October 23, 2015

802.16e/WIMAX SAR MEASUREMENT GUIDANCE

I. INTRODUCTION

This document applies to mobile WiMax devices operating in TDD configurations. It identifies certain typical WiMax system and device operating parameters necessary for determining SAR test requirements. Some of the test software and equipment limitations for configuring SAR tests are also described. When the guidance is insufficient for testing evolving products, case-by-case considerations are necessary until the details are widely available. The SAR test methodology and device test configurations may need to be adjusted accordingly as WiMax products continue to emerge.

SAR measurement systems require the measured signal to have a duty factor typical of periodic signals. This imposes specific test restrictions in setting up a WiMax device for SAR testing. Consequently, WiMax devices are usually configured with a combination of proprietary test software, vector signal generator, communication test sets or wireless protocol simulators for SAR testing. Depending on the number of active sub-carriers in the OFDM/OFDMA transmissions, a peak-to-average power ratio (PAPR) of 8 – 12 dB is expected. The high PAPR signals can introduce additional SAR measurement errors that are not compensated by existing measurement systems and standards using SAR probes calibrated with CW signal.

When it is unclear if the test setups may be acceptable, a KDB inquiry should be submitted to the FCC laboratory to verify the test requirements before begin testing. The WiMax system operating parameters, test setup conditions, SAR measurement methodologies and power measurement configurations used to test a device must be clearly explained in SAR reports to support the test results. Since WiMax may be incorporated in both peripheral and stand-alone host devices, such as USB dongles and cellphones, and operate in conjunction with other wireless technologies in the same host, the test procedures for these other transmitter technologies must also be taken into consideration during testing.

II. WIMAX DEVICE AND SYSTEM OPERATING PARAMETERS

Table 1 identifies the WiMax device and system operating parameters typically considered to determine SAR test requirements. In order to expedite inquiries, a similar table filled with the required parameters should be included in all WiMax inquiries (KDB or PAG inquiries). To maintain clarity, separate tables should be used when different parameters are used for different operating modes and frequency bands. When additional explanations are necessary to address specific test concerns in inquiries and test reports; these should be presented similar to the examples shown in the Annex of this document.

III. SAR TEST CONSIDERATIONS

Table 2 provides a summary of information required to describe the test software and supporting equipment used to configure typical WiMax devices for SAR measurement. The required output power and SAR results are also described in the table, along with other device and equipment specific concerns. Examples of descriptions and explanations are included in the Annex to illustrate how device and system operating parameters may be applied to configure test signals with the appropriate OFDMA symbol characteristics and duty factors for SAR measurements. The examples also explain the measurement difficulties relating to test software and supporting equipment requirements. These must be documented in the SAR report according to the system and operating parameters applicable to the individual device and test configurations supported by the test software and test equipment.

Power measurement results are generally used to identify SAR setup concerns and to support test reduction considerations in KDB inquiries; however, specific SAR results are usually not necessary for inquiries about test configurations submitted before testing begins. The procedures for estimating SAR measurement errors due to high PAPR OFDM/OFDMA signals are also described in the Annex.

Table 1: 802.16e/WiMax Device and System Operating Parameters

Description	**Parameter**	**Comment**
FCC ID		Identify all related FCC ID
Radio Service		Rule parts
Transmit Frequency Range (MHz)		System parameter
System/Channel Bandwidth (MHz)		System parameter
System Profile		Defined by WiMax Forum
Modulation Schemes		Identify all applicable UL modulations
Sampling Factor		System parameter
Sampling Frequency (MHz)		(F_s)
Sample Time (ns)		$(1/F_s)$
FFT Size (N_{FFT})		(N_{FFT})
Sub-Carrier Spacing (kHz)		(Δf)
Useful Symbol time (µs)		$(T_b=1/\Delta f)$
Guard Time (µs)		$(T_g=T_b/cp)$; cp = cyclic prefix
OFDMA Symbol Time (µs)		$(T_s=T_b+T_g)$
Frame Size (ms)		System parameter
TTG + RTG (µs or number of symbols)		Idle time, system parameter
Number of DL OFDMA Symbols per Frame		Identify the allowed & maximum symbols, including both traffic & control symbols
Number of UL OFDMA Symbols per Frame		
DL:UL Symbol Ratios		Identify all applicable DL:UL ratios; for determining UL duty factor
Power Class (dBm)		Identify power class and tolerance
Wave1 / Wave2		Describe antenna diversity info and MIMO requirements separately
UL Zone Types (FUSC, PUSC, OFUSC, OPUSC, AMC, TUSC1, TUSC2)		Describe separately the symbol and sub-carrier/sub-channel structures applicable to each zone type
Maximum Number of UL Sub-Carriers		Identify the allowed and tested or to be tested parameters; include separate explanations on the control symbol configuration used in the power measurements and how the maximum power level is determined for the control symbols
Measured UL Burst Maximum Average Conducted Power		
UL Control Symbol Configuration		
UL Control Symbol Maximum Conducted Average Power		

Description	Parameter	Comment
UL Burst Peak-to-Average (Conducted) Power Ratio (PAPR)		Identify the expected range and measured/tested PAPR; explain separately the methods used or to be used to address SAR probe calibration and measurement error issues
Frame Averaged UL Transmission Duty Factor (%)		Show calculations separately and explain how the applicable *cf factor (conversion factor)* used or to be use in the SAR measurements is derived and how the control symbols are accounted for

Table 2: Information on Test Equipment and Measurement Results

Equipment / Results	Description
Test Software	Describe the configuration details and test methodology used to setup the WiMax device for SAR testing, similar to examples in the Annex.
Signal Generator	
Communication Test Set, Protocol Simulator	
SAR Test Signal Characteristics and Structure	Describe the test signal and data/burst structure used or to be used in the SAR tests. Explain why the system operating parameters, test software, signal generator, communication test set, protocol simulator and other test configurations are chosen to evaluate the maximum exposure conditions.
Output Power Measurement	Include maximum average conducted power measurement results for the UL burst, at maximum duty factor, on high, middle & low channels for each modulation. Identify the control symbol configurations used in the power and SAR measurements; including measurement setup, test software and signal generator setup details and limitations.
SAR Measurement Results	SAR results are not necessary for inquiries about device test configurations before testing; however, tabulated SAR results are necessary for PAG requests submitted by a TCB. Representative SAR plots should be included to identify the measurement parameters such as the *conversion factor (cf)* used in the SAR measurements and other relevant information relating to the SAR probe and tissue dielectric property requirements.
Other Relevant Parameters and Issues	Any other concerns specific to the test device should be explained and addressed; for example, MIMO or non-standard WiMax systems.

Change Notice

10/23/2015: 615223 D01 802 16e WiMax SARGuidance v01 is replaced by 615223 D01 802 16e WiMax SARGuidance v01r01. Changed reference to PBA with PAG and included editorial and formatting changes to synchronize document with other KDB publications. Added heading numbering.

Annex A: Examples

The following **"<u>examples</u>"** are used to illustrate how certain information and system/device operating parameters are typically applied to determine the test methodology and device setup required for SAR measurements. Similar descriptions and explanations specific to the individual WiMax device and system are expected in WiMax inquiries (KDB and PAG) and SAR reports. Additional explanations are also included at the end of some of the examples (indented blue text in reduced font).[1]

A1. <u>Typical Device and System Operating Parameters of a EBS/BRS WiMax Device</u>

The test device is a 2.6 GHz WiMax USB dongle transceiver using the ##### chipset. It has two built-in antennas, one for transmitting and two for receiving. The system transmits on 5 ms frames using 5 MHz and 10 MHz channels. The 10 MHz channel bandwidth uses 1024 sub-carriers and 35 sub-channels, with 184 unused (null) sub-carriers and 840 available for transmission, consisting of 560 data and 280 pilot sub-carriers. The 5 MHz channel bandwidth uses 512 sub-carriers and 17 sub-channels, with 104 unused sub-carriers and 408 available for transmission, consisting 272 data and 136 pilot sub-carriers.

Control signals are transmitted in the first 3 symbols of each uplink burst. The rest of the uplink sub-frame contains normal traffic data bursts. The first 3 symbols are also used for ranging, which is shared with other users. During normal operation, the control symbols are transmitted at reduced power and the traffic symbols may transmit at maximum power. For SAR testing purposes, the configuration of control symbols is dependent on the test software and test equipment setup. The uplink allows a maximum of 15 traffic and 3 control symbols, 18 total, per frame. These conditions are applicable to both 5 and 10 MHz channel configurations used by this device.

> Include similar descriptions for other WiMax device and system implementations to identify the applicable signal and transmission characteristics necessary for evaluating SAR compliance.

A2. <u>WiMax Zone Types</u>

The device transmits using PUSC zone type only. Multiple users can transmit simultaneously within the system. FUSC and other zone types are not used by this device for uplink transmissions. The maximum DL:UL (downlink-to-uplink) symbol ratio is determined according to the PUSC requirements. The system transmits an odd number of symbols using DL-PUSC, consisting of even multiples of traffic and control symbols, plus one symbol for the preamble. The device transmits in multiples of three symbols using UL-PUSC. The OFDMA symbol time allows up to 48 downlink and uplink symbols to be transmitted in each 5 ms frame. TTG and RTG are also included in each frame as DL/UL transmission gaps; therefore, the system can only allow 47 or less symbols per frame. The maximum DL:UL symbol ratio allowed for this device and determined according to these PUSC parameters is 29:18. However, due to test vector configuration limitations, a DL:UL ratio of 31:15 is used for the SAR measurements. In addition, restrictions from the proprietary test software require special test vectors to be configured for the vector signal generator to work with the test device. The measured results are scaled to the maximum DL:UL ratio of 29:18.to determine SAR compliance.

> Include similar descriptions for other zone types used by the device and determine the applicable signal/transmission characteristics and configurations necessary to perform SAR measurements.

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[1] The descriptions and parameters used in these examples may not be identical to those used by an individual WiMax device. It must be verified that all information are applicable to the test device in question before cutting and pasting the descriptions in these examples into the documentation or SAR report of a specific inquiry or equipment certification to avoid discrepancies.

A3. Duty Factor Considerations

Although the chipset can support higher DL:UL symbol ratios, this device is only supplied to BRS/EBS WiMax operators with agreements to transmit at a maximum DL:UL symbol ratio of 29:18. The device is limited by both firmware and the corresponding WiMax system to operate at or below this maximum duty factor. Therefore, the maximum transmission duty factor supported by the chipset is not applicable for this device. The system can transmit up to 48 OFDMA symbols in each 5 ms frame, including 1.6 symbols for TTG and RTG. With a maximum of 18 uplink symbols all transmitting at maximum power, the duty factor would be 18/48 or 37.5%. However, the first 3 uplink symbols are used for control signals/channels that transmit at reduced power; additional considerations are necessary to determine the duty factor applicable to the SAR measurements. In addition, due to test software and signal generator constraints, both the control symbols and maximum DL:UL symbol ratio cannot be configured to perform the SAR measurements. The measured SAR must be scaled to the maximum control symbol power level and DL:UL symbol ratio according to the power levels of the traffic symbols used during the SAR measurements.

The SAR of this device is measured using a DL:UL symbol ratio of 31:15, consisting of 12 traffic symbols and 3 inactive control symbols. A duty factor of (12 x 102.857μs)/5000μs = 24.69% (or 12/48) is applied by the SAR system to calculate the measured SAR. The *cf* factor, a conversion factor related to 1/(duty factor), used by SAR measurement systems for periodic pulse signal compensation is set to 1/0.2469 = 4.05. If the control symbols were included in the SAR measurements, the difference in power levels between the control and traffic symbols must also be considered according to the SAR system measurement setup to determine if there are other signal/field compensation or conversion issues. The measured SAR using a DL:UL symbol ratio of 31:15 must also be scaled to the maximum DL:UL symbol ratio of 29:18 to account for duty factor differences for determining SAR compliance.

The control channels may occupy up to 5 slots during normal operation. A slot is a sub-channel with the duration of 3 symbols. There are a total of 35 (17) slots in the 10 MHz (5 MHz) channel configuration. The maximum power for each control symbol has been determined to be 28.57 mW (58.82 mW). A maximum of two simultaneous CQICH reports are possible, which can occupy up to 2 slots. A maximum of three slots can be used for HARQ ACK/NAK by the five possible DL HARQ bursts in the previous DL frame. The 5 ACK/NAK bits each occupies ½ a slot. These 5 slots correspond to 5/35 (5/17) of the total number of uplink slots. When the device is transmitting at its maximum rated power of 23 dBm (200 mW), the output power for these control channels is 200 x 5/35 = 28.57 mW (200 x 5/17 = 58.82 mW). For a DL:UL symbol ratio of 29:18, the measured SAR must be scaled by the factor (28.57 x 3 + 200 x 15) / (*actual_output* x 12) = 1.39 (58.82 x 3 + 200 x 15) / (*actual_output* x 12) = 1.43); where *actual_output* is the maximum average conducted power of the traffic burst measured for the corresponding high, middle or low channel and is assumed to be 185 mW in this example calculation. The plot below shows the waveform characteristics of the signal used in the SAR measurement. The pulse duration corresponds to a DL:UL symbol ratio of 31:15 and control symbols are not active. The power leakage for the inactive control symbols in the plot is at least 40 dB lower than the traffic symbols; therefore, the SAR contribution is insignificant. The measured SAR is compensated using a *cf* factor of 4.05, which corresponds to a duty factor of 24.69%.

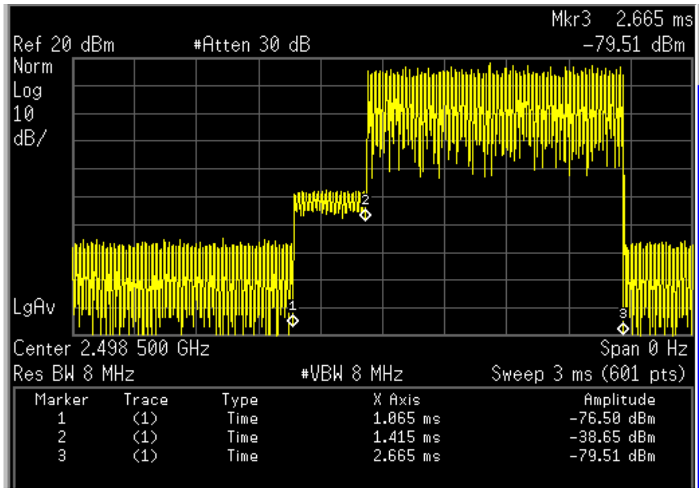


Figure 1: Uplink burst for 31:15 DL:UL symbol ratio with control symbols inactive

A desired SAR test configuration may include both control and traffic symbols configured at their corresponding maximum power levels for the maximum DL:UL symbol ratio. However, if this test configuration is not supported by the test software, test equipment or due to other setup constraints, the highest duty factor achievable using the applicable DL:UL symbol ratios and control symbol configuration must be considered. Testing a device with DL:UL symbol ratios that result in a duty factor higher than required could lead to output saturation issues and render the SAR results meaningless; therefore, must be avoided. On the other hand, testing with DL:UL symbol ratios that lead to too low a duty factor may not be representative of the expected normal maximum output operating range. When tests are configured using test software and signal generator for a 1-way communication link, the control symbols are typically kept inactive and the measured SAR must be scaled accordingly. When the maximum DL:UL symbol ratio is not used, the measured SAR must be scaled with respect to the maximum device and system operating conditions, i.e., worst case DL:UL symbol ratio, to demonstrate compliance.

A4. Test Software Details

The test software is installed on a host laptop computer to configure the test device, a USB dongle, to transmit at maximum output power. During normal operation, the output power of a client device is controlled by a WiMax basestation, which determines the characteristics of the transmission dynamically. For testing purposes, the device output power must be kept at its maximum using manufacturer supplied test software. The uplink transmission (signal characteristics) is maintained at a stable condition by the FCH, UL-MAP and DL-MAP information transmitted over the air from the signal generator. This enables the test device to transmit at maximum power with a constant duty factor according to the selected DL:UL symbol ratio, using a specific modulation, zone type, sub-channel configuration and other operating requirements. The test software for this device serves only one purpose, to configure the test device to transmit at maximum power during the SAR measurements.

Additional information for the supplier or source of the test software should also be included. When highly sophisticated test software is used as the only mechanism to configure and control the device for SAR testing, without a signal generator, details on how the DL:UL symbol ratio, modulation, zone type, sub-channel and other operating parameters are established through the test software are required.

A5. Signal Generator Details

A vector signal generator is used in conjunction with manufacturer supplied chipset test software to configure the test device for the SAR measurements. A #### model #### vector signal generator (VSG) is configured to transmit the downlink signals, containing the respective FCH, DL-MAP and UL-MAP required by the test device to configure the uplink transmissions. The waveform is configured for a DL:UL symbol ratio of 31:15, using the #### Signal Waveform Software with option #### for 802.16 WiMax, on the PC and downloaded to the VSG. The test device can synchronize itself to the signals received from the VSG, both in frequency and time. It then demodulates the DL-MAP and UL-MAP transmitted in each downlink sub-frame and determines the DL:UL symbol ratio (31:15). This downlink burst is repeated in each frame, every 5 ms, to simulate the transmission from a WiMax basestation. The UL-MAP received by the device is used to configure the uplink burst with all data (traffic) symbols and sub-channels active. Since this is a one-way communication configuration, control channel transmission is neither requested nor transmitted in the uplink. Even though a DL:UL symbol ratio of 31:15 is used, the uplink transmission is only active across 12 traffic symbols with the control symbols remain inactive. The measured SAR is scaled to the maximum output power and duty factor corresponding to a DL:UL symbol ratio of 29:18 with 15 traffic and 3 control symbols in the uplink transmission.

For TDD systems, both uplink and downlink transmissions are at the same frequency. The output power of the VSG is kept at least 80 dB lower than the test device to avoid interfering with the SAR measurements. In addition, a horn antenna is used for the VSG and it is kept more than 1 meter away from the test device to further minimize unnecessary pickup by the SAR probe.

Similar explanations and descriptions should be included for other signal generators used to configure the test device for SAR measurements. When necessary, screen captures of the signal generator/software setup parameters and block diagrams should be used to identify test signal characteristics and configurations.

A6. Communication Test Set and Protocol Simulator Details

Test setup descriptions and explanations of using a communication test set or protocol simulator to configure the test device for SAR measurements should be similar to those identified for test software and signal generator. Information for call setup, test signal configuration, operating and transmission parameters, power control, DL:UL symbol ratio, traffic and control symbol details, stability of the test signal and test conditions are necessary to determine if the specific test setup is suitable for making SAR measurements. The test device must be configure to transmit with a periodic duty factor, at the worst case DL:UL symbol ratio with all sub-carriers active and at the corresponding maximum power levels of the traffic and control symbols.

A7. Power Measurement

The measurement of maximum average conducted output power for the uplink bursts using different modulations should have the same setup and device operating configurations used for the SAR measurements. In typical configurations, power is measured with a spectrum analyzer (*identify the model & specifics etc.*) and the device is connected to the vector signal generator through a directional coupler. In TDD, the average power is measured for the uplink bursts through triggering and gating. The resolution bandwidth (kHz) and sweep time (ms) should also be specified to support the power measurement results.

5 MHz Channel BW			
Channel No.	Frequency (MHz)	QPSK (dBm)	16QAM (dBm)
low (----)			
middle (----)			
high (----)			
10 MHz Channel BW			
Channel	Frequency (MHz)	QPSK (dBm)	16QAM (dBm)
low (----)			
middle (----)			
high (----)			

In addition to measuring the maximum average conducted output power for the SAR test configurations, when the worst case DL:UL symbol ratio is not used for the SAR measurements maximum average conducted output power should also be measured for the uplink burst using the maximum DL:UL symbol ratio, zone type, traffic and control symbol power requirements. Depending on the measurement setup and equipment used; for example, power meter or spectrum analyzers, a description of the triggering, gating and other equipment conditions should be described to support the results.

A8. <u>SAR Measurement</u>

In conjunction with the SAR measurement configurations described for WiMax, the USB dongle procedures in KDB Publication 447498 D02 are also applied to test this device. Since it has a swivel USB connector and a swivel antenna, the additional test considerations have been confirmed through a separate KDB inquiry and followed accordingly to perform the measurements. The following is a summary of the SAR measurement results:

5 MHz Channel BW							
Channel No.		High (----)		Middle (----)		Low (----)	
Frequency (MHz)		2499		2600		2687	
SAR (W/kg)		measured	scaled	measured	scaled	measured	scaled
USB horizontal-A	QPSK						
USB horizontal-B							
USB vertical-C							
USB vertical-D							
USB tail/end							
antenna at 90°							
USB horizontal-A	16QAM						
USB horizontal-B		test reduction confirmed				test reduction confirmed	
USB vertical-C		test reduction confirmed		test reduction confirmed		test reduction confirmed	
USB vertical-D		test reduction confirmed				test reduction confirmed	
USB tail/end		test reduction confirmed				test reduction confirmed	
antenna at 90°				test reduction confirmed			
SAR has been measured using a DL:UL symbol ratio of 31:15 consisting of 12 traffic symbols and 3 inactive control symbols. The measured SAR is scaled to a DL:UL symbol ratio of 29:18 consisting of 15 traffic symbols at 200 mW and 3 control symbols at 58.8 mW, according to the maximum average conducted power measured for the 12 traffic symbols on the corresponding channels. Test reduction is applied to the 16QAM configurations, which has been confirmed through KDB inquiry.							

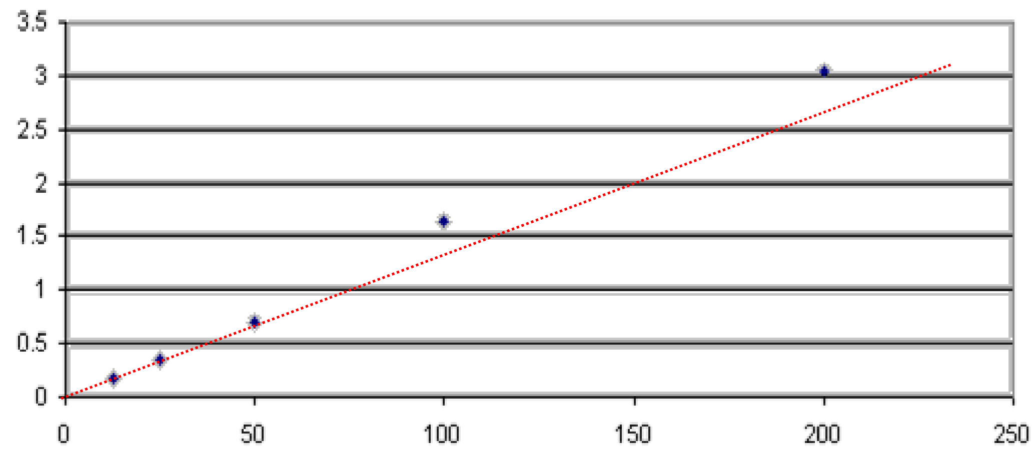
Note: separate tables should be used for different channel bandwidths.

The required test configurations typically vary with device and host platform requirements. A summary of the measured SAR results is required for a PAG request submitted by a TCB. Preliminary SAR measurement results are not necessary for KDB inquiries from a grantee or its test lab concerning WiMax test configurations and requirements. Test reduction is applicable only when it has been accepted through KDB inquiries, which is usually determined according to output power measurement results and other device operating requirements. Without prior KDB confirmation, all normally required test configurations are expected for TCB PAG review.

A9. PAPR and SAR Error Considerations

The SAR probe used in the measurements is calibrated with a sinusoidal CW signal. Since the DL:UL symbol ratio configuration used in the SAR tests provides a periodic uplink burst, the duty factor can be compensated by selecting the correct conversion factor *(cf)* for the SAR measurements. If the duty factor were non-periodic, compensation is typically not possible and substantial SAR measurement error could be expected. The high PAPR of OFDM/OFDMA is expected to introduce additional SAR measurement errors because the SAR probe is not calibrated for this type of random noise-like signals with large amplitude and phase variations within the bursts. The SAR error is also expected to vary with the average power and average PAPR at each measurement point, both temporally and spatially. In order to estimate the measurement error due to PAPR issues, the configuration with the highest SAR in each channel bandwidth and frequency band is measured at various power levels, from approximately 10 mW or less, in 3 dB steps, until the maximum power level is reached. As shown by the results and plot below, SAR is linear to power only when the probe sensors are operating within the square-law region. As power continues to increase, the measured SAR error becomes increasingly larger. Since these are single point peak SAR values measured with the probe positioned at the peak SAR location, at 2 mm from the phantom surface, the values are substantially higher than the 1-g SAR required to determine compliance. The results indicate that at approximately 200 mW SAR could be overestimated by 8 – 10%. This type of measurement error is dependent on the signal characteristics, the results demonstrate that there is no SAR underestimation.

Average Power (mW)	**12.5**	**25**	**50**	**100**	**200**
Single Point SAR (W/kg)	0.181	0.356	0.714	1.65	3.14



A10. Other Relevant or Specific Information

During normal operation, ranging is performed to enable the device to transmit within the correct time references. When ranging occurs, data transmission is disabled. This is necessary to prevent WiMax client devices from transmitting with incorrect timing, which could interfere with other users. Since the average exposure is substantially higher during normal traffic conditions, SAR evaluation is unnecessary for ranging. Bandwidth requests from WiMax client devices are included in the control channels, additional SAR considerations are also unnecessary.