

Link Level Performance

- OFDMA outperforms SC-FDMA.
  - OFDMA can have up to 5dB gain w.r.t. SC-FDMA for SIMO.
  - The benefit of OFDMA becomes significant for MIMO.





J. Zhang, et al., “Comparison of the Link Level Performance between OFDMA and SC-FDMA”, IEEE 2006

Required DFT Sizes

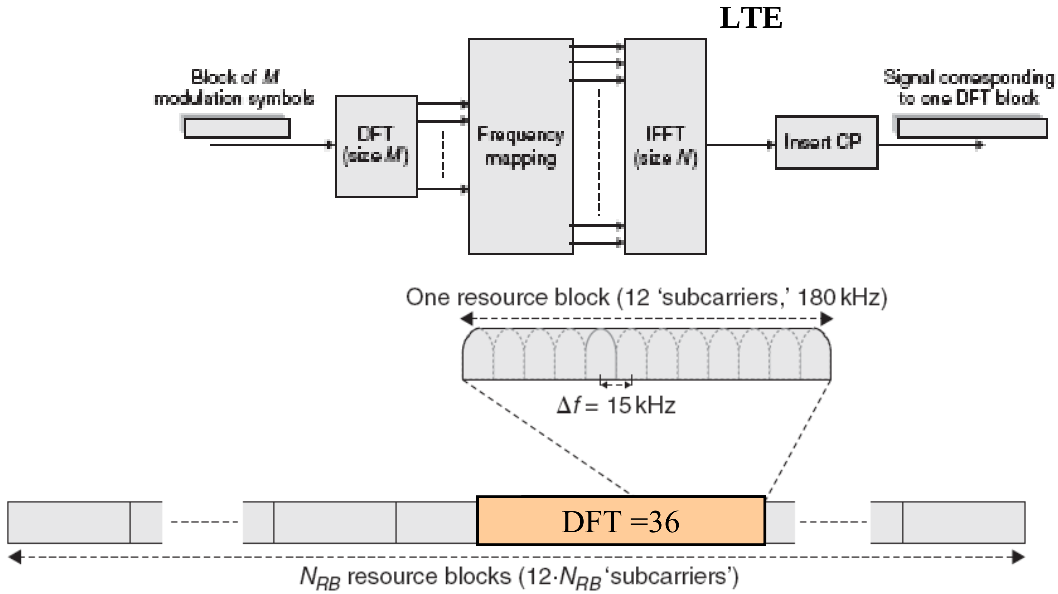
- SC requires variable DFT sizes depending on radio resources allocated
  - LTE: radix-2, radix-3 and radix-5

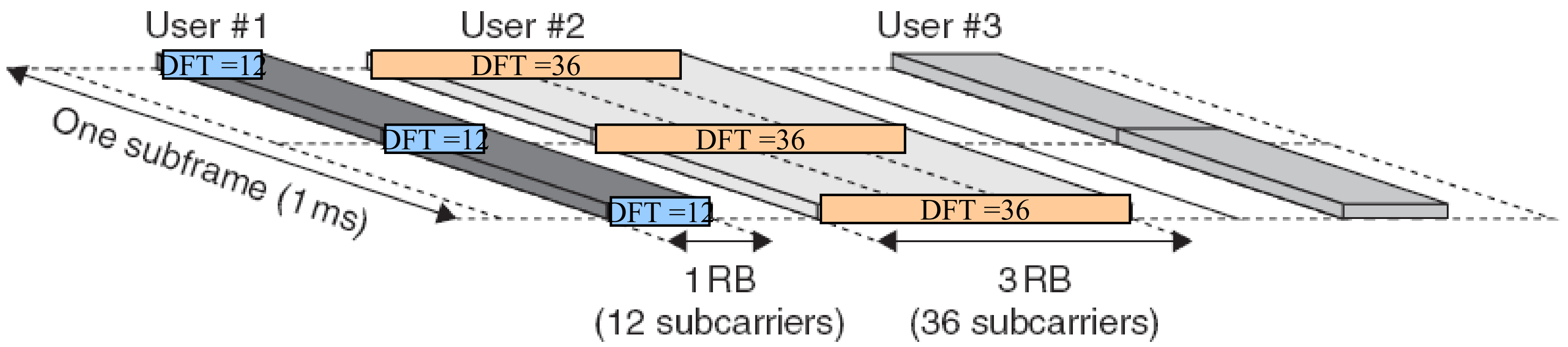
$$N_{DFT} = 2^n \cdot 3^m \cdot 5^p$$

c.f.) 802.16e: radix-2, radix-3

- 1 subchannel / Nfft =2048

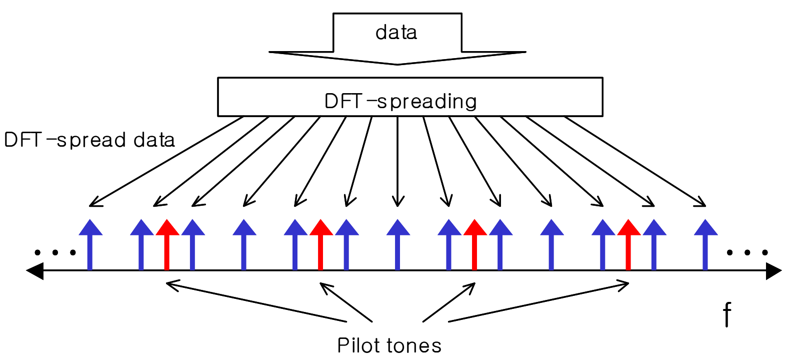
$$N_{DFT=48} = 2^n \cdot 3$$



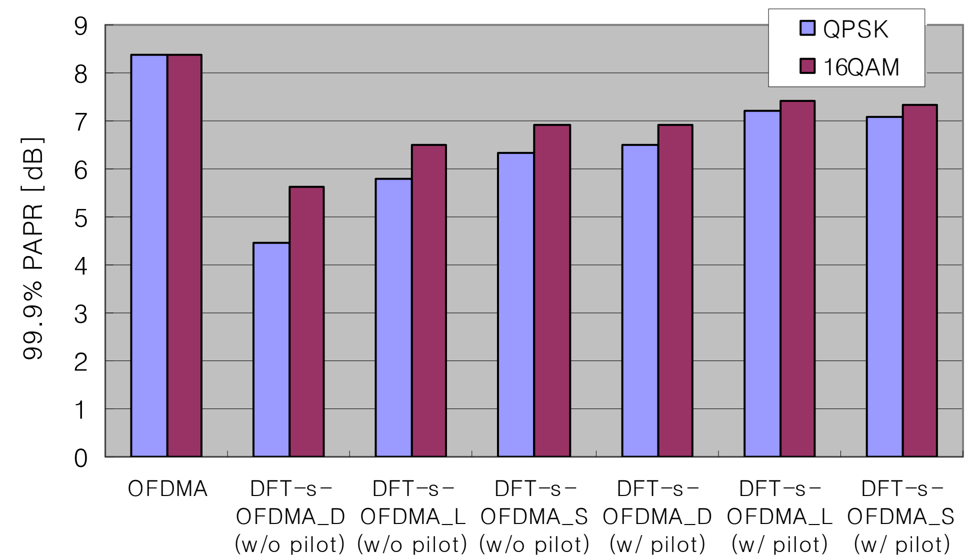


Insertion of Reference Signals

- Lack of flexibility
  - Frequency domain insertion
    - Back to high PAPR
  - Time domain insertion
    - Due to constraints on time multiplexing for reference signal, we end up with increased problems w.r.t. backward compatibility of frame structure.
    - Less flexible on pilot arrangement.
    - Channel estimation error becomes critical for SC-FDMA.
- Pilot pattern is likely to be even more sensitive to support collaborative SM.



Example of frequency domain insertion



System Level Preliminary Evaluations

OFDMA Parameters

Parameter	Description	Value [802.16m]
F_c	Carrier frequency	2.5 GHz
BW	Total bandwidth	10 MHz
N_{FFT}	Number of points in full FFT	1024
F_s	Sampling frequency	11.2 MHz
Δf	Sub-carrier spacing	10.9375 kHz
$T_0=1/\Delta f$	OFDM symbol duration without cyclic prefix	91.43 μs
CP	Cyclic prefix length (fraction of T_0)	1/8
N_{usc}	Number of used data sub-carriers	840
N_{scch}	Number of used data sub-carriers per sub-channel	24
N_{maxch}	Number of sub-channels	35

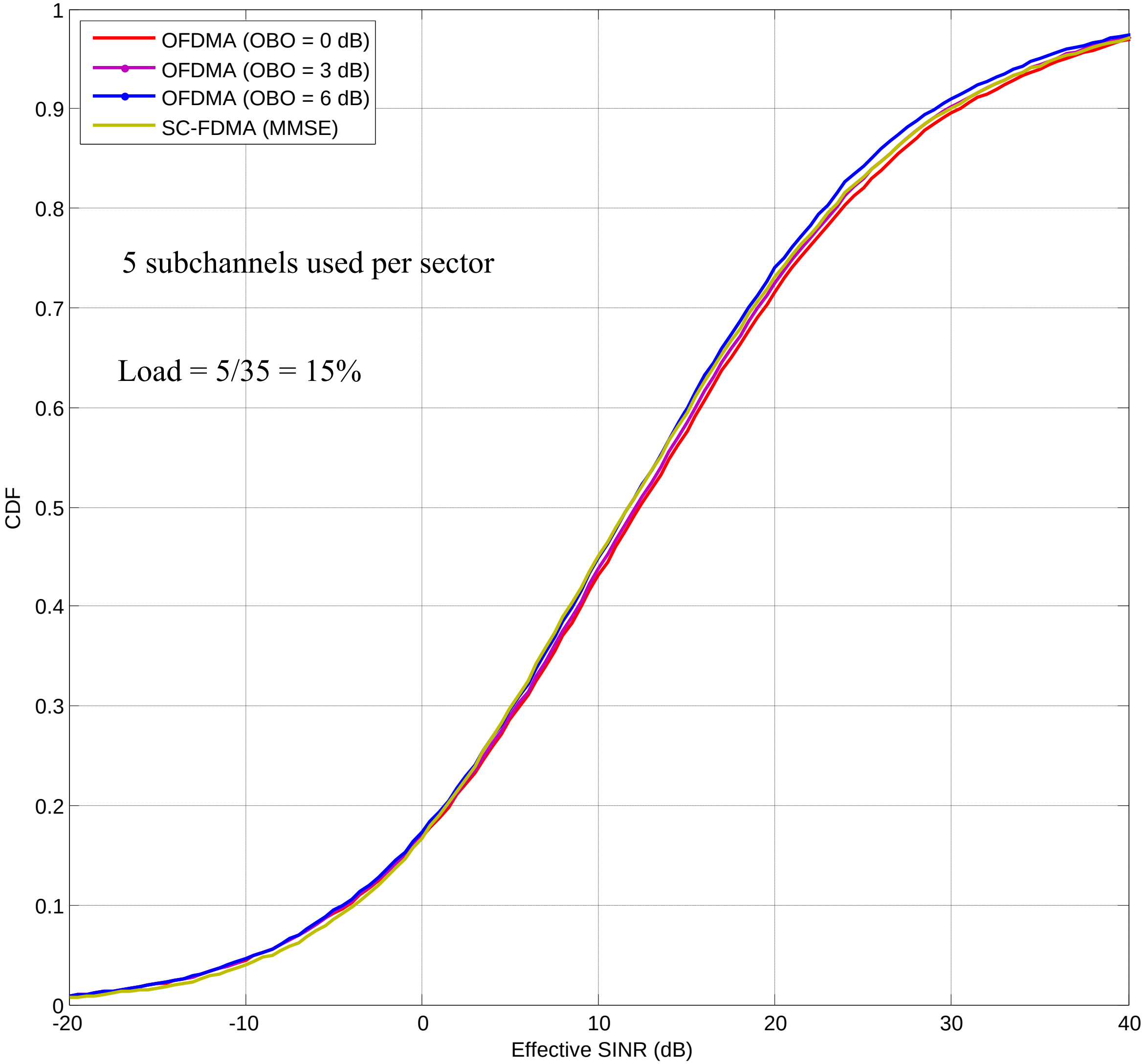
Test Scenarios

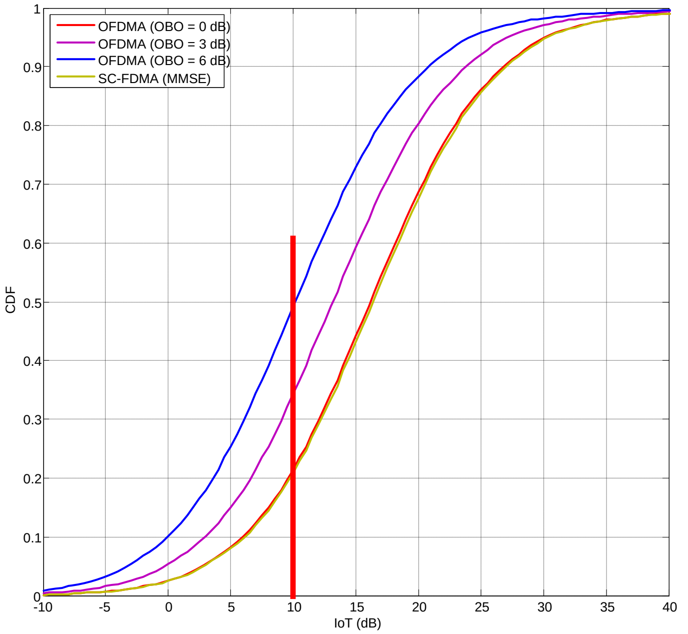
Scenario / Parameter	Baseline	NGMN	Urban Macrocell
Requirements	Mandatory [802.16m]	Optional [802.16m]	Optional [802.16m]
Site-to-Site distance	1.5 Km	0.5 Km	1 Km
Carrier frequency	2.5 GHz	2.5 GHz	2.5 GHz
Operating Bandwidth	10 MHz	10 MHz	10 MHz
MS Tx Power	23 dBm	23 dBm	23 dBm
Penetration loss	10 dB	20 dB	10 dB
Path loss model	PL (dB) = 130.62 + 37.6log10(R) **(R in km)**	PL (dB) = 130.62 + 37.6log10(R) **(R in km)**	PL (dB) = 35.2 + 35log10(R) + 26log10(*f*/2) **(R in meter, *f* in GHz)**
Lognormal shadowing standard deviation	8 dB	8 dB	8 dB
Inter-site shadowing correlation	0.5	0.5	0.5
Channel Mix	ITU Veh A (30 km/hr) – 100 %	ITU Ped B (3 km/hr) – 100 %	ITU Veh A (30 km/hr) – 100 %

System Parameters

Parameter	Value
Number of sites	19
Number of sectors per site	3
Wrap-around technique	Yes
Frequency reuse	1
Number of MS Tx antennas	1
Number of BS Rx antennas	1
BS antenna pattern	$-\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \quad ; \quad A_m = 20\ dB, \theta_{3dB} = 70^\circ$
BS antenna gain	17 dBi
MS antenna pattern	Omi-directional
MS antenna gain	0 dBi
BS noise figure	5 dB
Thermal noise density	-174 dBm/Hz
Number of sub-channels requested by each MS	**1**
Average number of MS per sector	5
Sub-carriers mapping	Localized
Receiver structure	MMSE

CDF of SINR: NGMN Scenario



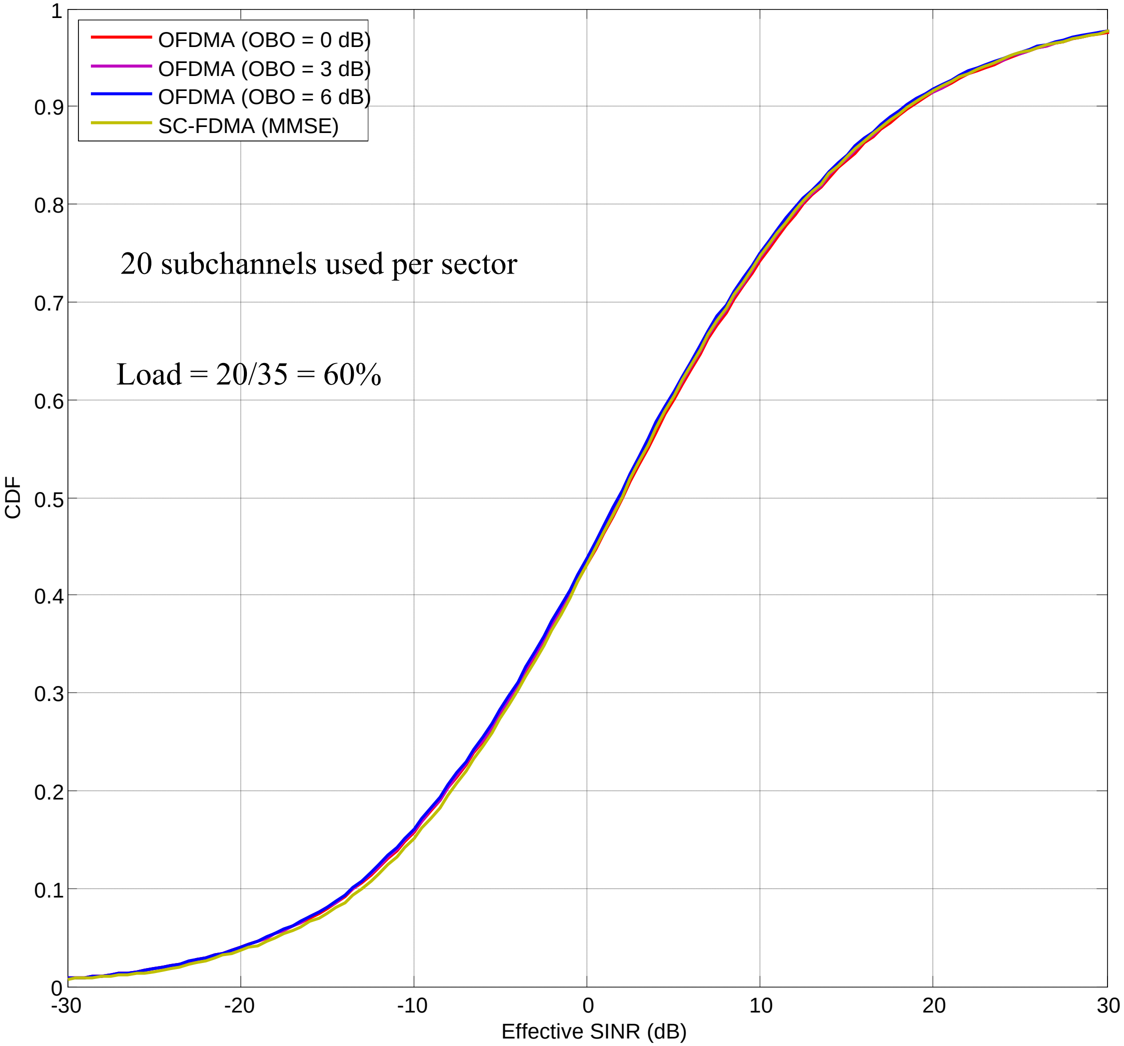


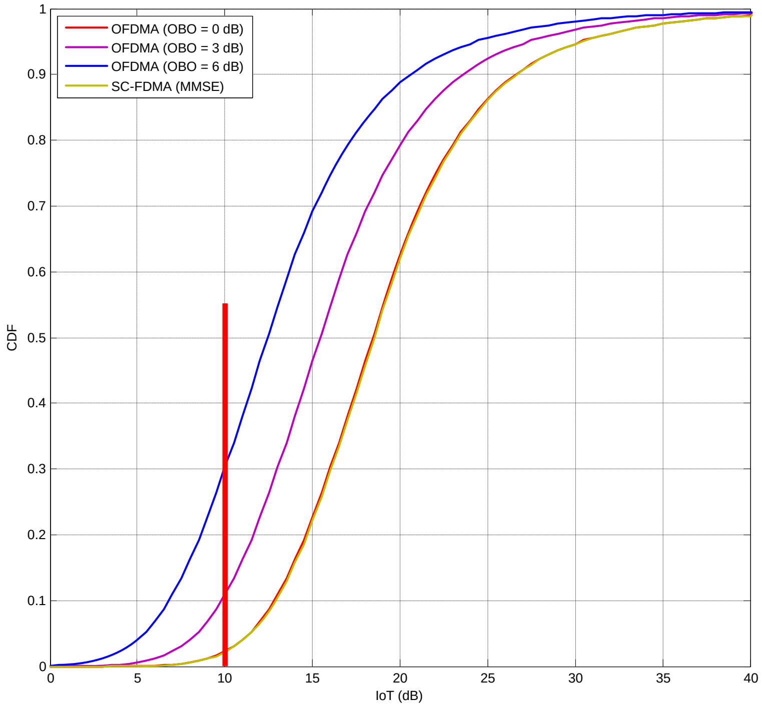
- **This is an interference limited scenario.**
- **OBO has little impact on OFDMA.**
- **OFDMA has close performance to SC-FDMA even for OBO = 6 dB**

Still Need to add Channel Estimation Errors Modelling

This context is in favour of OFDMA

CDF of SINR: Baseline Scenario





- **This is interference limited scenario with 20 users/sector.**
- **OBO has little impact on OFDMA.**
- **OFDMA has close performance to SC-FDMA even for OBO = 6 dB**

Still Need to add Channel Estimation Errors Modelling

This context is in favour of OFDMA

Observations

- In interference-limited scenarios, OFDMA always achieves higher SINR values
- OBO does not degrade the performance of OFDMA in interference-limited scenarios
- For 5 users per sector (15% Load), NGMN is already interference limited
- For 20 users per sector (60% Load), baseline scenario is interference limited

OFDMA is better suited to scenarios with low site-to-site distance and high sector loading/throughput

Summary & Conclusion

- Drawbacks of SC-FDMA
  - Degrade link performance especially with high order modulation and MIMO in real channel estimation scenario.
  - Additional out of band emission problematic with adjacent channel or bandwidth efficiency
  - Additional complexity and power consumption on transmitter and receiver
  - Lack of flexibility on pilot/reference signal insertion

- Conclusion & Proposal
  - **Sticking with dominant OFDMA basis is better** to ensure:

    Easier & safer backward compatibility

    Reaching increased spectral efficiency

    Easy and flexible collaborative MIMO in uplink

    Suitability to High Loading & Throughput per sector

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Thanks for your attention…

Q&A