WiMAX FORUM®
WHITEPAPER

RADAR/WiMAX® NETWORK INTERFERENCE MITIGATION

BEST PRACTICES

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1 Introduction

Around the world, national regulatory authorities (NRAs) have authorized the licensing and deployment of fixed and mobile broadband wireless access (BWA) services in the 3.3-3.7 GHz bands. In many instances, licensees have adopted and deployed BWA systems based on IEEE Std 802.16, often employing profiles for this band that have been developed by the WiMAX Forum®.

Meanwhile, in some cases, these bands retain incumbent radiolocation (radar) uses, either in the same administration (country) or in adjacent administrations (countries), based on the authorizing administration and international allocations.[1] The United States Department of Defense and other nations operate several such radar systems in these bands. Based upon previous and ongoing analysis and testing, by military as well as non-military experts, there is a potential for electromagnetic interference (EMI) among WiMAX® networks and radar systems.

This document denotes several techniques that could improve sharing between WiMAX networks and radar systems. The adoption or adaptation and use of these techniques by WiMAX network operators and/or vendors could result in greater compatibility among WiMAX networks and radar systems.

Neither the feasibility nor the practicalities of implementing these techniques have been studied in actual WiMAX network or radar deployment scenarios. Furthermore, some of the techniques listed in this section would need further study. This paper, therefore, is designed to present the possible mitigation techniques as a prelude to further analysis and a foundation for discussion.[2] Discussion of any or all of the mitigation techniques in this paper constitutes neither a recommendation nor an obligation on any party to implement that mitigation technique in any given instance. It is hoped, however, that this white paper will provide information to help guide operators and vendors in attempting to preclude or mitigate interference if and when it occurs.

2 General Characteristics of the Radiolocation Systems

2.1 Parameters for Interference Analysis

Recommendation ITU-R M.1465-1, "Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 3 100-3 700 MHz," contains technical characteristics of the radar systems. The broad parameters of one type of ship-borne radar system in this band, as defined by Recommendation ITU-R M.1465-1, are described in Table 1.

TABLE 1

Table of Characteristics of Radiolocation Systems in the Band 3 100-3 700 MHz

Parameter	Ship systems
Use	Surface and air search
Modulation	Q7N
Tuning range (GHz)	3.1-3.5
Tx power into antenna (kW) (Peak)	4 000-6 400

[1] Parts of the bands in question also are used by fixed satellite service providers as part of what is often called the "extended C-Band." Electromagnetic compatibility issues between WiMAX® networks and FSS are, however, beyond the scope of this paper.

[2] This paper was developed as part of an ongoing dialogue between officials of the U.S. Department of Defense and the WiMAX Forum®.

Pulse width (□s)	6.4-51.2
Repetition rate (kHz)	0.152-6.0
Compression ratio	64-512
Type of compression	CPFSK
Duty cycle (%)	0.8-2.0
Tx bandwidth (MHz) (–3 dB)	4
Antenna gain (dBi)	42
Antenna type	PA
Beamwidth (H,V) (degrees)	1.7, 1.7
Vertical scan type	Random
Maximum vertical scan (degrees)	90
Vertical scan rate (degrees/s)	Not applicable
Horizontal scan type	Random
Maximum horizontal scan (degrees)	360
Horizontal scan rate (degrees/s)	Not applicable
Polarization	V
Rx sensitivity (dBm)	Not available
S/*N* criteria (dB)	Not available
Rx noise figure (dB)	5.0
Rx RF bandwidth (MHz) (–3 dB)	Not available
Rx IF bandwidth (MHz) (–3 dB)	10
Deployment area	Worldwide

2.2 Technical Characteristics

The band 3 100-3 700 MHz is used by radars with installations on land, on ships and on aircraft. In general, the predominant use of mobile radars is on ships and aircraft, while land-based systems are used during military operations or aboard tethered balloons for surveillance over land or coastal areas. Functions performed include searching for near-surface and high altitude airborne objects, sea surveillance, and tracking of airborne objects. Both un-modulated and angle- modulated pulse modulation is employed, and the typical peak transmitter power ranges from 500 kW to 6 400 kW.

In this document, we discuss the ship-borne radar, which is a multi-function radar deployed aboard escort ships. Operational areas of these ship-borne radars include littoral and high seas. These radars are typically operated on a round-the-clock schedule. When providing escort for other ships, it is not uncommon to find up to 10 of these radars operating simultaneously.

2.3 Potential Effects on WiMAX® Systems

High-power S-Band radars operating in the vicinity of 3 300-3 800 MHz WiMAXnetworks may result in degradation of WiMAX system link performance (increased packet error rates, increased frame error rates, and packet delays). High-power radar signals may also overload WiMAX receiver front-ends, causing permanent or temporary disruption of WiMAX network services. Radars may have very low duty cycles as compared to WiMAX system frame rates but radars possess very high peak envelope power (PEP) in order to illuminate distant targets/threats and receive this echo back strong enough that it can be processed. Radar out-of-band (OOB) noise, although very low relative to fundamental peak pulses, is still very high as compared to WiMAX base station or CPE received power levels.

3 General Interference Mitigation Techniques

There are several techniques that could reduce the effects of interference between radars and WiMAX® networks in the 3.3-3.7 GHz band. Generally, these techniques can be categorized as diversity techniques of spatial, frequency, time and phase, understanding that spectrum is generally allocated and assigned solely in the frequency dimension. In general, when sharing in this domain, other diversity techniques can help to mitigate and promote sharing, because diversity comprises all four dimensions (4-D). 3 GHz radars are minimal spectrum users in the 4-D sense, but they perform necessary and critical missions around the world. The need to succeed in finding solutions for compatible operation of radars and WiMAX networks has led to a list of potential mitigation techniques, which include:

1- Reducing potential antenna coupling

2- Beamforming

3- Sector blanking

4- Frequency tunability

5- MIMO implementation in WiMAX® networks

6- Site Shielding

7- Elevation Antenna Beam Down-Tilt

8- Dynamic Spectrum Allocation

These techniques are briefly described in the following sub-sections, and are further discussed in Table 2, along with additional mitigation techniques that may show promise.

3.1 Reducing Antenna Coupling

In general, main beam-to-main beam coupling is rare for scanning radar antennas with narrow beam-widths. However, since the WiMAX antenna does not rotate, main-lobe radar to main-lobe WiMAX coupling is possible. Ship-borne and ground-based radars using narrow pencil beams normally spend much of the time searching regions near and above the horizon. Airborne radars, however, could be looking downward toward the ground. Consequently, the antenna coupling situations that are normally of concern are:

-Radar side lobes to WiMAX side lobes;

-Radar main lobe to WiMAX side lobes; and

-Radar side lobes to WiMAX main beam.

Separation distance and antenna pattern nulling usually mitigate antenna coupling.

3.2 Beamforming

Downlink antenna beamforming is a technique in which the gain pattern of an adaptive array is steered to a desired direction through either beam steering or null steering signal processing algorithms. When these algorithms are implemented using a digital signal processor, we refer to them as *digital beamforming*. This allows the antenna system to focus the maxima of the antenna pattern towards the desired user while minimizing the impact of noise, interference and other effects from undesired users that can degrade signal quality. Adaptive beamforming can be used by WiMAX systems; its effectiveness may depend on the application.

In a multi-user environment, an improvement in performance is observed due to the fact that an adaptive beam forms the maxima towards the desired signal and at the same time tries to steer nulls towards the interfering signals, thus reducing co-channel interference. Note that the beam pattern of both receive and transmit antennas can vary. Therefore, the set of nodes with which a given node can close a direct link depends on the beam patterns for both transmission and reception.

Antenna pattern nulling is effective for small numbers of strong interferers. For example, if a strong interfering signal is present at a specific location, that signal may be nulled-out using this method. However, doing this will also reduce the reception capability of the good signal in the same direction.

Downlink sub-sectorization is an alternative to downlink adaptive beamforming. Fixed beamforming over major groups is the method of choice for implementing sub-sectorization.

In uplink, WiMAX technology supports techniques to effectively enable uplink interference cancelation. More specifically, capabilities such as disabling subchannel rotation allows for better channel estimation and interference cancellation, reducing implementation loss and noise rise in WiMAX systems.

3.3 Sector Blanking

The aim of this technique is to reduce, in the direction of the victim system, the transmitting output power. Generally, WiMAXbase stations utilize multi-sectoral antennas. Accordingly, one way to reduce the potential for interference could be to use frequency planning for the WiMAX base stations such that an antenna sector that points towards the radar is not using the same frequency. Application to any particular system will highly depend on the frequencies available and the capabilities of the system. For example, interference to WiMAX base stations located in littoral areas could be reduced by sector blanking in the direction towards international waterways. Sector blanking may be associated with a receiver, as well.

3.4 Frequency Tunability

The ability of the WiMAX base station to retune its transmitted frequency due to observed interference could be useful in mitigating the interference effects. Many operators purchase several frequencies next to each other. However, if operators knew that vendors could make WiMAX equipment shift frequencies when interference was present, they might purchase spectrum in a different manner. This could also provide operators with self-configuring spectrum operation, instead of manually setting up cell sites, as the radios would use only the operators' specified frequencies, allowing the radios to interoperate without interference.

3.5 MIMO Implementation in WiMAX® networks

In order to improve sharing between WiMAX networks and radars, WiMAX systems could utilize an interference mitigation technology known as MIMO (Multiple Input, Multiple Output) SDMA (Space Division Multiple Access). Through this technique, a gain reduction in the base station transmit antenna diagram could be generated towards the interfered radar system (this would work better for fixed or slow-moving radars). MIMO can also reduce the minimum required separation distance. Like the sector-disabling technique, this approach would require the use of other frequencies to cover the area where the base transmit antenna gain is reduced. Space/time block coding could also be used to enhance the interference rejection to WiMAX networks.

3.6 Site Shielding

Site shielding isolation can be obtained by providing physical or natural shielding at the WiMAX base stations.

3.7 Elevation Antenna Beam Down-Tilt

A possible mitigation technique to improve sharing is antenna down-tilting at the WiMAX base stations. In the deployment scenarios envisaged in WiMAX systems, the cell size will be reduced to support high-speed transmissions, assuming a limitation of transmission power. Deployment based on a small cell size is also indispensable for WiMAX systems in order to achieve high frequency efficiency. Since the degree of antenna downtilting will be increased in the case of a small cell size, in order to avoid inter-cell interference in WiMAX systems using the frequency reuse, this will also result in the reduction of interference from a WiMAX base station to the radar and the reduction of the minimum required separation distance.

By increasing the downtilt of the base station antenna, there is a potential for an increase of the number of WiMAX base stations required to provide service in a given area and for a decrease of transmission power per WiMAX base station. Accordingly, when computing aggregate interference into a radar system, these two elements would have to be taken into account.

3.8 Dynamic Spectrum Allocation

The distribution of radio spectrum resources could either be static or dynamic, depending on the local situation in a given area. In areas where not all the frequency resources are fully utilized, a mechanism could be developed to dynamically inform WiMAX systems which bands may be utilized. Whenever a radar must change its operational frequency, the WiMAX system may also have to change its frequency in the surrounding area.

A way for the administration to provide such information to the WiMAX network operators and radar system operators may be to have a database containing all relevant information about the current services or stations using the radio resources in the area. The database would need to be up-to-date and would have to include information such as central carrier frequency, channel bandwidth, etc. The administration would have to develop or modify its regulatory framework and laws to accommodate such licensed operations.

This method, however, is very complex due to the nature of the type of radar and WiMAX systems and the way they are deployed. The technique will be limited by the amount of spectrum issued to the WiMAX network and radiolocation license holders.

3.9 Higher Layer Interference Mitigation

Methods previously described in this section are based on spectrum management and the PHY layer design; other network layers may also provide means to enhance compatibility between WiMAX networks and radar operations. Even when interference is detected at the PHY layer, the upper layer(s) may provide efficient features such as Radio Resource Management (RRM) for interference mitigation, e.g. sensing algorithms and measurement data in the mobile station as well as in the base station to reliably detect and measure interference conditions. Based on RRM and the sensed interference information, more effective use of mitigation techniques may be possible. The ongoing standardization activities on Device Reported Measurements and Diagnostics (DRMD) as well as in IEEE Std 802.16m lay the foundation enabling introduction of appropriate functions into the specifications

4 Summary Table of Potential Interference Mitigation Techniques

The potential interference mitigation techniques that may be applied to WiMAX® systems are summarized in this section in TABLE 2. It should be noted that some of the mitigation techniques already may be implemented in order to reduce WiMAX systems’ interference with other WiMAX networks.

TABLE 2

Possible Interference Mitigation Techniques

Mitigation Technique	Comments
Antenna Location, Optimization of Antenna Directivity Loss Toward Radar Site	▪ Considering the geographic conditions, WiMAX base station antennas may be located in areas where natural or man-made shielding minimizes interference from/to the radar antennas. ▪ In some cases, the building/terrain attenuation can be expected to be between 0 and 20 dB. ▪ Not universally applicable; in areas where this technique is applicable, detailed site engineering would be required. ▪ WiMAX system antennas may be configured such that the antenna back lobes are facing the same areas where the radar may be located.
Beamforming / MiMO Implementation in WiMAX® networks	▪ An antenna pattern null may be steered toward the radar or WiMAX base station site direction to reduce the interference by adopting dynamic beamforming antenna such as dynamic adaptive array antenna. (This bullet applies to WiMAX systems with smart API antennas). ▪ The level of interference mitigation is a function of the number of antenna elements and the propagation effects. ▪ The receive antenna radiation pattern can be shaped to create a null in direction of the radar. ▪ This technique would need significant development work for advanced / smart antenna systems. ▪ Approach would require use of other frequencies or base stations to provide coverage and would reduce performance/spectral efficiency of WiMAX systems.
Dynamic Spectrum Allocation	▪ This technique may reduce interference between the WiMAX networks and radar systems by avoiding the use of, or vacating, a channel that is identified as being occupied based on cognitive signals detection of a radar at the WiMAX system or on database methods. ▪ Methods outlined in subclause 6.3.15 of IEEE Std 802.16 would be applicable to dynamic spectrum allocation approaches. ▪ The effectiveness of this technique is highly dependent upon the amount of spectrum issued to the licensee. ▪ Automatic re-planning of the spectrum use over a licensed network is complex and would require significant effort to develop. ▪ Use of such a technique would reduce the capacity of the spectrum a license holder has obtained. ▪ Dynamic Frequency Selection may be an acceptable alternative for unlicensed devices, since the spectrum is obtained free of charge.
Elevation Antenna Beam Down-Tilt	▪ Interference reduction will highly depend on the vertical antenna beam pattern. ▪ Some down-tilt is already used in network planning to reduce inter-cell interference in WiMAX® systems for efficient use of frequency resources. ▪ Changing antenna tilts may not be possible in already deployed systems, as adding additional down-tilt would increase number of base stations need to cover the same geographic area.

Mitigation Technique	Comments
Forward Error-Correction (FEC) And Interleaving	▪ Forward Error Correction (FEC) coding and bit interleaving may help in reducing the susceptibility of the WiMAX receiver to interference from the radar. ▪ In military communications systems, robust FEC has been proven to reduce radar interference. Investigation and comparison of the applicability to WiMAX systems would be required. ▪ FEC has been very effective in mitigating low-duty-factor EMI in other systems, where the peak EMI levels were up to 30 to 40 dB greater than the desired signal level. ▪ WiMAX systems already have this feature built-in; changes to the encoder and interleaver are difficult, so any additional gains to mitigation may be limited.
Frequency Planning	▪ For adjacent frequency spectrum, it maybe possible for WiMAX base stations to use spectrum that is as far away as possible from radars that might be a source of interference. ▪ Fixed WiMAX networks in 3.4-3.6 GHz band if deployed in point-to-point mode, as a backhaul network, or in small femtocells / microcells would help limit interference. ▪ Limiting WiMAX networks in 3.4-3.6 GHz to point-to-point , backhaul, or in small femtocells / microcells is counter to current deployments which are using the band for broadband coverage and mobile use over a wide areas. ▪ Would need to understand radar use scenario along with WiMAX network frequency planning process by operators to understand level of applicability.
Frequency Tunability	▪ Automatic re-planning of the spectrum use over a network is complex and would need automated tools and algorithms developed to not only take into account the maximization of spectrum allocated to the network operator but to also minimize interference."
Higher Gain Subscriber Antennas	• Using meta-material technologies, higher-gain antennas could be developed to increase the overall EIRP of present WiMAX network subscribers. • Meta-materials are becoming practical for narrow frequency ranges. • For fixed WiMAX systems at a set frequency and bandwidth, a meta-material antenna could boost the gain of the antenna. • For a fixed WiMAX network user at a set frequency and bandwidth, a meta-material antenna can be developed to boost the gain of the antenna by ten-fold, or more, while keeping the antenna size the same. • However, higher subscriber antenna gain may increase interference to radar and the whole WiMAX system would have to be rebalanced. • Impact to mass-produced subscriber devices of multiple form factors would need to be understood to evaluate applicability; issues include cost, form factor, exposure requirements.
Higher Layer Interference Mitigation	▪ Radio Resource Management / Device Reported Measurements and Diagnostics may improve algorithms / methods used to more efficiently reduce potential for interference.

Mitigation Technique	Comments
Lower Antenna Height	▪ Lower base station antenna heights in littoral areas could reduce interference from ship-borne radars. ▪ Variations in antenna height are already in use to reduce interference between base stations within WiMAX systems deployed in dense areas where demand is high. ▪ It may not be possible to lower the macro cell below a 30-meter height; otherwise cell coverage may be degraded. ▪ Would require more base stations to cover same geographic area and could increase deployment costs.
Receiver Filters and Limiters	▪ For WiMAXBase Stations in littoral areas, special receiver filters may be useful to lower interference into WiMAX networks. These filters could have steep roll-off, if technology permits, and may provide better protection against known out-of-band radar interference. ▪ WiMAX basestations in littoral areas may also benefit from limiters or LNAs that can withstand high power signals. ▪ Would need to evaluate economic impact to WiMAX networks of use of such filters.
Reduced Potential Antenna Coupling	▪ Multiple techniques to achieve and include: Elevation Antenna Beam Down Tilt, Lower Antenna Height, Antenna Location and optimization of antenna directivity loss toward radar site, Antenna Pattern Dynamic Null Steering, Beamforming and Sector Blanking ▪ Main lobe to main lobe coupling is rare, more common will be side-lobe to main lobe and side-lobe to side lobe interactions.
Reducing WiMAX® Cell Size	▪ A reduced WiMAX network cell size would establish a high carrier-to-noise plus interference ratio that would be less susceptible to radar interference. However, a reduction in cell sizes would require increased base station deployment and possibly cause an increase in the aggregate interference to the radar. ▪ Would increase cost of WiMAX network deployment.
Sector Blanking	▪ Frequency planning required providing reduced interference will impact flexibility to deploy a WiMAX Network. ▪ Will require knowledge of planned frequency use of radar systems and may be of limited success in mitigation to mobile radar platforms.
Site Shielding	▪ Site shielding would reduce the coverage area provided by a WiMAX base station ▪ Method could be applied to both the WiMAX base station and a radar transmitter.
Timed transmission	• WiMAX networks have frame lengths set for 5 ms, uplink and downlink for TDD and HFDD systems. If timing could be synchronized between a WiMAX system and radar system, it could create a window for shared use of spectrum in the time domain. This window also would have to be timed with a universal standard such as GPS for accuracy. This technique requires further investigation and would not be applicable to all the radar platforms and their operating requirements. • Would need significant work within IEEE and WiMAX Forum to understand the overall system impact • Would need to quantify the impact to spectrum efficiency and capacity of the WiMAX network.

Mitigation Technique	Comments
Transmit Mask / Filters	▪ If possible, WiMAX transmitter may add a transmit filter, sufficiently narrow, that can reduce the out-of-band emissions of the transmitter. ▪ The transmit mask spectral emissions can also be reduced by using pre-distortion linearization of power amplifiers. ▪ These would allow more WiMAX base stations to share the limited spectrum in the 3.4-3.6 GHz band. One of the issues for WiMAX networks is that if the uplink signals are increased, there could be mutual EMI problems between base stations and other users in the band, because of the limited number of available frequencies in this band. ▪ The transmit masks' spectral emissions can also be reduced by using pre-distortion linearization of power amplifiers, which are currently available and can provide up to 20 to 40 dB of improvement. ▪ Would need to evaluate economic impact to WiMAX networks on the use of such filters
Transmit Power Control	▪ Setting the transmission power of WiMAX base stations to the minimum required level when a radar signal is detected could reduce interference. ▪ Techniques to detect radar signals would need to be understood; currently systems would not perform radar detection.
WiMAX® receivers adaptive radar pulse processor	• WiMAX receivers contain A/D converters and signal processing. With faster and higher resolution A/D converters and cost effectiveness of signal processing, along with speeds of FPGAs, radar signals could be processed out of WiMAX OFDM signals without loss of data. • With the known pulse timing and width of radar signals, and the known OFDM or OFDMA signals, a small amount of memory and FPGA's could process out radar signals without loss of packet data.
WiMAX® Set Receive Levels	• WiMAX base stations could request from subscribers a transmit level such that the base station receive level would be higher (e.g., -60dBm versus -70dBm). • This option would require subscribers to transmit higher power levels (EIRP) for the same coverage, requiring either amplifiers with higher power or higher gain antennas. • For mobile WiMAX receivers, a higher power request would result in decreased battery life, a potential for more interference to radar systems and increased costs for devices. However, radar has a very low duty cycle and repeat rate, such that power requests would be very infrequent.