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Draft Proposal for Comment
Etiquette Rules and Procedures for Unlicensed Bands

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I. Abstract

This document is a draft for discussion of etiquette rules for short range wireless devices operating in the unlicensed frequency band. Regulators like the Federal Communications Commmission (FCC) can be invited to apply these rules to the operation of 'unlicensed' wireless devices. The wireless devices may support asynchronous and/or isochronous digital communications. The proposed set of rules builds on rules that govern operation of wireless devices in Europe [11] and Japan and enhances them for adoption in the United States. It is our belief that these rules will enable the regulators of our spectrum to set an etiquette that enforces fair sharing of our precious national resource, while still allowing people to innovate at all levels of the protocol stack.

II. Goals

The goal of this proposal is to define a set of rules and procedures that:

(1) prevent mutual interference and collisions between transmitters;
(2) allow all transmitters to contend and, with probabilistic fairness, gain access to at least a portion of the allocated spectrum;
(3) maximize overall spectrum utilization and capacity;
(4) allow innovation in physical layer (PHY) communications technologies and medium access control (MAC) protocols.

Specifically, this proposal allows the co-existence of different types of MAC protocol (e.g. ETSI HIPERLAN/2 [4, 5], IEEE 802.11 [2, 3], Bluetooth [7] etc.) that support different types of communications such as voice, data and video.

While an explicit goal of this proposal is to prevent disparate devices[1] from interfering with each other's communication operation, the proposal does not eliminate this possibility completely. Wireless device manufacturers will implement the MAC of their choice to implement additional system behaviors of their choice. Such a MAC may include additional interference protection to ensure that their own devices operate properly when in the vicinity of each other.

This proposal does not avoid the inevitable reduction in throughput as the number of devices operating in close proximity increases.

[1] We use the term "device" and "wireless device" interchangeably to mean a radio frequency communication device operating in the unlicensed band

III. Constraints

The proposed set of rules and procedures have been developed with the following constraints in mind:

a. Only transmitters are considered. We make no assumptions about receivers or their existence
b. We make no assumption about the channel. The channel may be symmetric or asymmetric
c. We do not think in terms of bits, bytes, or frame. That is left for the higher layer protocol designers. Instead, the parameters we work with are time, frequency, and power

We assume that transmitters can receive, although not necessarily at the same time.

IV. Definitions

Before getting into the details of our proposal, we define some terms that are used often in this document. Some of these definitions are identical to the definitions adopted by the FCC [10] and ITU [19]

Interference: The effect of unwanted energy due to one or a combination of radio frequency (RF) emissions, radiation, or induction upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy [19].

Harmful Interference: Any emission, radiation or induction that endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communications service. (Reference: Sec. 15.3m [10])

Intentional Radiator: A device that intentionally generates and emits radio frequency energy by radiation or induction. This term generally means "radio transmitter." Examples are cordless telephones, baby monitors or garage-door openers. (Reference: Sec. 15.3m [10])

Transmitting System: One or more Intentional Radiator together with a receiver that is trying to receive the transmissions of such emitters

Channel: A connection or a path between initiating and terminating nodes of a circuit for conveying electromagnetic signals. A channel is also used to define a single path provided by a transmission medium via a separation in frequency, time or code. It is generally used in conjunction with a predetermined letter, number, or codeword to reference a specific radio frequency.

V. Proposal and Rationale

We propose that the following three rules be mandated by spectrum regulators for every wireless device operating in specific unlicensed bands[2].

Transmit Power Control (TPC)
    To reduce interference between neighboring devices and to increase capacity through increased spatial reuse of the channel [8]

Dynamic Frequency Selection (DFS)
    To reduce destructive interference resulting from simultaneous transmissions

Listen Before Talk with Channel Wait Time (LBT-CWT)

[2] We suggest that regulators apply these rules in at least part of any new spectrum that is allocated to unlicensed operation.

To eliminate the possibility of devices being shut out from using the spectrum

Below we specify the precise procedure to be followed in each of the three rules.

VI. Rules and Procedures

The rules and procedures described in this section may be applied to any unlicensed spectrum. However, wherever appropriate, we use the 5150 – 5350 MHz and the 5725 – 5850 MHz U-NII bands that the FCC has allocated for unlicensed use within the US as an example of unlicensed bands. We refer to these bands collectively as the 5 GHz band.

We propose that all devices must implement TPC. In addition, all devices must implement DFS in 67% of the allocated unlicensed band, and all devices must implement the LBT-CWT etiquette in a contiguous chunk of the remaining allocated unlicensed band.

1. Transmit Power Control

All wireless devices must implement a static Transmit Power Control mechanism across the entire band. A dynamic mechanism is desirable [12], and we invite suggestions. mplementation and parameters for TPC are discussed in greater detail in Section VII B.

2. Dynamic Frequency Selection

All wireless devices must employ Dynamic Frequency Selection to detect interference from other systems and to avoid co-channel interference with other systems. DFS associated with the channel selection mechanism is necessary for providing a uniform and efficient spreading of signal load across the allocated unlicensed band and to prevent devices from interfering with each other [12].

All wireless devices must:

1. Implement DFS across the low 67% of the allocated unlicensed band

2. Perform initial channel availability check when they are powered on
   - Before the device initiates a network on a channel it must check if there is interference on the channel.
   - The device may start using the channel if no interference signal with a power greater than *Interference Threshold* is detected over the *Channel Availability Check Time*.
   - In case a signal with power greater than *the Interference Threshold* is detected, the device may still begin using the channel if its transmissions do not cause harmful interference to the current transmitting system.

3. Stop transmission upon detecting an interfering signal
   - The device must reserve a portion of its *Transmission cycle*, called *Interference Check Percentage* to check for interference.
   - The device must cease normal transmissions on the operating channel within *Channel Clearing Time* if an interfering signal is detected and the device's transmission causes harmful interference to the currently transmitting system. An interfering signal exists when a signal with power greater than *Interference Threshold* is detected on the channel.
   - Upon detecting an interfering signal, the device's aggregate transmission time on the channel must not exceed *Channel Closing Transmission Time.*

Parameter values for DFS operation are given in Table 1*:*

Table 1: DFS Parameters

Parameter	***Value***
Interference Threshold	-62 dBm
Channel Availability Check Time	10 sec
Transmission Cycle	100 msec
Interference Check Percentage	10%
Channel Clearing Time	200 msec
Channel Closing Transmission Time	20 msec

Listen Before Talk with Channel Wait Time

All wireless devices must implement the Listen Before Talk with Channel Wait Time etiquette to allow devices equal opportunity to use the spectrum. The LBT-CWT must be implemented as defined below:

All wireless devices must:

1. Implement the LBT-CWT etiquette in the high 33% chunk of contiguous unlicensed spectrum

2. Perform carrier sense before sending packets. If the device detects signal power in the maximum gain direction greater than the *Interference Threshold* it must not transmit until it senses the channel to be idle.

3. If the channel is sensed idle (i.e. the maximum detected signal gain is less than *Interference Threshold)* and the transmitter has been waiting for a *Mean Channel Wait Time*, while the channel is idle, the device may begin transmissions. *Channel Wait Time* (t) is a uniformly distributed variable over an interval 15 µsec to 25 µsec.

$$
\begin{aligned}
f_T(t) &= \frac{1}{10} \quad 15\,\mu s \le t \le 25\,\mu s \\
&= 0 \quad elsewhere
\end{aligned}
$$

4. Once the device begins its transmission, it may transmit on the channel for no more than the *Channel Hold Time*, at which point it must relinquish the channel. On giving up the channel the device may go back into an LBT-CWT mode if so desired.

Parameters for LBT-CWT operation are defined in Table 2:

Table 2: LBT-CWT Parameters

Parameter	***Value***
Interference Threshold	-62 dBm
Mean Channel Wait Time	20 µsec
Channel Hold Time	350 µsec

VII. Discussions

TPC and DFS are generally considered as important innovations in the field of spectrum management world-wide. They have either already been incorporated as part of wireless networking standards (e.g. ETSI HIPERLAN /2 [12]) or are close to standardization (e.g. IEEE 802.11 TPC is also part of several popular cellular standards we well (e.g IS-95 [18]) LBT-CWT is an abstraction of the Carrier Sense Multiple Access with Collision Avoidance MAC that has been enormously successful all over the world.

Our proposal takes these true and tried ideas and puts them together in the form of an etiquette that all unlicensed wireless devices can follow. However, as we have stated previously, these rules in themselves do not solve all problems. In this section, we discuss some advantages and some issues associated with the rules and procedures outlined in Section VI. The objective is to provide information and recommendations to wireless device vendors on how they might consider harmonizing and solving a problem that is common to all.

A. Proposal Strengths

It is our opinion that one of the strongest attribute of this proposal is its simplicity. Regulations that are overly complex are generally difficult to understand and difficult to enforce. Also, complex regulations are frequently misinterpreted and misunderstood both by the adopters and the enforcers. In lieu of this fact, we propose three simple well understood and well studied procedures. Furthermore, keeping public interest in mind, we propose rules that allow multiple ways of implementing wireless systems, thus ensuring a competitive landscape. Below, we will highlight the significant advantages of our proposal.

I. *Prevent mutual interference and collisions between transmitters (Goal 1)*

The DFS and LBT-CWT rules described in Section VI ensure that ongoing transmissions are not disrupted by neighboring wireless devices. This property is a necessary requirement for building robust wireless systems.

II. *Last one in can still use the spectrum (Goal 2)*

By requiring all devices implement LBT-CWT in at least a portion of the unlicensed frequency band, the rule ensures that there is never a case when a wireless device is unable to operate in the spectrum.

III. *Transmission systems can improve capacity by implementing multi-user detection techniques (Goal 3)*

By allowing transmitters to transmit in the presence of existing signals, the proposed rules and procedures promotes the operation of multi-user detection systems. Multi-user detection is an evolving area of research and development in the radio communications community. Multi-user detection systems are capable of decoding individual transmitters in the presence of multiple transmitters. They can be used in spread spectrum systems such as in a Direct Sequencing - Code Division Multiple Access system to alleviate problems such as near-far effects (due to non ideal power control), cross-correlation of codes (due to non-ideal codes) and channel distortion [20]. Multi-user detection techniques have the potential of improving radio communication systems capacity [13].

IV. *Allows implementation of different Physical Layers (PHY) and different multiple access control (MAC) protocols (Goal 4)*

The set of rules and procedures enumerated in Section VI allow wireless device vendors to implement the PHY of their choice. This is because all three rules, TPC, DFS and LBT-CWT are based simply on Received Signal Strength Indicator (RSSI), which can be obtained easily from a variety of different modulation schemes.

Similarly, the rules and procedures in Section VI allow wireless device vendors to implement the MAC of their choice. For example, vendors can implement a data-centric MAC like the IEEE 802.11 wireless LAN MAC across the entire allocated band. Alternatively, they can implement a voice-centric wireless MAC like Bluetooth or isochronous traffic wireless LAN MAC like the HIPERLAN/2, over part of the band that does not require LBT-CWT. The part that requires LBT-CWT may be used to implement a reservation mechanism. Also, vendors may implement hybrid MACs, like HomeRF [6] as well.

B. Parameter Values

Where-ever possible, we use parameter values that have already been agreed upon by the various wireless networking standards committees. Our hope is that our choices would facilitate rapid adoption of the proposed rules.

1. *TPC Parameter Discussions*

The rationale behind TPC is to improve frequency reuse and to reduce unwanted emissions outside the unlicensed bands. To improve frequency reuse, and in effect increase overall system capacity, the device must control its range by reducing its transmission power to the minimum possible. Stated another way, the goal for system designers is to have the device transmit at its maximum power level only when it is absolutely necessary.

We do not specify how TPC should be implemented however; we expect that for to devices operate at the lowest transmit power level while still maintaining a reliable communication link, either some form of negotiation will have to take place between the transmitter and the receiver (closed loop power control) or an assumptions about the channel symmetry will have to be made (open loop power control) [18] The constraints enumerated in Section III limit us from outlining a precise power control algorithm.

To restrict unwanted emissions around the unlicensed bands, the TPC rules must also specify the maximum transmit power values. Maximum values are generally determined by considering the critical nature of the transmissions in the bands surrounding the unlicensed band. For example, for the 5 GHz U-NII band, FCC Part 15 rules and regulation state the following [10]:

Table 3: Limits for output power at the highest power level (as in the US)

Frequency Range	Maximum Transmit Power
5.150 – 5.250 GHz (low)	17 dBm (50 mW)
5.250 – 5.350 GHz (mid)	24 dbm (250 mW)
5.725 – 5.850 GHz (high)	30 dBm (1 W)

We note here that these values (Table 3) are slightly different from the ones specified by ETSI [12] (see Table 4)

Table 4: Mean EIRP limits for RF output power at the highest power level (as in Europe)

Frequency Range	Mean EIRP
5.150 – 5.350 GHz	23 dBm (200 mW)
5.470 – 5.725 GHz	30 dBm (1 W)

It is our recommendation that the FCC and CEPT (the European Conference of Postal and Telecommunications Administrations that oversees spectrum management in Europe) move towards harmonization along these parameters. It is also our recommendation that the FCC rethink the maximum transmit power limits that they have imposed in the low and mid U-NII bands since the DFS rule alleviates some of the interference concerns that the regulators may have had.

2. *DFS Parameter Discussion*

The original rationale for DFS was to prevent non-critical devices from interfering with satellite and radar signals which are designated as primary signals in many regions of the world. This reason is still valid. In addition, DFS also prevents disparate devices from trampling over one another – a problem that has plagued the unlicensed spectrum bands since the time they were sanctioned. Fortunately, DFS does not preclude innovation in PHY and MAC layer technologies.

Our proposal requires that DFS span the low 67% of the unlicensed band. For the 5 GHz band this means that DFS must be implemented in the low (5.15 – 5.25 GHz) and the mid (5.25 – 5.35 GHz) U-NII bands. When the bands are divided into multiple channels, say 12, this translates into a requirement that DFS be implemented in the lower 8 channels.

It is left to the wireless device vendors to determine how long they need to sense the channel before concluding whether or not there is interference on the channel. However, it is expected (required?) that devices will not have a false alarm rate of > 1% under AWGN.

Once again we note that we build on exiting or emerging standards, in this case recommending parameter values that are identical to the ones in the ETSI standard. The ETSI specification[3] is a result of a directive issued by the European Radio Commission (ERC) [11]. We do this to achieve greater world-wide harmonization and to encourage manufactures to build cost-effective devices which have a better chance of rapid consumer adoption.

3. *LBT-CWT Parameter Discussion*

The primary reason for mandating a LBT with Channel Wait Time is to prevent greedy transmitters from monopolizing the spectrum. A side effect of this requirement is that it leads to sub-optimal utilization when only a single device is using the spectrum. Channel efficiency, defined as the ratio of the *Channel Hold Time* over the sum of *Channel Hold Time* and *Mean Channel Wait Time* influences how much the *Mean Channel Wait Time* should be. It makes sense to have a small *Mean Channel Wait Time*.

Mean Channel Wait Time also affects channel efficiency by influencing of range of the device. The device must not knowingly attempt to transmit beyond a distance equal to the speed of light times the *Mean Channel Wait Time*. For a range greater than this number, the probability of packet collisions increases and consequently efficiency goes down. Limiting the range has an important advantage that it can provide better spatial reuse of frequency channels

The parameters we recommend in Section VI provide a channel efficiency of approximately 95%. We note that the probability that the entire spectrum, dedicated to LBT-CWT is completely utilized goes up as the number of devices using the spectrum increases.

Instead of mandating a fixed value for channel wait time, we specify a probability distribution with a mean wait time. This is done to give probabilistically fair opportunity to all devices that are vying for the channel. When all devices implement random back-off, disparate devices will work harmoniously. The random back-off also ensures that colliding devices do not continue to collide on every future transmission attempt. To manage congestion and avoid severe throughput degradation due to presence of many devices, we expect wireless device vendors to incorporate an additional random back-off algorithm in their implementation of the LBT-CWT etiquette (for example see [2]).

Finally, although we recommend a *Channel Hold Time* of 350 μsecs, we expect that systems built with greedy transmitters will implement hold times that are less than this value to minimize channel access delay between them. The *Channel Hold Time* is based on the packet transmission time, where a packet is assumed to be of size 2360 octets and the data rate is assumed to be 54 Mbps (this value is negotiable)

As with DFS, it is expected that devices will achieve a false alarm rate of < 1% under AWGN.

[3] The specification refers to the International Telecommunication Union (ITU) working document ITU-R.M [8A-9B.RLAN.DFS]

C. Open Issues and Possible Solutions

The above set of rules and procedures do not eliminate spectrum efficiency that emerge due to hidden terminals and unfortunately the hidden terminal problem affects all three rules.

A hidden terminal problem is described as follows: Two devices *X* and *Y* are within range of a third device *Z*, but are out of range of each other, i.e. X and Y are <u>hidden</u> from each other. *X* senses the channel, finds that no device is using it and begins transmitting to *Z*. *Y* does the same thing (*Y* does not detect *X*'s transmissions, since it is out of range from it). This results in a signal corruption at *Z* [1].

We expect that the wireless device vendors will address this problem so their own devices co-exist harmoniously. For example, MAC protocols, such as the IEEE 802.11 protocol deal with this problem through an RTS/CTS type mechanism [2].

When receivers can transmit and when channels are symmetric

In developing this proposal we make no assumptions about the receiver and the channel. Specifically, we do not require that receivers have transmission capabilities and that channel be symmetric. Due to this constraint we severely limit our ability to form rules that mitigate the hidden terminal problem. Furthermore, since we do not assume that a receiver can communicate with the transmitter, the procedure for achieving minimum power transmission as dictated by TPC is left open for system designers.

If we are to assume that receivers can also always transmit, the LBT-CWT etiquette outlined in Section VI can be enhanced to avoid hidden terminal problem in the following manner:

a. At the beginning of every transmission, the sending station sends out a small burst of energy no more than a maximum of 16 dBm (40 mW) for a time period between 4 and 40 µsec.
b. The intended receiver or representative receiver (in case of a broadcast transmission) acknowledges the energy burst by transmitting two rapid bursts each equal to a maximum of 16 dBm (40 mW) in succession, each for a time duration between 2 and 20 µsec with a 10 µsec gap between the two burst.
c. Any transmitter that hears the two short burst refrains from transmitting for time period of 200 µsec, at which point it will check the channel again i.e. perform LBT-CWT.

Note, the above procedure does not specify the precise language between the receiver and the transmitter (i.e. we do not specify the meaning of the bits in the frame or even what a frame is). Instead we offer the above as an etiquette recommendation to wireless device manufacturers who wish to harmonize with disparate devices operating in the same spectrum, while still employing different high-level protocols. A MAC built on top of the above rules can get rid of the any remaining corner cases.

A similar etiquette, based on energy levels, can be developed for implementing the TPC rules.

VIII. Related Work

In this section, we briefly discuss some ideas that have been explored by other researchers looking at etiquettes for unlicensed spectrum management. In [14] Reed argues for rules that are flexible enough to accommodate technologies that are just emerging. He states that the FCC should not dictate the choice of data switching architectures, information coding scheme, modulation scheme, antenna placement etc. but instead leave those choices to the system designers. We agree, the rules proposed in this document provide such flexibility to system designers and include provisions to embrace new technologies such as multi-user detection. While Reed advocates a notion of "transport capacity", i.e., capacity in terms of useful bits transferred over a distance between two pair of nodes, our proposal does not say anything about such capacity. This is because we make no assumptions about receivers. We do however agree with Reed that the term "interference" needs to be reconsidered by the FCC to be more than just a power level. By refining what constitutes interference (see Section VI) we allow system designers to optimize on overall system capacity.

In [15], Peha advocates market-based mechanisms for spectrum management as opposed to the traditional government managed mechanisms. The author makes the claim that by granting licensing which allow regional diversity and allowing licensees to further grant secondary licenses the government would encourage technological innovation and increase competition. It is not clear to us that this approach is generally advantageous for the consumers. People are best served when more of them can communicate with each other with the cost of communication devices being large (this is called the “network effect”[4]). Allowing different parties to hold regional licenses may not necessarily lead to the desired result. The general trend in the field is towards harmonization of parameters across the world. A primary reason for this is to reduce the cost of goods and allow faster spreading of technology.

In [16], Raychaudhuri proposes a spectrum etiquette protocol for coordinating device transmissions in the unlicensed band. The idea is to standardize a common protocol for announcement of radio and service parameters. The protocol is based on the low-bit rate mode of the IEEE 802.11b physical layer and a periodic announcement at the MAC/data link layer. His proposal requires manufacturers to agree on specific details of packet formats that contains source and destination MAC addresses, packet priority, cost/price bids, CRC etc. This approach to spectrum management is very different from our approach. As an explicit design goal we do not require manufacturers to agree on interpreting signals in terms of bits and bytes and we do not mandate any particular modulation technique.

IX. Concluding Remarks

Frequency spectrum is a precious national resource that must be managed carefully and fairly. The regulators of our spectrum need to be empowered with good, solid information so that they can make informed decisions that are good for all citizens. A good set of rules is one that promotes innovation in the field, is fair to all, preserves the performance of transmitting systems and maximizes the utilization of the spectrum. We believe that the rules proposed in this document achieve these goals. In conformance with the FCC desires, our approach to spectrum etiquette policy is technology neutral [17] . It permits co-existence and competition of multiple radio technologies that may be optimized for different applications. It is our hope that spectrum regulators and the radio communications community will look at this proposal with an open mind and consider it for adoption in the unlicensed bands.

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