Project	**IEEE 802.16.3 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**A Proposal for a 5.2/5.8 GHz License-Exempt (LE) WirelessHUMAN™ Network Standard Based on Modified IEEE 802.11a PHY and IEEE 802.16.1 MAC Standards**
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Re:	IEEE 802.16.4 WirelessHUMAN request for proposals
Abstract	This proposal discusses a wireless network system composed of autonomous/adaptive wireless base stations controlling a large constellation of oblong microcells. Data communications within a microcell is mediated using modified IEEE 802.11a PHY and IEEE 802.16.1 MAC standards. A BS Network Controller is used to oversee the allocation of frequencies amongst microcells of the base station, detect co-channel interference, and control the EIRP of the microcells.
Purpose	To initiate discussion within the IEEE 802.16.4 committee. To propose the development of a common set of MAC and PHY standards and a new RF PHY layer that will oversee the operation of wireless network terminals having adaptive qualities and being capable of autonomous operation in a controlled co-channel interference environment.
Notice	
Release	
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A Proposal for a 5.2/5.8 GHz License-Exempt (LE) WirelessHUMAN Network Standard Based on Modified IEEE 802.11a PHY and IEEE 802.16.1 MAC Standard

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1.0 Introduction

In the first part of this document we describe the RF configuration of a new type of 5 GHz Wireless MAN and how the existing IEEE 802.11a and proposed IEEE 802.16.1 Standards can be modified to meet the requirements of the new network. In the second half we attempt to address some of the specific issues raised in the IEEE 802.16.4 Call for Proposals.

2.0 Proposed RF Structure with MAC/PHY Layer Modifications

2.1 Overview of Proposal at the RF Physical Layer

It is proposed that a specification be developed for a 5 GHz License-Exempt wireless metropolitan area network (MAN) architecture that would embody an etiquette allowing a diversity of service providers to co-exist. The etiquette would operate at the RF network level and would be a series of equipment rules and operating conditions that would dynamically limit co-channel interference.

It is proposed that the basic building block of this architecture be a highly sectored macrocell containing from 24 to 35 oblong microcells arranged concentrically around a base station. The macrocell is called a rosette and the oblong microcells are called petals. Within a rosette a single channel is re-used 6 or 7 times. The petals are created by using highly directive antennas having fixed beams and very low sidelobe levels. Such characteristics electromagnetically isolate petals from each other, thereby allowing a high degree of frequency re-use.

The rosettes could be deployed within urban or rural neighbourhoods and would typically be mounted on power poles or small buildings. High speed wireless service would be provided over a radius of 750-1000 meters in a NLOS environment containing foliage and some obstructions. In environments having fewer obstructions, a range of 5-10 or more kilometers may be possible. The rosettes would be autonomous units, containing a switch or router within the base station which would mediate TCP/IP traffic amongst wireless subscriber users within the coverage area. Individual rosettes could also be connected to a high speed millimeter wave or optical backbone, giving the subscribers connectivity to a much larger network with access to such resources as VOIP PBX s, video servers, and the WWW.

A network control computer located inside the base station would assign channels to the petals of the rosette according to a co-channel interference mitigation algorithm. The algorithm would require information such as the sensing of other 5 GHz terminals and data from the adjacent rosettes; such as their GPS location, propagation path loss and location characteristics of the terminals within the adjacent rosette, and the channel assignment scheme of the adjacent rosettes petals. With such information the network control computer could assign channels to its own petals in a manner that minimizes interference to other terminals. In some instances the control algorithm would not activate some petals because of the high likelihood of causing interference to close-by users. In essence a de facto etiquette amongst rosettes would be exercised at the radio frequency network level.

In addition to such dynamic control processes, co-channel interference is further mitigated by the use of highly directive low side lobe antennas, both at the subscriber and the base station. Furthermore, the urban propagation environment is also expected to limit interference. Typically, the urban outdoor environment has a propagation path loss exponent of 2.8-3.0; also, this exponent increases with distance.

We feel that the antenna which generates the oblong shape of the petal should have a gain of about 17-20 dBi and a —3 dB beamwidth of 10-15 degrees in azimuth. Such characteristics are typical of antennas that have the largest dimension of their apertures in the order of 25 to 35 cms. When these antennas are stacked they produce base stations having diameters of 40-60 cm and heights of 1.5 to 2 meters. Subscriber antennas would typically have apertures of 25-35 cm. We have used modified DVB satellite parabolic dishes to achieve beamwidths of 8 degrees, gains of 26 dBi, and sidelobe levels of —35 dB. Dielectric Resonator antennas with 35 X 12 cm apertures have produced similar beamwidths with gains of about 15 dBi.

FCC EIRP limitations of 17 dBm/MHz and 23 dBm/MHz on respectively the lower and upper 5 GHz bands [Ref.3] limit the distance over which the subscriber and the rosette base station can communicate. Assuming gains of 20 dBi for the base station antenna, only 3 dBm/MHz output power spectral density would be required from the transmitter amplifier. It is felt that 500 milliwatt transmitting amplifier is all that is required to meet the FCC EIRP requirements. Such a transmitter would provide about 10 dB of backoff, ensuring linear performance of the OFDM modulation stipulated by the IEEE 802.11a specification.

We feel that the hardware required to implement both the subscriber and base station terminals can be low cost and is amenable to consumer market applications especially since it will be based on IEEE 802.11a technology. We do not expect significant differences in the technology used at the base station and subscriber ends of the link and the cost of the base station is not expected to be excessive.

The MAC/PHY layer for the proposed network architecture is based on IEEE 802.11a PHY [Ref. 1] and 802.16 MAC [Ref. 2] standards. We propose integrate modified parts of these two standard layers into a wireless MAN system that employs time-division-duplexing (TDD) and time-division-multiplexing (TDM).

2.2 Overview of IEEE 802.11a Physical Signaling Layer (PHY)

The 802.11a standard was developed to provide a wireless LAN with speeds up to 54Mb/s in the 5.7-5.8GHz U-NII bands. 802.11a employs TDD and TDM with collision detection and avoidance at the MAC level. It occupies a single channel of 16.6MHz. Modulation is OFDM with 52 carriers out of which 48 are used to carry data and 4 are pilots; each OFDM symbols takes 4µs out of which 3.2µs are used to carry data and 0.8µs are used as guard interval (cyclic prefix). The communication takes place in bursts (or packets) that are called frames in 802.11a. We will use PHY frame when referring to such a burst to distinguish between MAC and PHY frames.

A PHY frame consists in a preamble of 16µs, a SIGNAL field of 4µs and a DATA field with a variable number of OFDM symbols. The PHY frame is self-contained, having enough information for the receiver to synchronize, equalize and decode it. The first 8µs in the preamble are used to acquire the automatic gain control (AGC), coarse frequency offset recovery and coarse synchronization. The next 8µs are used for fine offset recovery and synchronization. The last 4µs are also used for channel equalization. During SIGNAL and DATA fields, frequency and symbol synchronization can be tracked using the 4 pilots whose combined signal-to-noise (SNR) has a 12dB improvement over data carriers. The OFDM channel equalizer (one tap FIR on each carrier) is easy to implement, it can be initialized in one OFDM symbol and it can track quick channel changes. The SIGNAL field transports the length of the packet (in bytes) and the transmission rate (6, 9, 12, 18, 24, 36, 48 or 54Mb/s). Thus, each data packet can be fully decoded at the receiver without any contribution at the MAC level. The DATA field contains 16bits for the SERVICE field, the true payload data, 6bits for TAIL and padding (used to fill up to an integer number of OFDM symbols).

Overall, the 802.11a PHY provides great robustness, packet independence and multi-path immunity (up to 0.8µs o r 240m). These properties make it a strong candidate for operation in the unlicensed bands. Note that, for long distance communication, the use of directional antennas shortens the multi-path. Thus we think a guard interval of 0.8µs should be enough for MAN applications, too.

2.3 IEEE 802.16.1 Media Access Control Layer (MAC)

The 802.16.1 MAC is designated for long distance point-to-multipoint wireless links. It supports QoS for real-time traffic and it is connection oriented, thus providing increased efficiency through header reduction. The entire traffic (uplink and downlink) is controlled by and goes through the BS. It supports already several different PHY layers and access schemes with both TDD and FDD. In the following we detail the operation of the 802.16 MAC with TDD/TDM, which we believe is a strong candidate for operation in the unlicensed band in conjunction with 802.11 PHY.

In the 802.16 MAC (with TDD/TDM) the basic data exchange is grouped in frames, called hereby MAC frames to distinguish between MAC and PHY frames. One frame consists in one downlink subframe and one uplink subframe separated by Tx/Rx Transition Gap. The uplink subframe is further divided into three portions: Registration Contention, Bandwidth (BW) Request Contention and scheduled uplink data. The downlink subframe contains MAC control – e.g. DL (downlink) Map and UL (uplink) Map – and payload data for various SS's, multiplexed in time (TDD) in a contiguous RF burst. Registration Contention is reserved for SS's that do not have a known round-trip delay and want to enter the network. Therefore, the Registration Contention includes the maximum allowed round-trip delay in addition to the required time-slots. BW Request Contention is reserved for registered stations (with known round-trip delay) that want additional uplink BW. The scheduled uplink consists in SS's bursts according to the schedule established by the BS in the UL Map. Upon transition between one SS to another on the uplink, a CPE Transition Gap is inserted.

In the following sections we analyze the feasibility of a TDD/TDM system based on the 802.11a PHY and 802.16 MAC. We detail the changes needed to adapt 802.11a PHY to the scope of 802.16.1 We also outline changes required to 802.16.1 MAC for efficient operation in the unlicensed bands with an 802.11a PHY.

2.4 RF Rationale for TDD

The main advantage of TDD in the U-NII band is that both the uplink and the downlink can operate at the same frequency, thereby allowing the development of techniques which can immediately monitor the condition of the channel, thereby allowing enhanced error control and limiting frame (or packet) loss. The channel monitoring and interference avoidance techniques that the BS Control Computer will execute will be simplified in comparison to FDD operation.

Other benefits over FDD operation include the simpler implementation of the high power amplifier and improved noise figure performance for the receiver sections of the subscriber terminals. The one limitation of TDD operating in the rosette architecture is that all petals within the rosette must have synchronized transmission and reception durations in an 802.11a frame. This is to prevent interference between like-channel petals of the rosette. The ratio of tx/rx duration is adjustable. Considering that most TCP/IP traffic is highly asymmetric the traffic imbalance between petals may not result in any significant loss in data delivery efficiency under TDD operation.

2.5 PHY Preamble Overhead Modifications

Because of TDD/TDM operation, both the uplink and the downlink must operate in a burst mode. The burst (or packet) mode requires re-synchronization, re-equalization, etc. for each packet. Therefore the preamble shall be transmitted with each data packet requiring an additional overhead. Here, the advantage of OFDM is that it requires only one symbol for equalization as opposed to rather long training sequences used with other modulations. In 802.11a PHY, the preamble required for automatic gain control (AGC), synchronization, carrier-offset recovery and equalization occur over the space of only 4 OFDM symbols (16μs). However, in addition to this, each packet in 802.11a PHY has a 16-bit SERVICE field, out of which only 7 bits are used to initialize the scrambler. We propose to use the other 9 bits to transport useful data. This is particularly important when using the lowest data rate (6Mb/s), where the overhead caused by SERVICE and TAIL (6 bits used to return the convolutional en/decoder to zero) fields amounts to a full OFDM symbol (4μs). Using the service bits could result in shortening the airtime for the MAC control packets.

Another place where the overhead can be reduced is within concatenated packets. On the downlink, since the channel may be different from subscriber to subscriber, different destinations may require different rates. This means that downlink will contain several 802.11a PHY frames, preferably concatenated (i.e. with no space between them). Since AGC, synchronization and carrier-offset recovery are only required for the first PHY frame (once set, they can be tracked using the 4 pilots), we propose to shorten the PHY preamble for the other PHY frames in the downlink such that it consists of only the last 4μs of the 802.11a preamble. This will provide enough information to refresh the equalization, so the PHY frames remain statistically independent. In terms of implementation this requires a minor change from 802.11a. To support this feature, we suggest to use a reserved bit (see below) in the SIGNAL field to specify if the current PHY frame is the last one or is followed by another PHY frame with shortened preamble. If we were to concatenate complete 802.11a frames, the implementation would be more difficult due to longer processing delay. For example, a new packet can enter the synchronization block even before having decoded the SIGNAL field from the previous packet.

2.6 PHY Duration

Since duration of an OFDM symbol in 802.11a PHY is 4μs (3.2μs data + 0.8μs cyclic prefix), the basic time allocation unit in the proposed 802.16.4 shall be also 4μs. Note that the PHY preamble duration is also multiple of 4μs. This change will apply also to the Tx/Rx and CPE Transition Gaps. It will affect also the structure of the DL Map and UL Map, where BW allocation shall be redefined in terms of the PHY rate and number of OFDM symbols. However, having higher granularity will significantly reduce the overhead caused by the MAC management messages and some MAC headers.

2.7 Clear Channel Assessment (CCA) function

The Clear Channel Assessment (CCA) function in the 802.11a PHY is not required by the 802.16.4 MAC. However, the hardware associated with this function can be used to assess the channel interference during Tx/Rx and CPE Transition Gaps. This may prove extremely useful to assess the available data rate for a certain connection in an unlicensed environment. For each received PHY frame, the modified 802.11a PHY shall report to the MAC the interference level immediately before the frame on the same scale it uses to report the received signal strength indicator (RSSI). As a consequence, the Clear Channel Assessment (CCA) function is not needed and shall be removed. It shall be replaced by the Received Interference Level Indicator (RILI) defined below.

2.8 Received Interference Level Indicator (RILI)

A new parameter called Received Interference Level Indicator (RILI) shall be added to the parameters reported by the PHY layer in RXVECTOR. The receiver shall detect and memorize the signal level within the 4µs prior to the first symbol in the preamble. It shall report this level as RXVECTOR.RILI. The scale of RILI and RSSI shall be the same. The PHY layer shall report the scale of these parameters (in dB) to the MAC upon initialization.

2.9 TXPWR_LEVEL parameter

The resolution of the transmit-power control (TXPWR_LEVEL) for the 802.11a PHY (only 8 levels) shall be increased to allow fine power control. This particularly important for the uplink where power control shall be employed to equalize the received signal strength at the BS. Also, there should be a fixed relationship between RSSI and TXPWR_LVL to allow simple power control. The range of TXPWR_LEVEL parameter in TXVECTOR shall be enlarged to allow better resolution. The PHY layer shall report the ratio between the scale of TXPWR_LEVEL and RSSI/RILI to the MAC upon initialization.

2.10 PLCP Header — SIGNAL field

The reserved bit R (bit 4) in the SIGNAL field shall be renamed TX_CONCAT and it shall used to specify if the current PHY frame is or is not followed by a frame with shortened preamble. The meaning of this bit is described below.

- SIGNAL.TX_CONCAT = 1 – a PHY frame with a shortened preamble follows the current frame.

- SIGNAL.TX_CONCAT = 0 – this is the last PHY frame in the sequence.

2.11 PLCP Header — SERVICE field

In 802.11a, the first 7 bits in the SERVICE field (16 bits) are used for (de)scrambler initialization and the other 9 bits are reserved. The last 8 bits in the SERVICE field shall be allocated for DATA leaving only 1 reserved bit.

2.12 Transmitting concatenated PHY frames

A new parameter called TX_CONCAT shall be added to parameters of the transmit procedure in TXVECTOR. This parameter has to possible values:

- TXVECTOR.TX_CONCAT = 1 – a PHY frame with a shortened preamble follows the current frame.
- TXVECTOR.TX_CONCAT = 0 – this is the last PHY frame in the sequence.

This parameter shall be copied in the SIGNAL.TX_CONCAT bit. When TX_CONCAT = 0, the transmit procedure shall end as described in 802.11a. When TX_CONCAT = 1, the transmit procedure, upon finishing the OFDM symbols in the current frame shall start transmitting the last 4μs of the preamble, waiting for the MAC to initiate the transmit procedure of the next PHY. Upon, receiving the TXVECTOR parameters of the next PHY frame, the PHY layer shall produce the SIGNAL field, followed by the DATA field.

2.13 Receiving concatenated PHY frames

Upon receiving the last OFDM symbol in a frame, the PHY layer shall look at the TX_CONCAT bit in the SIGNAL field. If SIGNAL.TX_CONCAT = 0, the PHY layer shall proceed as described in 802.11a standard. If SIGNAL.TX_CONCAT = 1, it shall not reinitialize the synchronization machines after receiving the last symbol in the current frame. Instead it shall use the first 4μs after the end of the current frame to reinitialize the channel equalizer, the next 4μs to decode the SIGNAL field, etc.

2.14 Summary of changes to 802.16 MAC

- Time allocation unit, Rx/Rx Transition Gap and CPE Transition Gab shall be 4μs.
- The duration of the 802.16 frame shall be allowed larger values, e.g. 4ms, 8ms and 16ms in addition to 0.5ms, 1ms and 2ms.
- If the downlink subframe of a MAC frame contains payload with different rates, then the payload shall be sorted and grouped in ascending order of the rates.
- Payload with same rate shall be grouped in the same PHY frame. When requesting transmission of PHY frame, the MAC shall specify whether this is or is not the last frame in the sequence.

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3.0 Issues Specifically Raised in the IEEE 802.16.4 Call for Proposals

3.1 Operation in the Presence of Interference in MAN environments

The rosette architecture deals with interference in the following manner:

- By the of use highly directive low side lobe antennas at the subscriber and base station terminals which limit the amount of co-channel interference produced to other terminals. Outdoor terminals compliant with IEEE 802.11a but possessing omnidirectional antennas will produce more co-channel interference to themselves than would the terminals proposed herein. Ref. 5 provides more details concerning this.

- Within the rosette, the Base Station Control Computer, prior to activating the base station and radiating power, monitors the local environment for other non-IEEE 802.16.4 terminals. Petals in which other terminals are detected would either be assigned non-interfering channels or remain inactive.

- The most recently installed rosette in a service area would be forced to choose a radiation channel plan which would minimize interference to older, adjacent rosettes. This plan would be determined by an algorithm using criteria based on propagation characteristics, base station locations, direction of radiation of petals for which potential co-channel interference could exist, etc. Some of the information needed to make such decisions would be taken from datagrams that all rosette base stations broadcast on the forward channel, or would be found at a URL.

- Interference from terrestrial wireless data systems into the earth imaging satellite systems operating in the 5250-5350 MHz band must be minimized. If there is no effort to do this then indications are that the Space Imaging lobbies at the ITU and WARC will more actively seek a ban on 5.25-5.35 GHz outdoor terminals. Inclusion of directivity and low side-lobe level emission requirements on outdoor 5.25-5.35 GHz terminals is a positive step in dealing with the concerns raised by the Space Imaging community.

3.2 Modification to the 802.11a Frequency Plan

The proposed system can be used in two License-Exempt 5 GHz channel bands that are available for outdoor applications. These bands are each 100 MHz wide at 5250-5350 MHz and 5725-5825 MHz.

It is proposed that each 100 MHz band contain 4 OFDM channels as specified in the IEEE 802.11a., where the band centres are separated by 20 MHz. The —3 dB modulated bandwith is somewhat less at 16.6 MHz. Thus, in the IEEE 802.11a standard, approximately 3.4 MHz of guard band is provided between the modulated spectra (-3 dB rolloff edges)

With the 4 channel frequency plan, the upper band shall have 4 OFDM channels centered each at 5745, 5765, 5785 5805 MHz. In the lower band the 4 channels would be centered at 5260, 5280, 5300, and 5320 MHz.

Also, a 5 channel frequency plan is proposed in which the OFDM spectra are placed closer to each other. A 17.5 MHz channel spacing plan is proposed. In this scheme there is only 0.9 MHz of guard band between modulation spectra; however, using the rosette scheme, there would never be any instances of adjacent petals containing adjacent channels, i.e., there would always be a 1 channel space between the channels used in adjacent petals.

A 5 channel frequency plan would increase the capacity of the rosette and would improve co-channel interference mitigation options when the rosettes are virtually rotated with respect to each other. This scheme would however necessitate sharper filtering in the hardware in order to comply with the FCC out of band emission requirements. We feel this is achievable using current IF signal processing techniques.

With a 5 frequency channel plan the centres of the channels would be at 5740.0, 5757.5, 5775.0, 5792.5 and 5810.0 MHz.

3.3 Accommodation of Increased Multipath and Propagation Delay.

The link budgets indicate that in a foliated environment with a PLE of 2.8-3.2, the separation between the base station and subscriber terminals will only be in the order of 1000 meters, given current FCC requirements. In LOS conditions, with a PLE of ~2.3, this distance may increase to 7000 meters.

The use of antennas having beam widths of ~ 15 degrees will do much to limit delay spread and multipath. Delay spread will be in the order of 30 nanoseconds for path lengths of 1 km. or less. At 7 Km, the spread with be in the order of 0.2 microseconds. Such spreads are trivial to the multipath amelioration capabilities of the IEEE 802.11a OFDM scheme, which is designed to handle delay spreads in the order of 0.8 Microseconds.

Multipath is not foreseen as a problem with narrow beamwidth systems. The high side-lobe rejection of the antenna (-35 dBC) effectively eliminates any direct (single bounce) multipath that may have resulted due to the source transmitter. Ref. 6 discusses experimental evidence of the multipath and delay spread mitigation processes that are seen with directive antenna systems.

3.4 Dynamic Frequency Selection

The selection of channels for petals is undertaken by the Base station Control Computer which selects a complement of channels according to an algorithm that minimizes the possibility of co-channel interference. The algorithm uses information provided by adjacent rosettes and supplied in datagrams sent on the forward channel (Section 3.6).

Subscriber terminals within a petal will often have the choice of up to three channels emanating from the same base station. This will normally be the case if the subscribers are quite near the base station or have an unblocked LOS path. This choice results from the fact that adjacent petals overlap, albeit at a lower power, with the main petal.

Terminals will gather and provide a mean RSSI , interference levels, and fading statistics, etc., for each available channel as part of their Log-On sequence. This will be done for all 4 (or 5) channels available to the network. The information will be used by the Base station Control Computer to decide on the channel the terminal should be assigned, taking into consideration such factors as user loading, interference conditions, and propagation anomalies.

3.5 Adaptive Power Control

All forward link channels of the rosette will be set to the same EIRP. This is a necessary condition for rosette operation and is meant to ensure the same level of intra-cell (self-generated) co-channel interference on all the petals of the rosette. The EIRP of the rosette will be set at a level between —7 and 23 dBm/MHz. This feature will allow packing of rosettes within areas of high subscriber use and is a technique, along with Frequency Sequence Coding of the petals (see below), used to minimize co-channel interference existing amongst rosettes.

All return link channels use power control. The dynamic range of the link return signal is in the order of 50 dB. Close-in subscribers will operate at reduced EIRP; users on the periphery of the rosette coverage area will run at a higher EIRP. EIRP is assigned to the terminal based on its short term RSSI readings which reflect the near-real time propagation conditions of the channel. Since the system operates in a TDD mode, there will be a direct correlation between the return and forward channel characteristics that will allow an accurate and immediate assignment of power on a packet -by-packet basis.

3.6 Cellular Deployment with Sectorization and Frequency Re-use.

The proposed architecture requires subscriber terminals to monitor and record the condition of the received (forward link) base station signals. This information will be collected by the subscriber terminal and sent to the base station on an occasional basis where it will be logged in the base station control computer. This information will include:

- The mean Path Loss Exponent for each channel that the subscriber terminal sees emanating from the base station;
- Co-channel interference level on each channel (petal ID);
- Mean RSSI of each channel (petal ID)
- Measure the variance of the RSSI for fading signals undergoing fading;
- Measure of the mean time between fading intervals;
- Measure of the distance to the base station.

The base station will have the following data available in its files:

- The channel to petal association sequence (Frequency Sequence Code) that is used,
- GPS location of base station;
- EIRP of base station;
- Number and identity of activated petals;
- Height of base station.

All of this information will be used by the base station control computer to set its frequency selection and re-use plan, and will be used in a dynamic fashion by the control algorithms to limit co-channel interference.

3.6.1 Frequency Re-use with First-Installed Rosettes

First installed rosettes or rosettes not immediately adjacent to others will:

- Scan the 100 MHz of bandwidth on each petal and measure the level of interference on a each allowable channel;
- Choose non-interfering channels and assign them to petals containing sources of 5 GHz interference (such as IEEE 802.11a terminals);
- Assign remaining sets of channels to petals according to a Frequency Sequence Code;
- Alternatively, the EIRP of the rosette can be reduced to a level calculated not to interfere with existing users.

Figure 1 shows how the frequency sequence of 4 channels (A,B,C,D) is distributed amongst 24 petals. The sequence has to remain spatially periodic since like-frequency sectors coincide will low side-lobes level zones generated by other like-frequency sectors (antennas).

Red: Chan A
Blue: Chan B
Violet: Chan C
Yellow: Chan D

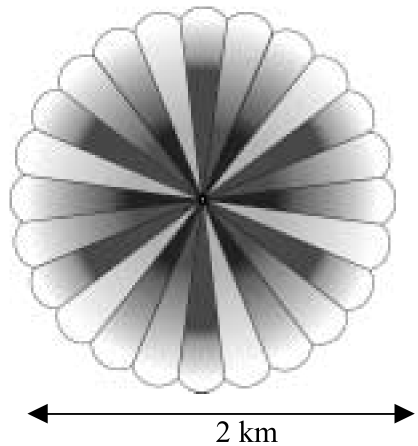

Figure 1
24 Sector Rosette; 4 channel Frequency Re-Use : Frequency Sequence ABCD

3.6.2 Frequency Re-use With Adjacent Rosettes

New rosettes installed in proximity to existing rosettes will determine the frequency sequence of the adjacent rosettes and gather other information such as the height, number of active petals, etc. of the adjacent rosettes. Information regarding the range of terminals in the adjacent rosettes and the path loss exponents for their respective channels will also be available. This information is broadcast by the all active rosettes and will be available at a URL. Having this information, the new rosette will calculate the amount of co-channel interference it may cause to existing terminals. In an attempt to minimize the interference it will vary its own Frequency Sequence and EIRP.

Figure 2 shows how a second rosette adjusts its frequency sequence in order to minimize interference with the first r

Frequency Sequence of First Rosette: ABCD

Frequency Sequence Of Second Rosette: ABDC

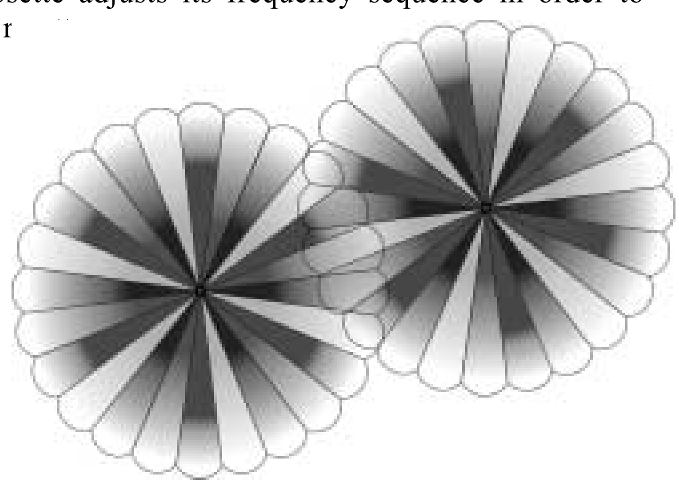

Figure 2 Two Adjacent Rosettes with Minimally-Interfering Channel Distribution

The fundamental objective of assigning different frequency sequences is to ensure that like-frequency petals do not align. The users most prone to interference will be situated on the periphery of the rosettes. Users closer to the base station have the benefit of stronger signal strength and have a better ratio of desired to interfering base station distances. Typically, only immediately adjacent rosettes would factor into the co-channel interference calculations. The low UNII Band EIRP and the high PLE that the links experience limit most co-channel interference to within the rosette (as self-interference from other like-frequency petals in the same rosette). Our simulations show that interference from rosettes spaced several rosette diameters apart is trivial under typical urban propagation conditions.

3.6.3 Frequency Re-Use With Close-Proximity Rosettes

Given the ad-hoc deployment that is expected with license-exempt equipment, it is expected that different service providers may try to densely pack rosettes in high volume service areas. While well spaced rosettes (typically with base stations spaced about 1 rosette diameter from each other) can mitigate co-channel interference by frequency sequencing; this technique will not work as well for situations where there is dense packing of rosettes. In such instances the Base station Control Computer will not activate problematic petals; or alternatively, may reduce the EIRP of the base station to lower limit, thereby reducing its coverage area. This last option is attractive as that it increases that data delivery density of the rosette (bits/square km) and is desirable in areas of high take-up.

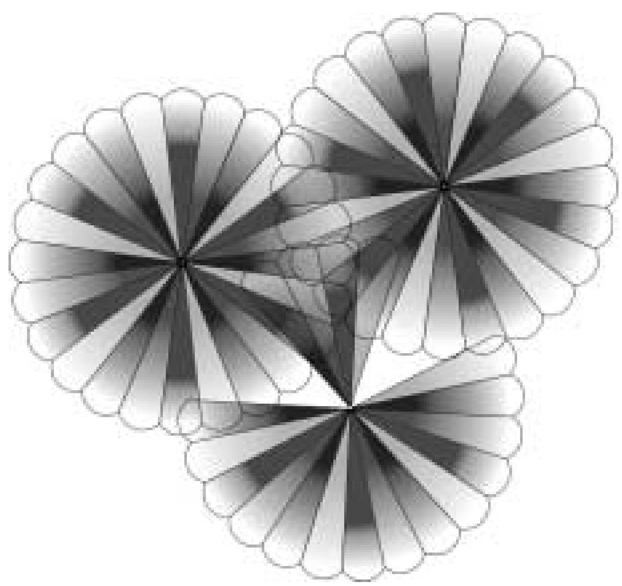

Figure 3

Close Packing of 3rd Rosette with Frequency Sequence ADCB showing interference mitigation by de-activation of potentially interfering petals

3.7 Requirements of For Antennas with Rosette Architectures and PAPR

The operation of this concept relies heavily on the standardization of base station and subscriber antenna radiation characteristics. Though absolute antenna gain is not specified, there is a requirement for an EIRP mask that must be applied. A typical mask that we have used for simulating the rosette systems is given in the table below.

Angular Azimuth Off-Set from Boresite (degrees)	Maximum Allowable EIRP (dBm/MHz)
+/- 7.5	23
+/- 7.5 to +/- 15	20
+/- 15 to +/- 30	7
+/- 30 to +/- 50	0
+/- 50 to +/- 90	-12
+/- 90 to +/- 180	-17

Table 1: Proposed Radiation Mask for Base station and Subscriber Antennas: 24 Petal Rosette

To achieve the beamwidths that are specified it is expected that the gain of the antennas will be quite high; between 15-20 dBi, depending on how the antenna is constructed. Such gains are advantageous because they allow for the reduction of the output power of the transmitter amplifier. An antenna with a 20 dB gain would only need a 3 dBm/MHz amplifier to comply with the FCC emission requirements. Such an amplifier would need a nominal output power of 16 dBm. Since there are, and will be many consumer grade 5 GHz power amplifiers capable of 500 milliwatts, there will be about 10 margin between the average OFDM carrier power and the saturated output of the amplifier. Such margin makes the issue of coding the OFDM data constellations to minimize the PAPR less constraining; and may not in the long run be a problem.

3.8 Adaptive Antennas

We feel that it will be possible to design compact adaptive antennas for subscriber applications. These antennas may not be all that complicated, requiring the steering of only 1-3 nulls to achieve acceptable performance. The provision of precise location information, such as the GPS coordinate of the base station stations would facilitate the adaptation process. Since fixed sites are assumed, there would be no stringent adaptation time requirements. Adaptive antennas could have wider beamwidths and be small, allowing them to be easily raised above rooflines.

3.9 Data Delivery Capacity

In a 24 petal structure operating on 100 MHz of bandwidth and assuming the use of IEEE 802.11a type OFDM modems having a mean forward link rate of 24 Mbps and a TDD duty transmit duty cycle of 0.75, the forward aggregate rate would be in the order of 400 Mbps. This would be higher in areas having better propagation performance, allowing the mean forward rate to be higher. Assuming that a rosette has a diameter of 2 km, the data delivery density would be in the order of 150 $Mbps/Km^2$. The return link rate, would be somewhat smaller because of the use of more robust modulation formats. Return rates in the order of 12-25 Mbps per rosette could be achievable.

4.0 Conclusions

- A proposal is made to insert another control layer in the IEEE 802.16.4 specification which would oversee the radiation characteristics of base station antennas. The control would be exercised at the RF PHY layer.
- To facilitate the operation of the RF PHY layer there will be a requirement to send commonly formatted datagrams that carry specific information about the radiation characteristics of the base station and subscriber terminals. These datagrams can be integrated within the current IEEE 802.11a PHY and IEEE 802.16.4 MAC.
- For reasons of interference control and co-existence with other users of the 5 GHz bands, it is proposed that directivitiy and sidelobe characteristics be standardized for outdoor antennas.
- This proposal is based on a TDD/TDM operation with fixed downlink power and power control on the uplink from subscribers.
- For the PHY layer we propose to reduce the preamble overhead via concatenation.
- To accommodate increased propagation delay we propose to use larger MAC frames.
- It is important to equalize received power level at the BS by using adaptive power control at the subscriber stations. This is facilitated by extending the 802.11a PHY power control resolution and by using known scales for both power control and receive-signal-strength detection.
- To improve the bit-rate/error-rate control we propose adding an interference level detector to the 802.11a PHY and comparing received signal strength with the interference level when deciding the optimum rate.

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