UL Multiple Access for 802.16m

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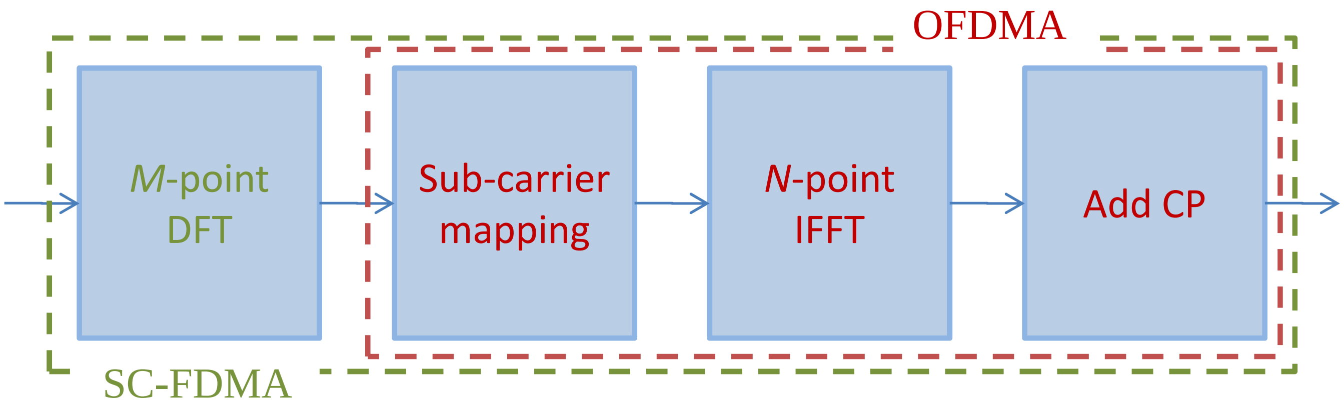
C80216m-08/084r2

Purpose:
For discussion of comparison between OFDMA and SC-FDMA, and approval of OFDMA as the UL multiple access by IEEE 802.16 WG

SC-FDMA and OFDMA: Main candidates for 16m multiple access scheme



<table>
<tr><th>SC-FDMA (generated in freq. domain)</th><th>OFDMA</th></tr>
<tr><td colspan="2">Orthogonal UL transmission
Frequency-domain equalization
Commonality with DL in freq. domain operation</td></tr>
<tr><td>Single-carrier property
Low PAPR
Restriction to maintain low PAPR</td><td>Multi-carrier property
High PAPR
Flexibility in freq. multiplexing of multiple waveforms</td></tr>
</table>

SC-FDMA vs. OFDMA: Pros. and Cons.

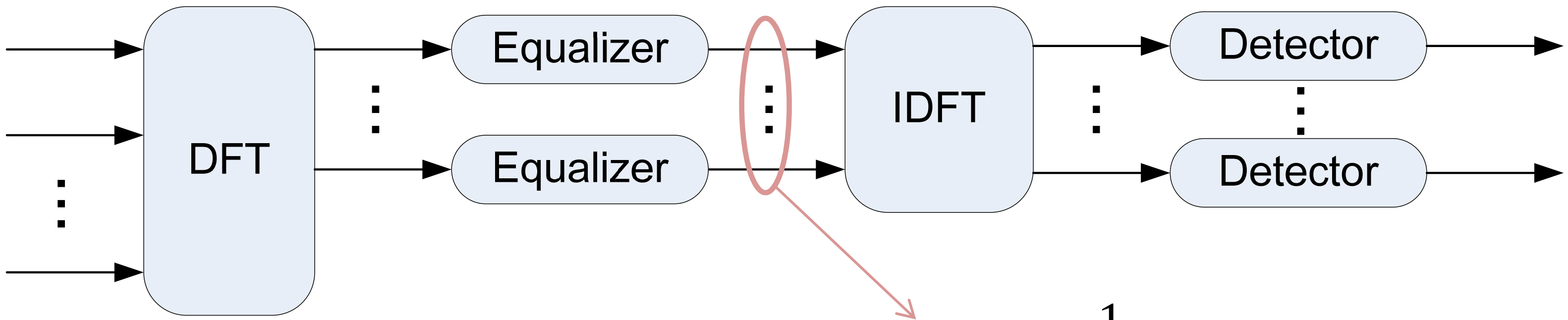
	SC-FDMA		OFDMA
	Single-carrier property		Multi-carrier property
DFT-spreading	used		unused
	SINR loss in freq. selective CH	Post-Equal. SINR	No loss in freq. selective CH
	MLD infeasible	UL-MIMO	MLD feasible
Multiplexing of multiple waveforms	restriction		flexibility
	Low	PAPR/CM	High
	Restriction	Pilot/Control CH design	Flexibility
	Reduced gain	Scheduling	Maximum channel-dependent scheduling gain

Purpose of this contribution is to check if

PAPR loss of OFDMA could be offset by overall link performance gain

Post-Equalization SINR

- Post-MMSE SINR of SC-FDMA

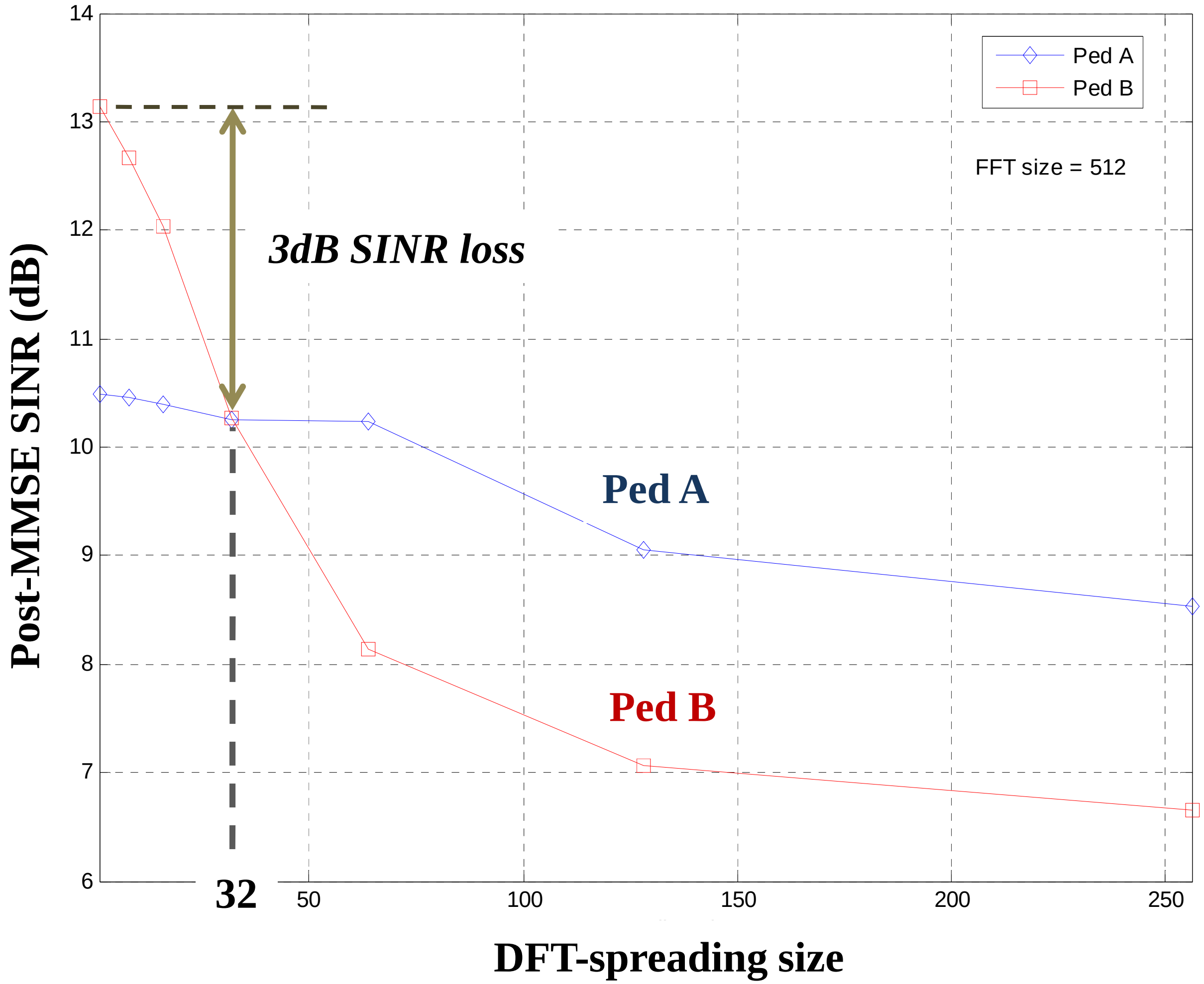


$$\gamma^{SC-FDMA} = \left(\frac{1}{\frac{1}{M}\sum_{m\in M}\frac{\gamma_m^{OFDMA}}{\gamma_m^{OFDMA}+1}} - 1\right)^{-1}$$

  - Due to DFT-spreading, distortion of orthogonality increases with freq. selectivity

1) T. Shi, et. al., “Capacity of single carrier systems with frequency-domain equalization,” *in proc IEEE CASSET ’04*, vol. 2, pp. 429-432, June 2004.

Post-Equalization SINR



- BW=5MHz, FFT size=512
- For Ped B, 3dB SINR loss is observed for DFT-spreading size of 32

UL MIMO Performance

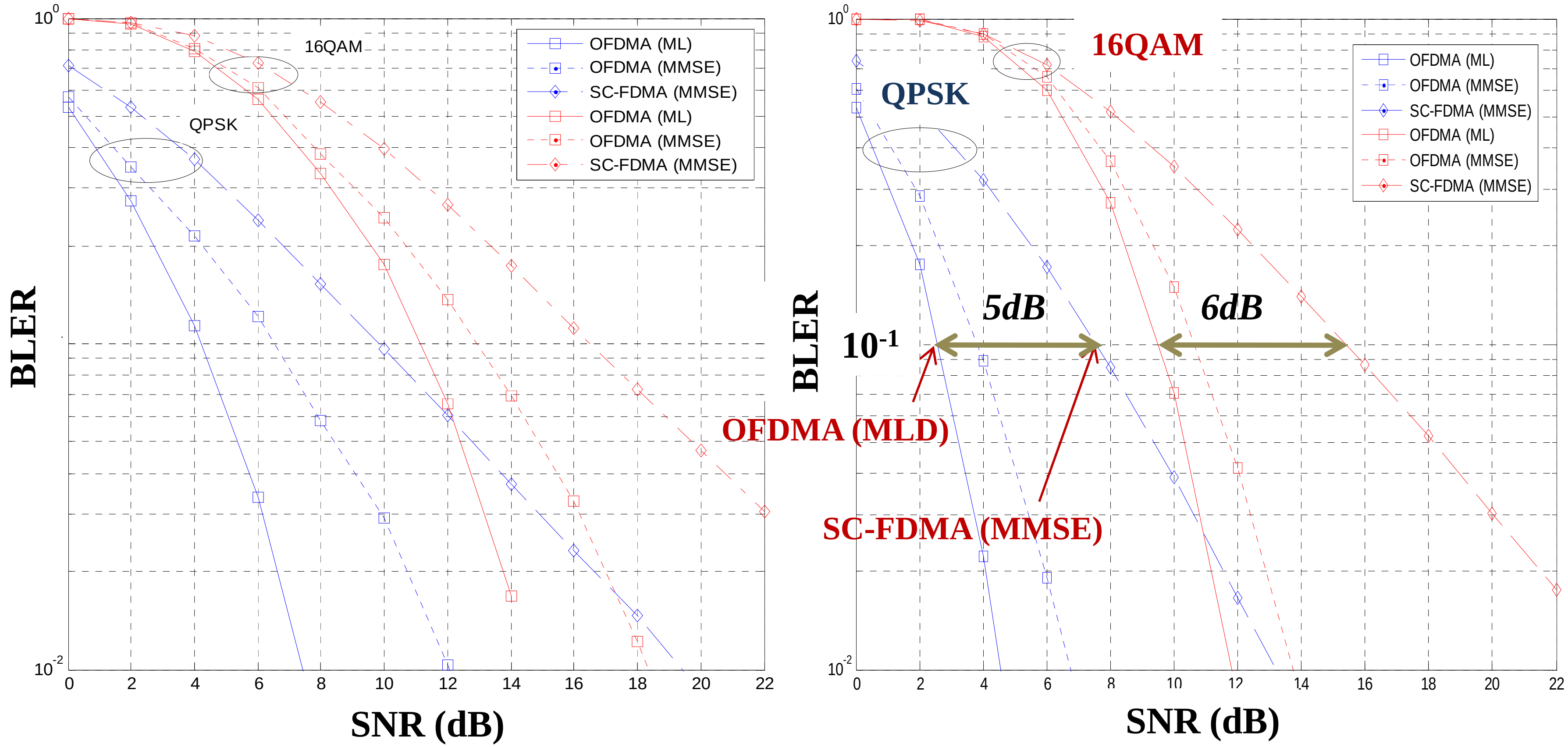
- MLD has gain over MMSE, but complexity is an issue
- For $K \times K$ MIMO,
  - For OFDMA, per-subcarrier operation is used
    - Operational dimension for MLD is $K \times K$
  - For SC-FDMA, per-DFT block (size M) operation is needed
    - Operational dimension for MLD is $KM \times KM$, which is infeasible

UL MIMO Performance

- **Simulation Parameters**

Center frequency	2.5GHz	
System BW	10MHz	
FFT size	1024	
Channel model	Ped A and Ped B (no spatial correlation, 3km/h)	
MIMO scheme	1×2 Open-loop CSM (Virtual 2×2)	
Modulation/ Channel coding	QPSK, 16QAM / CTC (R=1/2)	
Channel estimation	Ideal	
MA scheme	OFDMA	SC-FDMA
Sub-carrier mapping	Legacy PUSC (Distributed sub-carrier mapping)	Localized sub-carrier mapping
Receiver type	MMSE/ML	MMSE

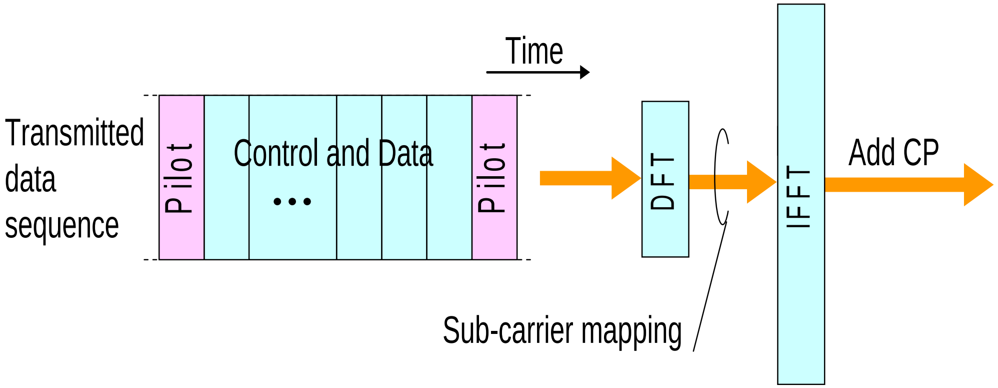
UL MIMO Performance



(a) Ped A (b) Ped B

- MLD OFDMA provides 5-6dB gain over MMSE SC-FDMA at BLER of 10^{-1}
  - based on combined effect of frequency diversity, post-MMSE SINR loss of SC-FDMA, and MLD gain.

Multiplexing for control signaling, data, and pilot

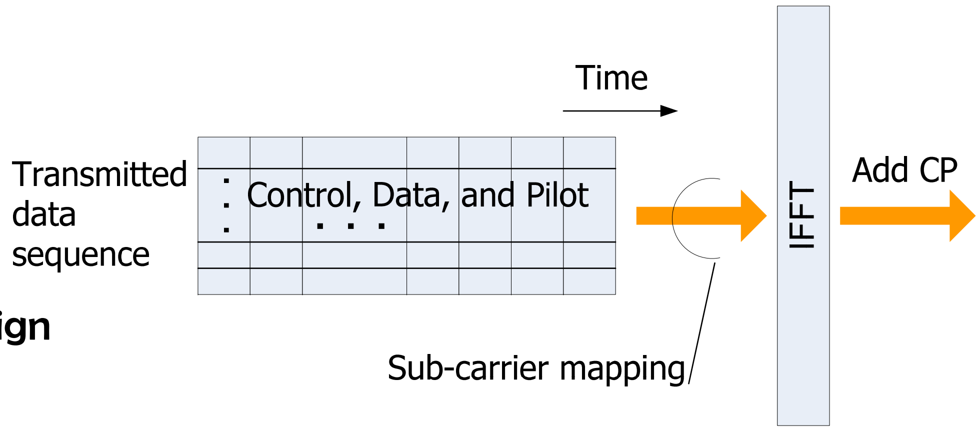


- Restriction on pilot design
  - Time-multiplexed pilot
- Careful sequence design needed
  - To have low PAPR and flat P.S.D.
  - Possible performance loss due to legacy OFDMA which doesn't adopt the same sequence
- CDM-multiplexed control data may cause legacy OFDMA degradation

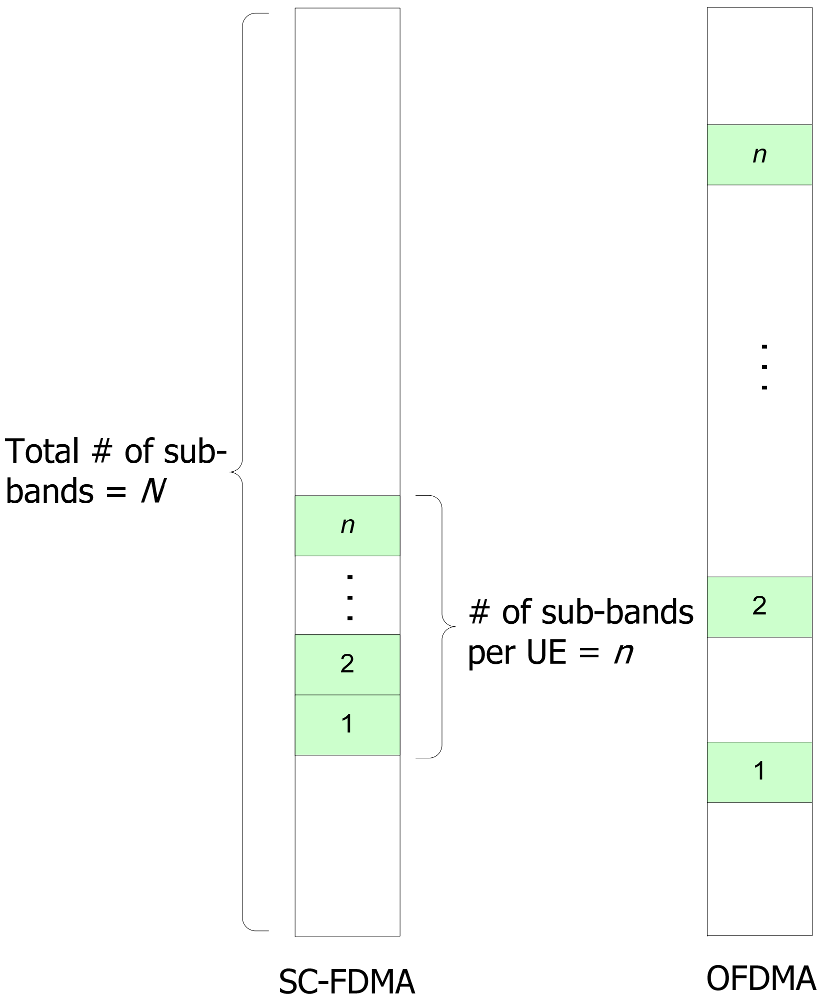
SC-FDMA

OFDMA

- Flexibility in multiplexing
  - Scheduling efficiency
  - Pilot design efficiency
  - Diversity in control channel design



Frequency-domain channel-dependent scheduling



- Totally, *N* sub-bands
- When *n* sub-bands needed for a UE,
  - SC-FDMA selects one best band consisting of contiguous *n* sub-bands to maintain single-carrier property
  - OFDMA can select best *n* sub-bands

Frequency-domain channel-dependent scheduling

- Asymptotic result for selection diversity with set size *K* [1)]

$$C_K \approx LogLog(K).$$

- Assuming *N* >> *n*,
  - For SC-FDMA,

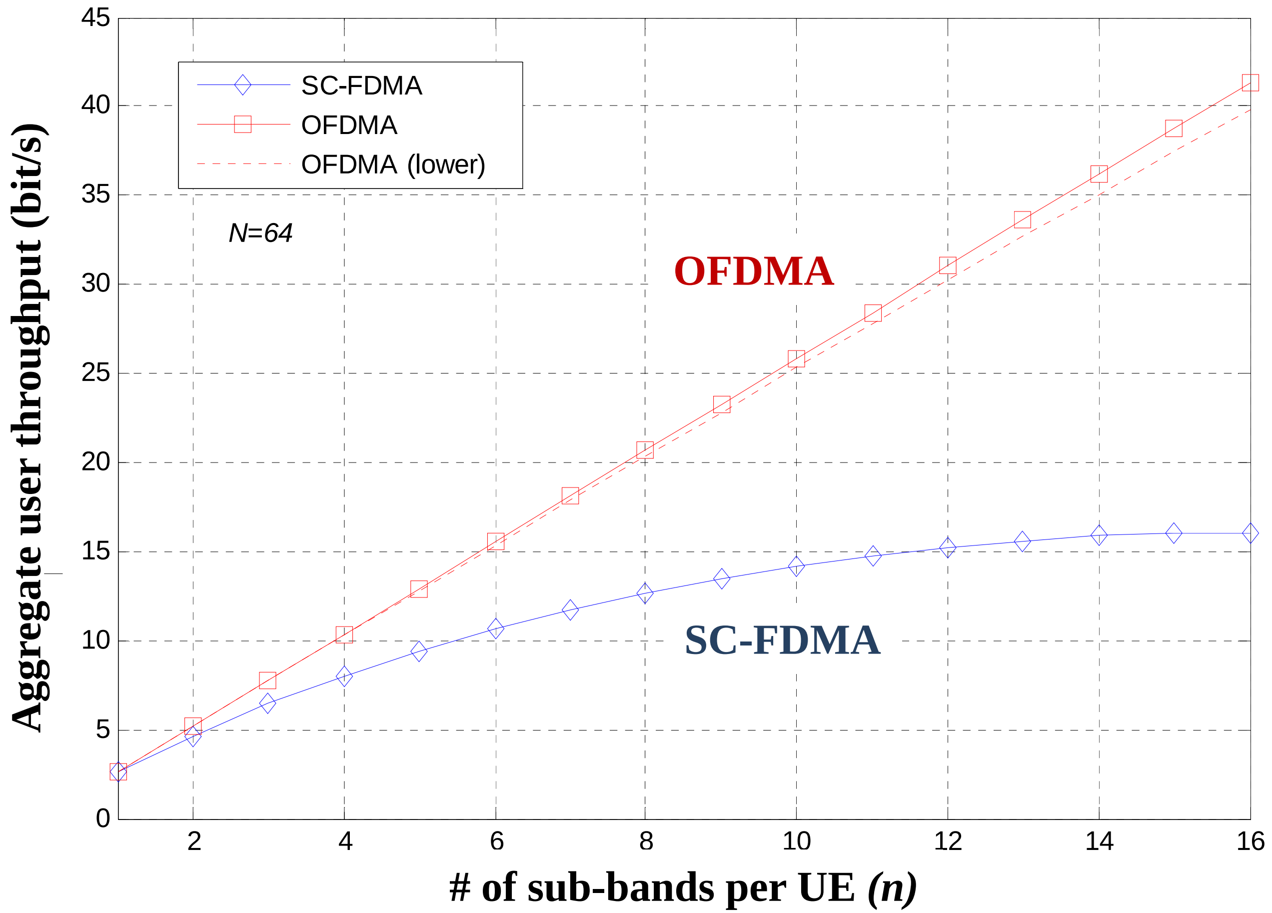
$$C_{SC-FDMA} \approx nLogLog(\frac{N}{n})$$

  - For OFDMA,

$$\begin{aligned} C_{OFDMA} &\approx LogLog(N) + LogLog(N-1) + \cdots + LogLog(N-n+1) \\ &\approx nLogLog(N) \end{aligned}$$

1) M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial side information," *IEEE Trans. Inform. Theory*, vol. 51, pp. 506–522, Feb. 2005.

Frequency-domain channel-dependent scheduling



- OFDMA throughput linearly increases with the number of sub-bands while SC-FDMA does not.

Frequency-domain channel-dependent scheduling

- Previous analysis provides some insight into freq. domain channel-dependent scheduling gain of OFDMA, but, seems extreme because
  - OFDMA throughput biased (Details could be found in C80216m-08_085r1)

- Here, simple simulation conducted to
  - Provide fair comparison
  - Observe the effect of frequency selectivity of real channel and correlation between sub-bands
  - Include the effect of channel gain averaged over assigned sub-bands

Frequency-domain channel-dependent scheduling

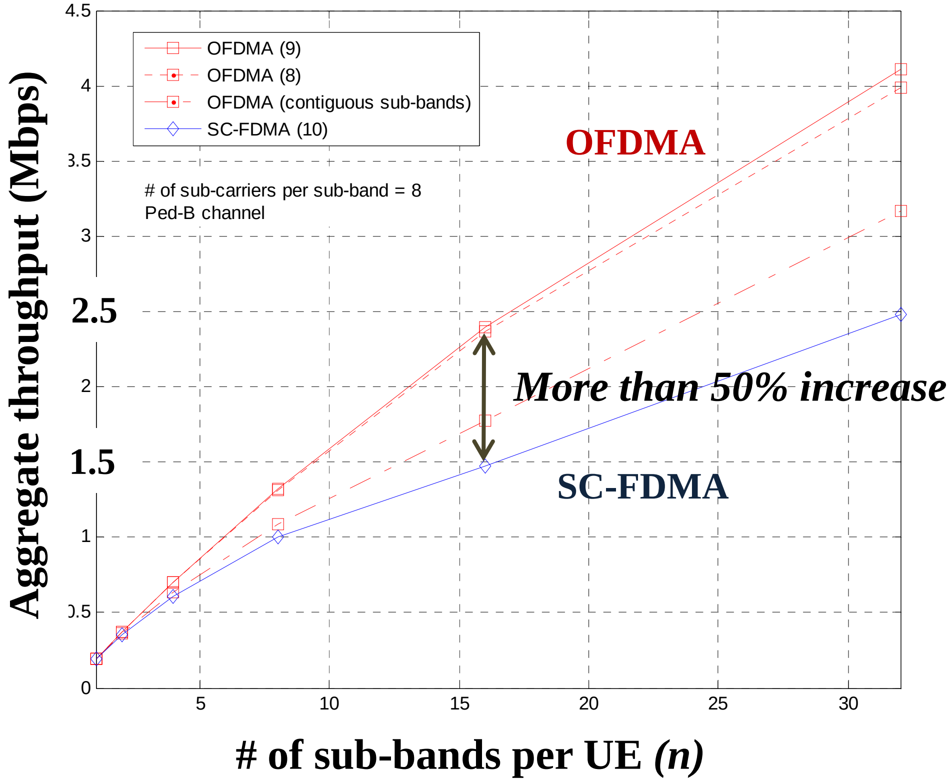
- Assuming one sub-band consists of consecutive *s* sub-carriers,

$$C_{OFDMA} = nLog(1 + \frac{1}{n}\sum_{i \in B} \overline{SNR_i})$$

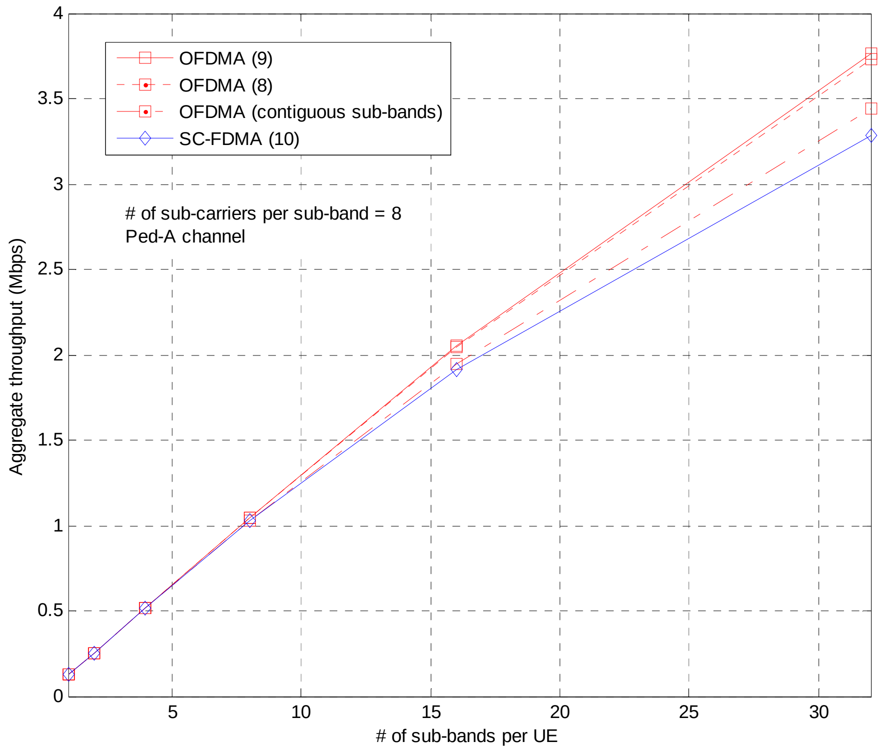
$$C_{SC-FDMA} = nLog(\frac{1}{\frac{1}{ns}\sum_{i=1}^{ns}\frac{1}{1+SNR_{b,i}}})$$

Center frequency	2.3GHz
System BW	5GHz
FFT size	512
Channel model	Ped A, Ped B
Equalizer	MMSE
Scheduling	Best *n* sub-bands selection and common MCS for OFDMA Best one (large) band selection for SC-FDMA

Frequency-domain channel-dependent scheduling



(a) Ped B

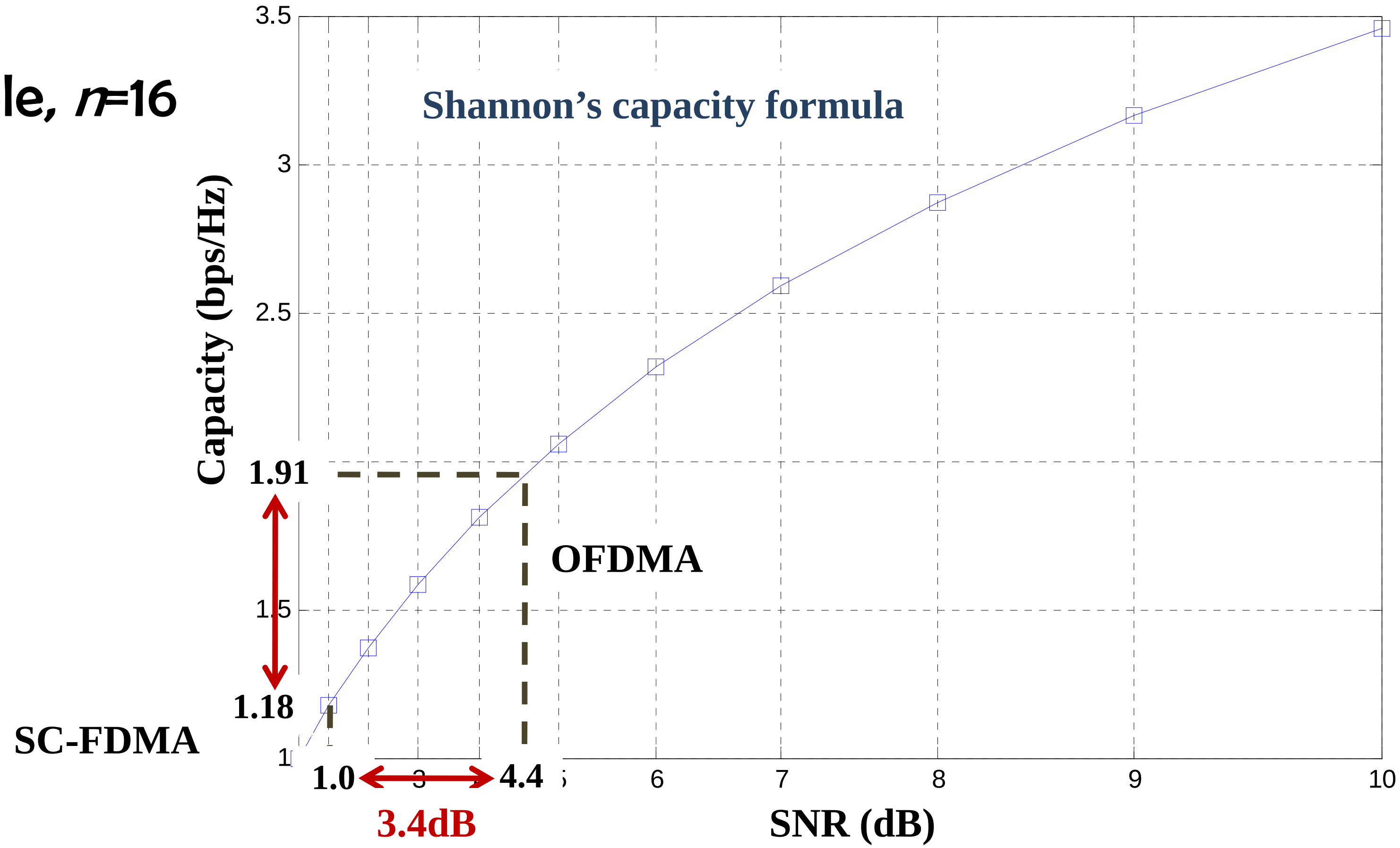


(b) Ped A

- In Ped B, more than 50% throughput gain obtained for OFDMA

Frequency-domain channel-dependent scheduling

- For example, n=16



- Roughly speaking, OFDMA throughput gain can be converted into power gain of 3.4dB

PAPR/CM

1) R1-050475, "PAPR comparison of uplink MA schemes," LGE, RAN1 #41, 2005.
2) R1-051237, "PAPR and Cubic Metric from a System Point of View for E-UTRA Uplink," Motorola, RAN1 #42bis, 2005.
3) C802.20-07-05, "Dynamic PA backoff schemes and SC-FDMA," Qualcomm, 2007.
4) C80216m-08_045, "On the Multiple Access Schemes for IEEE 802.16m: Comparison of SC-FDMA and OFDMA," Intel, 2008.

1)		PAPR	CM
QPSK	OFDMA	8.5	3.3
	SC-FDMA	6	1.07
16QAM	OFDMA	8.5	3.3
	SC-FDMA	6.5	1.84

- Even if SC-FDMA has power efficiency gain, it is worth noting that
  - Users inside the sector/cell with good channel condition will not transmit at their maximum power level and PAPR is not an issue [2-3].
  - In view of spectral mask margin, PAPR is not an issue when users are allocated away from the edge of spectrum [3].
  - More meaningful power efficiency difference is half of what we see [4].
  - PAPR reduction scheme can reduce the difference.

Overall Comparison

	OFDMA	SC-FDMA	Performance
Multiplexing for control signal, data, and pilot	**Flexibility**	**Restriction**	**OFDMA potential gain**
Channel-dependent scheduling	**Maximum gain**	**Reduced gain**	**OFDMA** has about **3.4 dB gain** when a UE gets 16 sub-bands out of 64 sub-bands.
Uplink MIMO	**MLD feasible**	**MLD infeasible**	MLD **OFDMA** has **5-6 dB gain** over MMSE SC-FDMA when CSM is used.
Post-equalization SINR	**No loss**	**SINR loss in freq. selective CH**	**SC-FDMA** has about **3dB loss** for DFT size of 32 when FFT size is 512 and Ped B CH is used.
PAPR/CM	**High**	**Low**	**SC-FDMA** has **2-2.5dB gain** for QPSK

Text proposal for 802.16m SDD

- **Adopt the following text proposal as the baseline of multiple access for SDD.**

=========================== *Start of Proposed Text* ================================

11. Physical Layer

11.x. Multiple Access

OFDMA as the uplink (UL) multiple access scheme for 802.16m has interoperability with WirelessMAN-OFDMA reference system. UL OFDMA has also commonality with downlink (DL) OFDMA system. In addition to orthogonal uplink transmission and simple frequency domain equalization, OFDMA has flexibility in channel design, multiplexing, and scheduling based on frequency-multiplexing of multiple waveforms and fine granularity. OFDMA also makes it possible to adopt maximum-likelihood detector (MLD) as a receiver, which is desirable, especially for UL MIMO schemes. Moreover, high PAPR of OFDMA can be reduced by power control, resource allocation and PAPR reduction algorithms. Therefore, ***OFDMA is adopted as the multiple access scheme for IEEE 802.16m***.

============================ *End of Proposed Text* ================================