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Re:	Uplink multiple access rapporteur chairs' report
Abstract	This contribution compares the coverage efficiency between OFDM and DFT-S-OFDM waveforms for 802.16m uplink, based on realistic channel estimation and power amplifier backoff requirements. In addition, the susceptibility of the signal waveform to adjacent channel interference is discussed.
Purpose	To provide supplementary information to the uplink multiple access rapporteur report for the decision on the adoption of new uplink multiple access techniques.
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On the comparison between OFDMA and DFT-S-OFDMA for the 802.16m uplink – coverage efficiency and susceptibility to adjacent channel interference

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1. Introduction

Coverage efficiency is one of the criteria that can be used for the comparison of new proposed uplink multiple access techniques with the legacy OFDMA.

This contribution provides a link budget analysis based on link level simulation results with non-ideal channel estimation, as reported in [2], which were submitted to the Rapporteur group on Feb 29. The current link budget is computed for the case of localized OFDMA and DFT-S-OFDMA (SC-FDMA). Instead of using the cubic metric, the amount of power amplifier (PA) backoff used in this link budget analysis is based on simulation results using the RAPP PA model, which is adopted by the 802.16m evaluation methodology [4], to meet the spectral mask requirements by FCC and ETSI. The referenced simulation results are discussed in C802.16m-08/45r1 [3], which evaluates scenarios for distributed and localized subchannel allocations respectively.

An additional criterion is the signal waveform's susceptibility to adjacent channel interference. This is an important aspect for comparison, even though it has not been addressed by the rapporteur chairs' report.

2. Link Budget Analysis

The link budget template in the 802.16m evaluation methodology document [4] is used for the analysis. Scenarios and assumptions for the link budget analysis are listed as follows:

- Frequency resources allocation localized at the center of the band
- Receiver interference density at 7 dB over the thermal noise density (IoT), same as the assumption used in [1], [9][1]
- Maximum MS transmit power: 31 dBm [3]
- Modulation and coding: QPSK, CTC R-1/2
- Channel models and mobility: ITU Pedestrian-B at 3 km/h, Vehicular-A at 120 km/h
- Required SNR for 1% PER for each fast fading channel is based on simulation results reported in [2] for the case of:
    - DFT-32 (32 subcarriers/OFDM symbol used for transmission)
    - SIMO (1x2)

  – Note that 'Fast fading margin' is reflected in the required SNR[2]
- Subcarrier spacing = 10.94 kHz
- Path loss model (802.16m EMD mandatory [4]):

  PL (dB) = 130.62 + 37.6 Log_{10} (d), d in km

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[1] Some other assumptions used by the link budget analysis [1], [9] are not applied to the current analysis, e.g., the AWGN block error rate is different as the simulated information block sizes are different, the occupied channel bandwidths are different, and the scheduling gain has not been verified.

[2] Based on an earlier version of the link budget template, as described in C802.16m-08/120r2, the required SINR may include the fast fading effect. This version is preferable to the adopted version in [4] when the required SNR for AWGN channel is not available.

2.1. ITU Pedestrian-B channel model at 3 km/h

The link budget comparison for OFDMA and DFT-S-OFDMA is shown in Table 1, for the ITU Pedestrian-B channel model at 3 km/h. The analysis shows that localized OFDMA with allocation at the band center has higher coverage efficiency at 4.72, as compared to DFT-S-OFDMA at 4.07. Therefore, in the analyzed scenario, the coverage efficiency of DFT-S-OFDMA is at 86.23% of that of OFDMA.

Table 1 Link budget comparison between OFDMA and SC-FDMA, ITU Pedestrian-B channel model, 3 km/h

Item	OFDMA	SC-FDMA	Remark
System Configuration			
Carrier frequency	2.5	2.5	GHz
BS/MS heights	32 / 1.5	32 / 1.5	m
Test environment	Urban/Suburban,outdoor pedestrian	Urban/Suburban,outdoor pedestrian	Indoor, outdoor vehicular, etc.
Channel type	Traffic channel	Traffic channel	Control channel/ Traffic channel
Area coverage	90	90	%
Test service	207.48 kbps	207.48 kbps	Data (rate)/ VoIP (rate)
Chosen modulation and coding scheme (explicitly state the use of repetition coding)	QPSK, R-1/2	QPSK, R-1/2	-
Total channel bandwidth	10	10	MHz
Multipath channel class (characterization of both temporal and spatial properties, e.g., ITU VehA with fixed spatial correlation)	ITU-Ped B	ITU-Ped B	-
Mobile speed	3	3	km/h
Transmitter			
(a) Number of transmit antennas	1	1	-
(b) Maximum transmitter power per antenna	31	31	dBm
(c) Transmit backoff	0.47	0.43	dB; (Ref: C802.16m-08/45r1)
(d) **Transmit power per antenna = (b) - (c)**	30.53	30.57	dBm
(d1) **Total transmit power per sector = function (a) & (d)**	30.53	30.57	dBm
(e) Transmitter antenna gain	0	0	dBi
(e1) Transmitter array gain (depends on transmitter array configurations and technologies such as adaptive beam forming, CDD (Cyclic delay diversity), etc.)	0	0	dB
(e2) Control channel power boosting gain	0	0	dB
(e3) Data carrier power loss due to pilot/control boosting	0	0	dB
(f) Cable, connector, combiner, body losses (enumerate sources)	0	0	dB
(g) **Transmitter control EIRP = (d1) + (e) + (e1) +(e2) - (f)** **Data EIRP = (d1) + (e) + (e1) -(e3) - (f)**	30.53	30.57	dBm
Receiver			
(h) Number of receive antennas	2	2	-
(i) Receiver antenna gain	17	17	dBi
(j) Cable, connector, body losses	2	2	dB
(k) Receiver noise figure	5	5	dB
(l) Thermal noise density	-174	-174	dBm/Hz
(m) Receiver interference density	-167	-167	dBm/Hz
(n) **Total noise plus interference density = 10 log (10((l)/10) + 10((m)/10))**	-166.21	-166.21	dBm/Hz
(o) Occupied channel bandwidth (for meeting the requirements of the test service)	350.08	350.08	kHz
(p) **Effective noise power = (n) + (k) + 10log((o))**	-105.77	-105.77	dBm ([2]; DFT-32)
(q) Required SNR (1% PER; fast fading)	8.75	10	dB [2]
(r) Receiver implementation margin	0	0	dB
(r1) Fast fading margin (include scheduler gain)	0	0	dB
(r2) HARQ gain	0	0	dB
(r3) Handover gain	0	0	dB
(r4) BS diversity gain	3	3	dB
(s) **Receiver sensitivity = (p) + (q)+ (j) + (r) + (r1) - (r2) - (r3) - (r4)**	-102.02	-100.77	dBm
(t) **Hardware link budget = (g) + (i) - (s)**	149.55	148.34	dB
Calculation of Available Pathloss			
(u) Lognormal shadow fading std deviation	8	8	dB
(v) Shadow fading margin (function of the area coverage and (u))	5.6	5.6	dB
(w) Penetration margin	10	10	dB
(w1) Other gains	0	0	dB
(x) **Available path loss = (t) – (v) – (w) + (w1)**	133.95	132.74	dB
Range/coverage Efficiency Calculation			
(y) Maximum range (according to the selected carrier frequency, BS/MS antenna heights, and test environment – see System Configuration section of the link budget)	1.23	1.14	km
(z) Coverage Efficiency ($\pi (y)^2$)	4.72	4.07	sq km/site

2.2. ITU Vehicular-A channel model at 120 km/h

The link budget comparison for OFDMA and DFT-S-OFDMA is shown in Table 2, for the ITU Vehicular-A channel model at 120 km/h. The analysis showed that localized OFDMA with allocation at the band center has higher coverage efficiency at 4.05, as compared to DFT-S-OFDMA at 3.49. Therefore, in the analyzed scenario, the coverage efficiency of DFT-S-OFDMA is at 86.17% of that of OFDMA.

Table 2 Link budget comparison between OFDMA and SC-FDMA, ITU Vehicular-A channel model, 120 km/h

Item	OFDMA	SC-FDMA	Remark
System Configuration			
Carrier frequency	2.5	2.5	GHz
BS/MS heights	32 / 1.5	32 / 1.5	m
Test environment	Urban/Suburban,outdoor vehicular	Urban/Suburban,outdoor vehicular	Indoor, outdoor vehicular, etc.
Channel type	Traffic channel	Traffic channel	Control channel/ Traffic channel
Area coverage	90	90	%
Test service	207.48 kbps	207.48 kbps	Data (rate)/ VoIP (rate)
Chosen modulation and coding scheme (explicitly state the use of repetition coding)	QPSK, R-1/2	QPSK, R-1/2	-
Total channel bandwidth	10	10	MHz
Multipath channel class (characterization of both temporal and spatial properties, e.g., ITU VehA with fixed spatial correlation)	ITU-Veh A	ITU-Veh A	-
Mobile speed	120	120	km/h
Transmitter			
(a) Number of transmit antennas	1	1	-
(b) Maximum transmitter power per antenna	31	31	dBm
(c) Transmit backoff	0.47	0.43	dB; (Ref: C802.16m-08/45r1)
(d) **Transmit power per antenna = (b) - (c)**	30.53	30.57	dBm
(d1) **Total transmit power per sector = function (a) & (d)**	30.53	30.57	dBm
(e) Transmitter antenna gain	0	0	dBi
(e1) Transmitter array gain (depends on transmitter array configurations and technologies such as adaptive beam forming, CDD (Cyclic delay diversity), etc.)	0	0	dB
(e2) Control channel power boosting gain	0	0	dB
(e3) Data carrier power loss due to pilot/control boosting	0	0	dB
(f) Cable, connector, combiner, body losses (enumerate sources)	0	0	dB
(g) **Transmitter control EIRP = (d1) + (e) + (e1) +(e2) - (f)** **Data EIRP = (d1) + (e) + (e1) -(e3) - (f)**	30.53	30.57	dBm
Receiver			
(h) Number of receive antennas	2	2	-
(i) Receiver antenna gain	17	17	dBi
(j) Cable, connector, body losses	2	2	dB
(k) Receiver noise figure	5	5	dB
(l) Thermal noise density	-174	-174	dBm/Hz
(m) Receiver interference density	-167	-167	dBm/Hz
(n) **Total noise plus interference density = 10 log (10((l)/10) + 10((m)/10))**	-166.21	-166.21	dBm/Hz
(o) Occupied channel bandwidth (for meeting the requirements of the test service)	350.08	350.08	kHz
(p) **Effective noise power = (n) + (k) + 10log((o))**	-105.77	-105.77	dBm ([2]; DFT-32)
(q) Required SNR (1% PER; fast fading)	10	11.25	dB [2]
(r) Receiver implementation margin	0	0	dB
(r1) Fast fading margin (include scheduler gain)	0	0	dB
(r2) HARQ gain	0	0	dB
(r3) Handover gain	0	0	dB
(r4) BS diversity gain	3	3	dB
(s) **Receiver sensitivity = (p) + (q)+ (j) + (r) + (r1) - (r2) - (r3) - (r4)**	-100.77	-99.52	dBm
(t) **Hardware link budget = (g) + (i) - (s)**	148.30	147.09	dB
Calculation of Available Pathloss			
(u) Lognormal shadow fading std deviation	8	8	dB
(v) Shadow fading margin (function of the area coverage and (u))	5.6	5.6	dB
(w) Penetration margin	10	10	dB
(w1) Other gains	0	0	dB
(x) **Available path loss = (t) – (v) – (w) + (w1)**	132.70	131.49	dB
Range/coverage Efficiency Calculation			
(y) Maximum range (according to the selected carrier frequency, BS/MS antenna heights, and test environment – see System Configuration section of the link budget)	1.14	1.05	km
(z) Coverage Efficiency $(\pi (y)^2)$	4.05	3.49	sq km/site

3. Susceptibility to Adjacent Channel Interference

The non-linearity of the PA causes spectral re-growth of a filtered signal, which results in adjacent channel interference (ACI) to the signal in the adjacent band. Note that the magnitude of the out-of-band emission, i.e. the adjacent channel interference rolls off as the frequency separation of adjacent band increases.

In the case of OFDM, the interference on a few edge subcarriers affects only the data symbols loaded on the corresponding subcarriers. Some of these errors can be corrected with the inherent channel coding of the encoded block. For SC-FDM, as the data symbols are spread across the allocated transmission band, the interference on a few edge subcarriers will affect all the data symbols in the encoded block, which would result in an elevated error floor.

In other words, SC-FDM suffers more degradation from ACI while OFDM is robust to ACI.

Therefore, the number of guard tones required for OFDM would be lower than that for SC-FDM. A smaller number of guard tones leads to improved spectral efficiency in the uplink.

4. Conclusion

In the link budget analysis of localized OFDMA and SC-FDMA, it has been shown that the coverage efficiency of OFDMA outperforms SC-FDMA. SC-FDMA achieves only 86.2% of the coverage efficiency of OFDMA based on the analysis. The scenario analyzed is based on transmission at the band center over 32 subcarriers. As the cell edge users are power limited, it is desirable to concentrate the transmission power over a smaller number of subcarriers to extend the coverage range. In this scenario, the gain of SC-FDMA over OFDMA, with respect to the requirements for power amplifier (PA) backoff, is insignificant, as shown in [3]. On the other hand, the link performance simulation results for non-ideal channel estimation, as reported in [2], show that OFDMA outperforms SC-FDMA by about 1.25 dB for QPSK, R-1/2, DFT-32. A larger performance gain of 2 dB has been observed in earlier simulation results for a different block size [5] [6].

When the uplink transmission has to be scheduled for the band edge, the gain of SC-FDMA over OFDMA with respect to PA backoff is 0.9 dB, according to the results in [3]. This will still result in higher coverage efficiency for OFDMA as compared to SC-FDMA, because of the higher link performance gain of OFDMA over SC-OFDMA.

Therefore, taking into consideration the realistic requirements on PA backoff, realistic link level performance, localized OFDMA outperforms SC-FDMA in the link budget and coverage efficiency by 16% in the analyzed scenario for band center transmission.

OFDM has been adopted by a number of air interface standards in recent years because of its higher spectral efficiency as compared to single carrier signal waveform, e.g., SC-FDM. When multiple channels are deployed in adjacency to each other, OFDM allows narrower channel spacing, as a consequence of its multicarrier (orthogonal) characteristic. This has been verified by a prior simulation study for the case of downlink with multiple channels [8]. The implication from that investigation can also be applied to the case of uplink.

In conclusion, we recommend OFDMA to be retained as the uplink multiple access technique for 802.16m.

5. References

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