Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**OFDM (FFT 256) Fixed & Mobile System Considerations**
Date Submitted	**2003-01-10**
Source(s)	Marianna Goldhammer — Voice: +972 3 645 6241, marianna.goldhammer@alvarion.com Naftali Chayat — Voice: +972 3 645 7801, naftali.chayat@alvarion.com Yaron Alpert — Voice: +972 3 766 1616, yaron.alpert@alvarion.com Vladimir Yanover — Voice: +972 3 645 7834, vladimir.yanover@alvarion.com Tal Kaitz — Voice: +972 3 645 6273, tal.kaitz@alvarion.com Michael Genossar — Voice: +972 3 767 4238, miki.genossar@alvarion.com All with ALVARION 21a HaBarzel Street, Tel Aviv, Israel
Re:	Call for contributions IEEE 802.16e-02/01: Mobility Enhancements to IEEE Standard 802.16/802.16a
Abstract	OFDM mobile system deployment, channel models, services, parameters, etc.
Purpose	To emphasize the differences between FWA and mobile systems
Notice	
Release	
Patent Policy and Procedures	

<mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

OFDM (FFT 256) Fixed & Mobile System Considerations

Marianna Goldhammer, Naftali Chayat, Yaron Alpert, Vladimir Yanover, Tal Kaitz, Michael Genossar
Alvarion

1. Introduction

The 802.16e drafting group should share the understanding of the mobile system basic system parameters and requirements, in order to have a common understanding of the drafting target, with the scope to provide a good "fix & mobile" system. We present our views, in order to open the discussion regarding possible directions for PHY / MAC proposals.

2. Channel spacing

The OFDM system should target channel spacing between 1.25MHz and 10MHz, with a focus on channel spacing of 3.5 – 5MHz. The target data rates should be correlated with the channel spacing.

3. FDD/TDD

Both FDD and TDD frequency allocations should be supported.

4. Operating environments and path-loss models

3GGP has defined the following operating environments [1]:

- Indoor environment – served by pico-cell, indoor Base Station;
- Outdoor-to-indoor and pedestrian – served by micro-cell;
- Vehicular and high antenna – served by macro-cell;
- Mixed: macro-cells overlaying micro-cells.

The macro/micro/pico cell definition is as follows:

- Pico - cell hex radius (r) < 100 m;
- Micro - 100 m < (r) < 1000 m;
- Macro - (r) > 1000 m.

Radio Environment

Indoor Office Environment

The indoor office environment uses ***pico-cells***. As described in [1]:
"This environment is also characterized by **small cells** and **low transmit powers**. Both **base stations** and pedestrian users **are located indoors**. A lognormal shadow fading standard deviation of 12 dB can be expected. Fading ranges from Rician to Rayleigh, with Doppler frequency offsets set by walking speeds."

Is desired, that the indoor equipment will be similar with the WLAN solutions: low cost Access Point, using a SS symmetrical solution.
For this kind of deployment, the already defined 802.16a PHY, OFDM – OFDM (no sub-channelization) is perfectly suitable.

Outdoor to Indoor and Pedestrian Environment

This radio environment uses ***micro-cells***. As described in [1]:
This environment is characterized by **small cells** and **low transmit power**. **Base stations** with low antenna heights **are located outdoors**; pedestrian users are located on streets and inside buildings and residences. Log-normal shadow fading with a standard deviation of 10 dB is reasonable for outdoors and 12 dB for indoor. Building penetration loss averages 12 dB with a standard deviation of 8 dB.
This environment involves high path-loss and UL OFDMA becomes necessary. As the existing sub-channelization mode does not allow to take advantage in increasing the cell size, and also the 6dB gain resulting from 4 sub-channels is too low, a new UL OFDMA mode will be beneficial. In its design, should be taken into consideration that the PCMCIA experience shows low transmitted powers (17dBm or less), while the Base Station Tx powers will be probably higher than in FWA.

Vehicular and High Antenna Environment

This radio environment uses ***macro-cells***. As described in [1]:
“This environment is characterized by **larger cells** and **higher transmit power**. Log-normal shadow fading with 10 dB standard deviation are appropriate in urban and suburban areas.”
In this environment, with high DL powers, requirements for the UL OFDMA are even stronger. The new OFDMA mode shall provide high (15dB?) gain in link budget and to have a reduced peak-to-average (back-off), relative to the OFDM mode.

Mixed Environment

As described in [1]:
“It can be a “vehicular environment” (macro cells) and an “outdoor to indoor environment” (micro cells) in the same geographical area. In this area fast moving terminals (vehicles) should probably be connected to the macro cells to reduce the handoff rate (number of hand-offs per minute) and slow moving terminals (pedestrians) should be connected to the micro cells to achieve high capacity.”

Repeater-cells

The **repeater-cells** are cells created by Repeaters, being possible in both **indoor** and **out-door** environment. The Repeater should be based on a SU solution, to allow for low-cost (symmetrical SU-AU solution). Only one stream should be used in UL or DL.

Path-loss model

It is proposed to use the path-loss Stanford models, as presented in [3], for macro-cell deployment. The advantage of the Stanford model resides in the fact that it is frequency scalable. The shadowing parameter “s” should be computed according to the lognormal distribution, with “sigma” as defined above (3GPP definition). Nevertheless, we still have to chose path-loss models for indoor deployment and urban outdoor-to-indoor and pedestrian deployment.

5. Channel impulse response models

Same UMTS channel models are proposed by ETSI and ITU-R [2], for 3 radio environments. The ETSI channel models are described in [1], as reproduced below.

For each terrestrial test environment, a channel impulse response model based on a tapped-delay line model is given. The model is characterized by the number of taps, the time delay relative to the first tap, the average power relative to the strongest tap, and the Doppler spectrum of each tap. A majority of the time, r.m.s. delay spreads are relatively small, but occasionally, there are "worst case" multipath characteristics that lead to much larger r.m.s. delay spreads. Measurements in outdoor environments show that r.m.s. delay spread can vary over an order of magnitude, within the same environment. Although large delay spreads occur relatively infrequently, they can have a major impact on system performance. To accurately evaluate the relative performance of candidate Radio Technology, it is desirable to model the variability of delay spread as well as the "worst case" locations where delay spread is relatively large.

As this delay spread variability cannot be captured using a single tapped delay line, up to two multipath channels are defined for each test environment.

Considered frequencies and vehicular speeds

The Doppler spectrum depends on the maximum vehicular speed and on the radio frequency.

As resulting from Nokia previous submissions, the typical speed for mobile applications is 60-70km/h. It is proposed by us to focus the system design for 70km/h. Performance evaluation should be done for 120km/h and 250km/h, in order to know the resulting performance degradation.

The considered spectrum is up to 6GHz. Nevertheless, the main usable bands are the 3G bands (2GHz), the MMDS bands (2.6GHz) and the 3.5GHz bands. It is proposed to focus the system design for 2.6GHz band. Performance should be also evaluated at 3.5GHz and 5.8GHz.

We expect that for the Vehicular test environment, the simulations for the difficult Channel B response will show degradation in maximum data rate. As both ITU-R and 3GPP consider that "large delay spreads occur relatively infrequently", we should not target maximum performance with this channel model.

Tapped Delay Line parameters

Table 1: Indoor Office Test Environment Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Rel. Delay (nsec)	Avg. Power (dB)	Rel. Delay (nsec)	Avg. Power (dB)	
1	0	0	0	0	FLAT
2	50	-3.0	100	-3.6	FLAT
3	110	-10.0	200	-7.2	FLAT
4	170	-18.0	300	-10.8	FLAT
5	290	-26.0	500	-18.0	FLAT
6	310	-32.0	700	-25.2	FLAT

Table 2: Outdoor to Indoor and Pedestrian Test Environment Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Rel. Delay (nsec)	Avg. Power (dB)	Rel. Delay (nsec)	Avg. Power (dB)	
1	0	0	0	0	CLASSIC
2	110	-9.7	200	-0.9	CLASSIC
3	190	-19.2	800	-4.9	CLASSIC
4	410	-22.8	1200	-8.0	CLASSIC
5	-	-	2300	-7.8	CLASSIC
6	-	-	3700	-23.9	CLASSIC

Table 3: Vehicular Test Environment, High Antenna, Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Rel. Delay (nsec)	Avg. Power (dB)	Rel. Delay (nsec)	Avg. Power (dB)	
1	0	0.0	0	-2.5	CLASSIC
2	310	-1.0	300	0	CLASSIC
3	710	-9.0	8900	-12.8	CLASSIC
4	1090	-10.0	12900	-10.0	CLASSIC
5	1730	-15.0	17100	-25.2	CLASSIC
6	2510	-20.0	20000	-16.0	CLASSIC

6. Deployment architecture

The 3G systems, using WCDMA, can be deployed using same frequency in all the sectors and base stations. For the mixed deployment mode, min. 3 frequencies are necessary, and this probably explains the allocations of 15MHz, for WCDMA, using 5MHz channels.

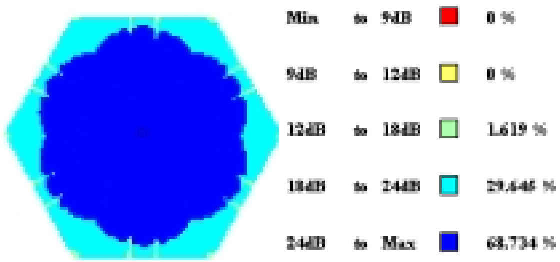
For FWA systems, 4 or 6 sectors are used. We did simulations in order to understand the difference between the deployment of FWA and mobile systems.

FWA versus Mobile deployment

The main difference in cellular deployment comes from subscriber antenna: omni in mobile, directive with front-to-back isolation in FWA. The SU antenna will receive interference from different Base Stations. Following is an example of single cell and multi-cell deployment simulation, for 3.5GHz, 3.5MHz channel spacing. Stanford B deployment model was used, with a shadowing margin of 10dB. The Base Station antenna height is 35m and has a down tilt of 4deg. The user height is 1m, and the omni antenna gain is 0dB. We used 6 sectors and 6 channels. All the Base Stations are fully loaded.

Single cell mobile deployment

The single cell deployment, not influenced by the inter-cell interference, at a Tx power of 10W, allows operation with a min. S/N = 18dB for 98.5% of the 1km radius cell area. The average data rate per 6 sectors / 6 channels cell, with the simulation assumptions, resulted to be 6*10.2Mb/s = 61.2Mb/s, or 10.2:3.5= 2.9bit/s/Hz.

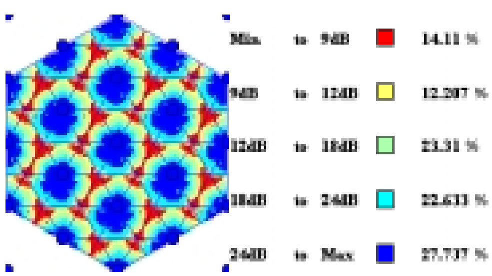


Tx=10W

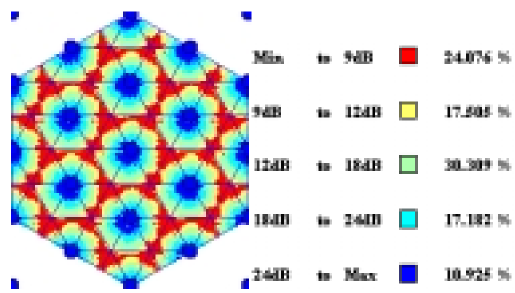
In case of single cell, 3 channels and 6 sectors, the capacity is 6*9.6Mb/s = 57.6Mb/s.

Multi-cell with mobile SS

The multi-cell down-link (SS) performance is influenced by DL interference. At the same transmitted power, only 50% of the covered area will work at the maximum rate. If the power will be reduced to Tx=1W, the area covered with good S/(N+I) will be reduced to 28%.



Tx=10W



Tx=1W

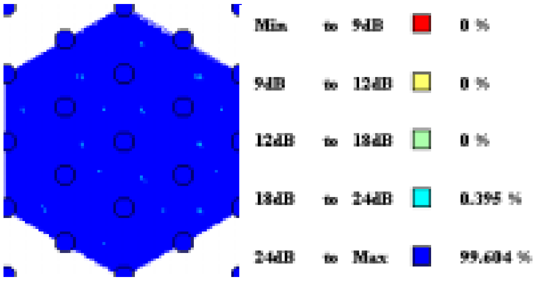
In this case, for 10W transmitted power, the cell capacity results to be:

- 30Mb/s, for 6 sectors, 6 channels;
- 24.6Mb/s, for 6 sectors, 3 channels;
- 15Mb/s, for 3 sectors, 3 channels.

Even if it is degradation due to multi-cell deployment, the resulting capacity is significantly higher than in the 3G case.

Multi-cell with FWA SS

In FWA deployment, 17dBi SS antenna gain, there is NO inter-cell interference. For only 1W transmitted power, the maximum rate (64QAM, rate ¾), is obtained for 99.6% of the area.



Tx=1W

Down-link interference reduction

The examples above show that with omni antennae used by the mobile it is difficult to assure the coverage everywhere. One remedy is to use a larger number of narrower channels, in conjunction with careful cellular planning. Another is to introduce downlink sub-channelization to the OFDM mode, which will incur significant implementation complexity and peak-rate reduction. This is an issue for further study and discussion.

Up-link interference reduction

OFDMA should be defined in up-link, with a possibility to allocate only a given number of sub-channels per sector.

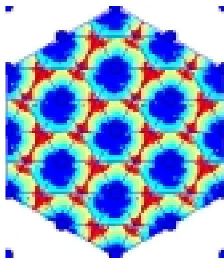
This will have the same effect as increasing the number of frequency channels.

Optimum number of frequency channels for macro / micro cells

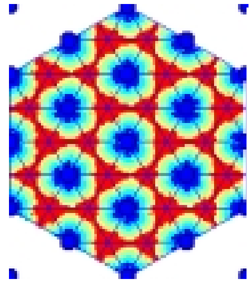
We did simulations for the following deployment scenarios:

- 6 channels, 6 sectors
- 3 channels, 6 sectors
- 3 channels, 3 sectors.

For single cell deployment, is possible to use the same frequency twice (3 channels, 6 sectors), obtaining an increase in capacity of 95%.
In multi-cell deployment, due to the interference problem, the increase in capacity is 80%.
The number of available channels has an important effect on S/(I+N) ratio. With 6 channels, the maximum data rate (min. 18dB S/(I+N)) is obtained in the previous example, with Tx=10W, for 50% of the cell area. With 3 channels, targeting same capacity, the maximum data rate is obtained only on 28.5% of the cell area. With 3 channels, using only 3 frequencies, the maximum data rate is obtained for 28.6% of the area, but the spectral efficiency per cell is the same as for 6 channels, 6 sectors.



6 channels, 6 sectors



3 channels, 6 sectors

In conclusion, the 6 channels spectrum allocation for a Broadband Mobile System will permit to achieve optimum spectrum efficiency, at high average cell capacity.

Optimum number of frequency channels for mixed radio environment

In the mixed radio environment, the macro-cells overlap the micro-cells.
The solution for this deployment mode will be, as in 3G, will be to have different frequency channels allocated for macro-cells and micro-cells. As it is possible to get good capacity with 3 frequencies, 6 sectors, the necessary frequency channel number will be:

- 3 channels for macro-cells
- 3 channels for micro-cells
- 1 channel for separation.

Conclusion: 7 frequency channels are necessary for mixed macro and micro cell deployment.

Examples of such allocations are those in ITU-R Region 2, Latin America, were 25MHz of spectrum are allocated for fixed services, allowing 7 channels of 3.5MHz.

Combined FWA and Mobile deployment

The combined deployment will target areas where the Internet access is not provided by ADSL or Cable systems.
The 802.16e Base Station shall work with both mobile and fixed stations. Our view is that the same MAC frame shall include 2 burst profiles, fixed and mobile, as detailed in the submission: "**Mobility Support in 802.16 MAC".**
In a 6 channels, 6sectors deployment, the fix subscribers will work at maximum rate, antenna directivity providing the necessary isolation.

7. Mobile services, QoS, and mobile devices

The services to be provided by the 802.16e system are detailed below:
Fixed services – already covered by 802.16a

- Main mobile services:
- Multimedia streaming;
- Browsing;
- E-mail;
- Games;

- Video conference;
- Voice.

The maximum downlink data rates (per user) required by 3GPP are 2Mb/s – indoor, 384kb/s pedestrian, outdoor-to-indoor and vehicular up to 120km/h, and 144kb/s for vehicular 250km/h.
The traffic associated with different application types, as a design target, according to our understanding, is detailed bellow.

	Max. DL	Min. DL	Max. UL	Min. UL	Max. Delay
IP Streaming	1.5Mb/s	128kb/s	384kb/s	32kb/s	300ms
Internet	6Mb/s	128kb/s	1.5kb/s	32kb/s	See [1],sec.1.2.2
E-mail	1.5Mb/s	64kb/s	1.5Kb/s	32kb/s	See [1],sec.1.2.2
Games	1.5Mb/s	384kb/s	384kb/s		50ms
Video-conf	384kb/s	32kb/s	384kb/s	32kb/s	50ms
IP Voice	40kb/s	12kb/s	40kb/s	12kb/s	50ms

As an OFDM system requirement, a SS (Subscriber Station) can handle more than one traffic type, with the condition that the traffic will be sent time multiplexed, using only one DL (downlink) stream. By stream we mean a single MAC allocation.

QoS

ITU-R / 3GPP defined QoS classes for mobile services, covering circuit switched bearers and packet data bearers.
The mobile IP services are classified as follows:
- Conversational class (real time reach media conversation);
- Streaming class (relaxed delay requirements);
- Interactive class (e.g. WEB browsing);
- Background class (e.g. e-mail).

The 802.16e should provide an adequate solution to support all the mobile IP QoS categories.

Target subscriber devices

The target subscriber devices, for mobile service operation, are: PDAs, Laptops, and new generation phones. They are characterized by low transmitted power, 0dB antenna gain, and operation from battery.

8. Other mobile specific aspects

Operation from battery

The mobile systems operate from battery, introducing special requirements as compared with FWA systems:
- Provide the system gain for operation at maximum cell size, while complying with the minimum defined rate
- Optimize the design for minimum power consumption.

In our understanding, this implies the following design requirements:

- Provide uplink OFDMA, at least 15dB gain;
- Define an UL OFDMA mode with a very small number of carriers / sub-channel allocation (4 or 5) to have a reduced peak-to-average and back-off, as compared with 50-53 carriers/sub-channel.

The power-save mode of operation shall be considered by the standard.

9. Conclusion

The presented mobile system specific aspects may guide in the 802.16e PHY and MAC protocols proposals.

Bibliography

[1] ETSI TR 101 112 V 3.2.0), “Selection procedures for the choice of radio transmission technologies for UMTS”, ETSI Technical Report, 04-1998.

[2] RECOMMENDATION ITU-R M.1225 “GUIDELINES FOR EVALUATION OF RADIO TRANSMISSION TECHNOLOGIES FOR IMT-2000”, 1997.

[3] IEEE 802.16.3c-01/29r4, Erceg and all, Channel models for FWA applications.

[4] Tero Ojanpera, Ramjee Prasad, “WCDMA:Towards IP Mobility and Mobile Internet”, Artech House, 2001