### E. Modulation Efficiency

The Commission has requested comments regarding whether establishing a minimum modulation efficiency of 1 bps/Hz would avoid inefficient use of the spectrum.[54] WINForum, and most other commenters, have resisted imposing an efficiency standard for the 5 GHz band. As both WINForum and Motorola argued, efficiency is appropriately measured only using a metric that considers frequency re-use, such as a bps/Hz/cell or bps/Hz/unit-area standard.[55] 3COM also points out that an efficiency requirement "would increase the complexity of the system hardware" which would increase both cost and development time and would thus "delay the introduction of many NII/SUPERNet devices."[56] Notwithstanding these legitimate concerns, many incumbent users of the band propose an efficiency requirement substantially higher than 1 bps/Hz, including commenters proposing a 3 bps/Hz limitation, apparently seeking to render NII/SUPERNet devices cost-prohibitive.[57] On balance, WINForum opposes any spectrum efficiency requirement premised on pure modulation efficiency, but has asked its 5 GHz Sharing Rules Drafting subcommittee to take up this issue in its deliberations to determine if some efficiency metric is at once accurate and measurable.

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[54]*Notice* at ¶53. Contrary to a few of the commenters' assertions, WINForum itself has not proposed, nor favors, a minimum spectral efficiency requirement.

[55]WINForum Comments at 27; Motorola Comments at 11.

[56]3COM Comments at 6.

[57]Comments of Altstatt Associates, ET Docket No. 96-102 (July 15, 1996) at 2; Comments of Larus, ET Docket No. 96-102 (July 15, 1996) at 2.

## F. Channel Sharing Rules

Upon initial inspection, the issue of channel sharing rules appears to have generated the greatest diversity in the record, with comments ranging from complete etiquette proposals to advocacy of no protocol whatsoever. After exploring these issues with numerous commenters, however, WINForum believes the perceived disparities between the comments are not completely at odds. The fundamental problem is that "sharing rules" subsumes a range of potential regulatory structures ranging from simple RF (*i.e*, power, channelization) rules to specification of complex protocols at the application layer or higher (*i.e.*, bit-level standards designed to ensure interoperability). It appears quite clear from the record that high level protocols are inconsistent with a minimal technical regulatory structure and are appropriately left to voluntary standards organizations. Indeed, WINForum, and many other commenters, believe that an etiquette comparable to the unlicensed PCS rules may be excessively complex for NII/SUPERNet devices. At the same time, WINForum believes that something more than simple RF rules will be necessary to ensure efficient, fair, and open access by all classes of devices -- although even that conclusion is not indelible.

WINForum has always advocated -- and continues to advocate -- developing sharing rules though a deliberative industry consensus process. In its original comments, WINForum announced that it was forming a new subcommittee to draft proposed sharing rules for NII/SUPERNet devices, and invited all manufacturers and developers to participate.[58] The

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[58]WINForum Comments at 28. WINForum is also actively pursuing liaison relationships with the ATM Forum and ETSI.

initial meeting of the Sharing Rules Drafting Subcommittee was, in fact, held on July 30, 1996, in Boulder, Colorado, and was well attended by industry participants. In the wake of this meeting, WINForum remains confident that these complex technical issues are capable of resolution and that a minimal sharing rules draft can be developed in a timely manner. WINForum also continues to encourage interested industry participants to join at its next meeting on September 11-13, 1996, in Washington, D.C.[59]

### G. Out-of-Band Emissions

The Commission articulated a series of regulations on out-of-band emissions and requested comments on the potential technical or economic difficulties in achieving compliance with these proposed rules.[60] Nortel and Motorola join WINForum in expressing general agreement with the Commission's suggestions, but all three believe that the industry should determine the limits and test procedures for out-of-band emissions.[61] WINForum, in fact, in its previous comments provided a series of definitions for measuring out-of-band emissions

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[59]WINForum's invitation to interested participants was intended to encompass those companies, regardless of membership in WINForum, who were interested in manufacturing or developing unlicensed products for the 5 GHz band. As L/Q notes, WINForum has taken the position that parties actively opposing the allocation do not appear "interested" in defining sharing rules for the band, and were requested not to attend. L/Q Comments at 2 n.4. L/Q fails to note, however, that WINForum explicitly invited Globalstar to meet with WINForum to discuss potential resolution of their interference concerns outside of the sharing rules drafting subcommittee context.

Although WINForum originally had indicated that membership requirements were to be suspended for the initial meeting only, in the interest of achieving the broadest possible representation, WINForum invites any entity eligible for membership in WINForum to continue to attend further meetings without joining WINForum. WINForum encourages participants to join WINForum, and notes that, because the sharing rules draft will be a WINForum proposal, only members would ultimately be able to vote on adopting the draft as a WINForum position.

[60]*Notice* at ¶50.

[61]WINForum Comments at 29-31; Nortel Comments at 9-10; Motorola Comments at iv.

that would retain consistency with the Commission's goals while providing manufacturers with more certainty and ease in compliance.[62] WINForum urges the Commission to adopt its suggested definitions.

### H. "Safe Harbor"

The Commission has proposed to create a "safe harbor" that would free NII/SUPERNet device users of the risk that their operations could be terminated by other existing and future users of the band. WINForum supported such a plan, noting that the such an approach would mitigate the need noted by many commenters to establish a new class of protected Part 15 operations (*i.e.*, a new "Part 16" class). While the cost of NII/SUPERNet devices is targeted to be very low, many rural and educational users may not be able to risk even a small investment in equipment absent some reassurance that their purchase will serve their needs now and in the future. The "safe harbor" approach appropriately meets users' planning needs while creating an environment where the risk of potential interference is limited at best. WINForum thus urges the Commission to adopt its "safe harbor" proposal.

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[62]WINForum Comments at 29-31.

## V. WINFORUM SUPPORTS DEVELOPMENT OF LONGER RANGE COMMUNITY NETWORK SYSTEMS IN THE 5.8 GHz BAND

WINForum continues to believe that a longer range extension of NII/SUPERNet devices are desirable and necessary for many networking solutions. At the same time, WINForum also recognizes and supports the initiatives already taken by developers in the 5.8 GHz band under Part 15 to address the market for lower cost, 10-15 km T1-class functionality through the use of spread spectrum systems. As WINForum has argued in its prior comments, the opportunity to create longer distance fixed links on an unlicensed basis should be technology-neutral, permitting any system employing a spectral power density on par with spread spectrum systems already authorized.

WINForum also observes that there should be no specific use restrictions on Part 15 devices, *i.e.*, that if a manufacturer could develop technology allowing "longer distance" links consistent with the power limitations, channelization, and sharing rules developed for the 5.15-5.35 GHz band, no regulation should preclude use of the lower band for "community networking." The rules for use of the lower band, however, *must* limit use of the band to very high rate data systems. Once the rules are crafted, however, any application of technology consistent with those rules should be permissible. In contrast, the Commission may wish to foster further development of community networks in the upper band by, for example, permitting somewhat narrower channelization at 5.8 GHz.

## VI. UNLICENSED SPECTRUM SHOULD NOT BE LICENSED OR AUCTIONED

As a final matter, WINForum continues to urge the Commission to reject any requests to license any aspect of NII/SUPERNet operations. As WINForum, and many other commenters, have noted, the benefit of authorizing Part 15 systems are undermined completely if licensing becomes a prerequisite.[63] Not only will licensing, even expedited licensing, serve to delay the introduction of these services, it defeats the purpose of allocating spectrum purely for the public as a resource where all users share equally and equitably.

WINForum also reiterates its strong opposition to attempting to auction any parts of the proposed NII/SUPERNet bands. While WINForum generally concurs that the public should be compensated for the use of spectrum, in this case the spectrum is being allocated as a public good. Beyond the obvious policy arguments against auctioning unlicensed spectrum,[64] WINForum also notes that as a pragmatic matter, applying auctions to certain classes of operations in the band is difficult or impossible. Moreover, auctioning the rights to provide "community network" services defeats the vision of these services as assisting communities to be self-supporting and able to access the National Information Infrastructure without the intervention of third party service providers. WINForum thus urges the Commission to reject any proposals for auctioning of unlicensed spectrum, whether designated for community networking or other purposes.

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[63]Apple Comments at 20; CEMA Comments at 5; Comments of Cylink Corp. ("Cylink Comments"), ET Docket No. 96-102 (July 15, 1996) at 9; FRC Comments at 5; Metricom Comments at 15-17; Microsoft Comments at 5-6; Rockwell Comments at 3.

[64]Apple Comments at 22; CEMA Comments at 5; Cylink Comments at 9; LACE Comments at 34; Rockwell Comments at 3.

## VII. CONCLUSION

WINForum strongly supports the Commission's proposed action in this docket. WINForum believes that the Commission's proposals to allocate 350 MHz of spectrum in the 5 GHz band for new unlicensed technologies supporting multimedia networking will have tremendous benefits for all Americans. WINForum also believes that the record compiled in this proceeding provides a solid basis for immediately acting on the Commission's proposals, with the minor modifications suggested by WINForum herein. WINForum recognizes that the Commission's allocation will precede development of final sharing rules, but WINForum believes that finalizing the allocation is necessary to lend assurance to smaller companies that devoting resources to sharing rules development will not be in vain. Accordingly, WINForum at once commends the Commission and urges it to take the penultimate step to realizing the next generation of unlicensed wireless products for the country by rapidly issuing its Report and Order in this proceeding.

Respectfully submitted,

**WIRELESS INFORMATION NETWORKS FORUM**

By: J. Ron Cross

J. Ron Cross, Chairman
Wireless Information Networks Forum
1200 19th Street, N.W., Suite 300
Washington, D.C. 20036-2401
(202) 429-5138

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# THE NEED FOR CHANNELIZATION AND PROCEDURAL RULES FOR NII/SUPERNET


## Summary

The desire to permit a wide range of technologies in any particular unlicensed segment often leads to the conclusion that no rules concerning the bandwidth of the unlicensed devices are necessary. This paper investigates the penalty of permitting mixed bandwidth devices and investigates the effect that some access procedures have on the question. It quantifies the penalty of uncontrolled bandwidths.

It is shown that when there is no frequency channelization, wideband devices with high signaling speed requirements suffer disproportionately by interference from low signaling speed narrow bandwidth devices that share the same spectrum. Imposition of a severe output power limit for narrow bandwidth devices would help equalize access probability, but further rules would also also necessary to achieve the NII/SUPERNet objectives. The rules will be more complex and inefficient if a wide range of low bandwidths is permitted.

The conclusion is that the minimum bandwidth should be as high as feasible to accompdate the range of alpplications proposed for SUPERNet and that the lower NII/SUPERNet band should be channelized as WINForum proposes.


## Interfering Potential Versus Bandwidth for Systems of Equal Throughput and no Coordination

Consider a system of devices which require a bandwidth $B_m$ in order to perform its function. This could be a SUPERNet system utilizing 25 MHz of bandwidth. Further, consider one or more other systems of devices in the same coverage area with bandwidth B ($B < B_m$) where B is a part of $B_m$ and no part of B lies outside $B_m$.

Further, assume that each system throughput demand creates a given utilization of the bandwidth which is independent of B. That is, the device density and throughput demand is such that each segment of the spectrum is utilized the same fraction of the time by each system. This condition leads to optimum spectrum utilization efficiency and it should be an objective of any spectrum sharing rules that it be encouraged. This equal throughput condition may come about because the systems are independent of each other and obey no common coexistence rules, or through their observance a set of coexistence rules.

Under the equal throughput condition, the density of devices transmitting at any time is proportional to 1/B.

The area over which any given device can interfere with a device of the maximum bandwidth ($B_m$)is approximately related to it's power level by:

$$\text{Area} = k_1 P^{2/\alpha} \qquad \text{Eq. 1}$$

where $\alpha$ is the path loss exponent. That is, the path power loss varies as $r^\alpha$ where r is the distance from the interferer.

> To see this; note that the receive power is proportional to $Pr^{-\alpha}$, thus the distance r at which the received power is sufficient for communication is proportional to $P^{1/\alpha}$. The area is proportional to $r^2$, thus the above.

The average number of devices interfering with a device of bandwidth $B_m$ is proportional to the area over which it can interfere times the density of devices transmitting at any time. Thus,

$$K = k_2\left(\frac{P^{2/a}}{B}\right) \qquad \text{Eq. 2}$$

where K is the mean number of interfering devices.

To make the interfering potential for devices of differing bandwidth the same, K should be the same for any bandwidth. One way to do this is to require that the power be related to the bandwidth as

$$P = (k_2 B)^{\alpha/2} \qquad \text{Eq. 3}$$

Since $\alpha$ is typically about 4, the power should be proportional to the square of the bandwidth.

If the power permitted for devices of bandwidth $B_m$ is $P_m$, then

$$P = P_m \left( \frac{B}{B_m} \right)^2 \qquad \text{Eq. 4}$$

Thus, if no procedural rules enforcing coexistence are utilized, this power ratio is necessary to equalize the access capability of the wide bandwidth and narrow bandwidth systems.

However, this still does not provide a quality transmission capability for either system. If one system requires a relatively constant flow of information in order to assure some level of audio or video quality and the other system does not, further rules are needed.

Also, access rules can be utilized to permit various bandwidths. The Unlicensed PCS (UPCS) rules of Part 15, subpart D will be investigated next.

**Interference Potential Versus Bandwidth for the UPCS Sharing Rules**

The power/bandwidth relationship above was developed without any particular set of sharing rules in mind. It assumes that the separate systems obey no common spectrum sharing rules. The power level relationship could be a factor in equalizing the access probability, but sharing rules can also help alleviate it and are necessary in order to gain any assurance of quality. The question remains whether a set of rules can be developed that will assure an equitable level of sharing with a mix of bandwidths.

The two sets of sharing rules for Unlicensed PCS (UPCS) will be investigated relative to this.

The NII/SUPERNet interim rules are the same as the UPCS asynchronous rules. These require a packet-by-packet access-and-drop method.

The isochronous rules cover an access-and-hold application. The isochronous rules also have a provision which allows any system to break into a connection if other devices are monopolizing the channel.

The UPCS rules have drawbacks for the NII/SUPERNet case and are not proposed as they now stand for NII/SUPERNet. They are only used as examples of the two principal cases of information flow which must be supported by NII/SUPERNet.

The Asynchronous UPCS and Interim NII/SUPERNet Rules

The interim rules of the NII/SUPERNet NPRM and the asynchronous UPCS rules utilize a Listen Before Talk (LBT), then occupy for a short period (10 ms) then delay or back-off as the method of sharing. This is an example of fast access, short hold, packet-by-packet rules. That is, access, send a packet or short burst of packets, then drop to give others a chance, then access again to send the next burst.

These rules are optimized for data only communication where the main objective is to send a finite amount of digital information in a very short time interval.

This set of rules has a severe drawback for wide bandwidth systems relative to coexistence with narrow bandwidth systems. In the LBT mechanism utilized to gain access to a channel, devices monitor only the bandwidth segment they intend to occupy, thus multiple narrow channels can operate within a wider band channel. The back-off method used to lower the incidence of collision in busy conditions and to provide for alternate device access when more than one device is busy does not work effectively in this case. Individual devices are required to delay after a channel use to allow other devices to access. This guarantees a quiet period to the narrow bandwidth devices for contention resolution but it does not guarantee a quiet period for the wideband devices since they sense more than one narrow bandwidth channel and the narrow bandwidth channels are not required to be quiet simultaneously. The wideband

devices, being sensitive to multiple channels, will sense activity when any channel of a multiple number is in use. This can create a lock-out condition for the wide bandwidth channels.

The wideband devices are thus subjected to a worse interference condition than that which would exist without common rules. Thus, in high demand situations, this condition alone prevents the wide bandwidth system from achieving the throughput of the narrow bandwidth system.

The asynchronous UPCS rules lessen the problem by encouraging the disparate bandwidth systems to locate in separate segments of the sub-band. This is at best an inadequate solution.

This lockout problem can be solved by further rules. For example, the backoff requirement could be deleted. This would have a disastrous effect on throughput and quality in heavy demand situations, but would work in low demand situations. Another way would be to require that narrow bandwidth systems coordinate to guarantee an all-off condition during backoff.

However, the backoff disparity might be solved, the inequity would still be the same as for uncoordinated systems. The conditions for winning contention become the same as for interference in the uncoordinated interference case. The $P^{\alpha/2}$ relation is necessary for the wideband devices to have an even chance to win contention. This is shown in appendix A2.

The UPCS rules require the output power to be proportional to the square root of the bandwidth. Appendix A1 shows the ratio of the number of narrow bandwidth devices sensed by wide bandwidth devices to the number of devices sensed if all were wide bandwidth under the equal spectrum demand situation and with the UPCS square root of bandwidth rule. This is

$$\frac{K_{21}}{K_{22}} = \left(\frac{B_2}{B_1}\right)^{(\alpha-1)/\alpha}$$

$K_{21}$ is the mean number of type 1 devices sensed with power on by a type 2 devices and $K_{22}$ is the number of type 2 devices sensed with power on by a type 2 device.

Since $\alpha$ is typically equal to about 4

$$\frac{K_{21}}{K_{22}} = \left(\frac{B_2}{B_1}\right)^{3/4}$$

when the square root of bandwidth rule is used. Thus, the narrow bandwidth devices have a strong advantage using the UPCS power rule.

It can be concluded that

1. Uncoordinated short access time packet-by-packet procedures require a bandwidth squared power relationship if differing bandwidths are used.
2. The UPCS asynchronous rules, even when improved, do not change conclusion 1.

<u>The Isochronous UPCS Rules</u>

The isochronous UPCS rules require an LBT to first occupy, then permit use of the time/frequency channel for an extended period. LBT is the first level method of access and a Least Interfered Channel (LIC) rule prevents monopolization in high density cases. Appendix A1 shows that these rules approximately compensate for the bandwidth difference when the device signaling rates are the same for each system bandwidth. These rules assure more nearly equal spectrum sharing by mixed bandwidth systems provided the signaling speed per time-frequency channel is the same for devices of each system type. This occurs because the devices are permitted to time divide the continuously occupied channels.

The wideband isochronous devices have a time selection advantage. If any time slot is in use, a narrow bandwidth device cannot access during that slot. Since the narrow bandwidth devices require more time to generate a given amount of throughput, they need to occupy multiple wideband time slots per channel.

Normally, the narrow bandwidth devices require continuous occupancy of a frequency channel, thus if any time channel of a wideband segment is in use, the nearby narrow bandwidth device cannot access. There is potential for either the wideband or the narrow bandwidth system to acquire an inordinate number of channels, but the LIC rule permits the other system to occupy a busy channel when this happens. Thus, balanced sharing can occur.

Appendix A1 shows that the ratio of the number of narrow bandwidth devices sensed by wide bandwidth devices to the number of devices sensed if all were wide bandwidth under the equal demand situation and with the UPCS square root of bandwidth rule is

$$\frac{K_{21}}{K_{22}} = \frac{\sigma_2}{\sigma_1}\left(\frac{B_1}{B_2}\right)^{1/\alpha}$$

in the isochronous case.

Where $\sigma_2$ is the signaling speed in bits per second for device type 2 and $\sigma_1$ is the signaling speed for device type 1.

A higher signaling speed device has an access disadvantage using the UPCS isochronous rules ($K_{21}>K_{22}$) unless it can obtain the higher signaling speed by accessing random slots within a frame (that is, by accessing multiple low speed channels in order to send at a higher speed). This means that the system is rewarded that can access capacity in the smallest units; a device that requires a signaling speed that is much higher than another should build up it's signaling speed capability by accessing time channels in small increments (units of signaling speed) randomly throughout the time space. This leads to both complexity and inefficiency.

Unless the units can operate on multiple frequencies simultaneously, the channel width should be as wide as practical so that a large number of units of signaling speed (time slots) are available in reeasonably large increments. Statistical sharing is more even when there are many possible choices.

These conclusions illustrate that the access-and-hold type of sharing rules can compensate for bandwidth differences, but the particular UPCS rules are not appropriate for systems such as SUPERNet which must accommodate a range of signaling speeds.

## The NII/SUPERNet Case

The NII/SUPERNet system is required to support a range of applications and signaling rates.

1. Available Bit Rate: For data and other static information such as still graphics, a fast response time is the principal requirement. Response times in the order of 1 second or less are appropriate, thus high signaling speed and short holding times (milliseconds to tens of milliseconds) characterize this need. A wide frequency band is required and means for temporary occupation of large portions of the time space is needed.

2. Constant Bit Rate: Examples are voice and compressed video. This requires a wide range of signaling rates; from about 32 Kb/s for a voice channel to over 1 Mb/s for compressed video. The holding times are long.

3. Variable Bit Rate: This is characterized by the peaks of compressed video. Provisions are needed to assure that the connections do not waste capacity by always requiring the peak signaling rate.

In summary, a range of signaling rates from about 32 Kb/s to above 1 Mb/s for constant and variable bit rates are needed at long holding times and the full 20 Mb/s requested by WINForum is needed both to provide short holding times for case 1 and to permit efficient time derived channels for cases 2 and 3.

## Conclusion

It is shown that for uncontrolled access at any bandwidth within the NII/SUPERNet range, a bandwidth squared power relationship is needed. That is, the power should be proportional to the square of the bandwidth. It is further shown that for the two archetypal situations covered in the UPCS rules and

necessary for NII/SUPERNet, fast access, quick response on the one hand and access and hold on the other, the best competitive strategy is to acquire signaling speed capacity in small units; probability of access is approximately inversely proportional to the signaling speed being accessed.

This is compared to the NII/SUPERNet need for multimedia (data, voice and video) applications.

The favored strategy of acquiring signaling speed capacity in very small increments promotes inefficient use of spectrum, thus the increment size needs to be set in accordance with the application range requirements. When there is no channelization, wideband devices with high signaling speed requirements suffer disproportionately from interference by low signaling speed narrow bandwidth devices that share the same spectrum. Imposition of the power penalty for narrow bandwidth devices would help equalize access probability, but further rules are also necessary to achieve the SUPERNet objectives. The rules will almost certainly be more complex and inefficient if a wide range of low bandwidths is permitted.

Devices and systems that have only a packet-by-packet, quick response time need (traditional data communication systems or LANs) may prosper in a free-for-all environment with no enforced access procedures. Uncontrolled access at any bandwidth will strongly support the quick access short hold type applications. Short time increments of one or a few milliseconds will suffice to achieve the fast response if the full channel is used. However, such systems, if uncontrolled will unduly interfere with constant and variable bit rate systems. This must be taken into account in the procedural rules that are necessary to achieve the SUPERNet need.

Since the main objective in allocating the SUPERNet band is to allow deployment of high speed digital wireless networks with a range of signaling speeds, the lower limit of bandwidth allowed in a major section of this band should be set to a value that supports 20+ Mb/s with current technology. Given the need to provide for isolation between channels occupied by different systems, a 25 MHz channel width would serve the purpose of the rulemaking proposed by the FCC. A combination with a minimum bit rate of 8 Mb/s should be considered. It should be noted that this leaves manufacturers free to develop higher signaling speed systems.

## APPENDIX

### A1. The UPCS Power/Bandwidth Rule and Its Relationship to Channelization and Signaling Speed

The unlicensed PCS (UPCS) rule is

$$\frac{P_2}{P_1} = \sqrt{\frac{B_2}{B_1}}$$

This is based on the following criteria:

Given two types of device, one type of bandwidth $B_1$ and the other of bandwidth $B_2$ consider the power received by each type of device from it's own type and from the other type each at the same path attenuation. The UPCS rule forces the ratio of the power received from the opposite type device to that received from a like type device to be equal for each type device acting as the receiver. This is achieved if the power ratio follows the UPCS rule.

Let $D_1$ be the low bandwidth type device and $D_2$ be the wider bandwidth device and let $\beta$ be the path attenuation ratio.

| Power received at: | Power received at: |
|---|---|
| A. $D_2$ from $D_2 = \beta P_2 = P_{22}$ | B. $D_2$ from $D_1 = \beta P_1 = P_{12}$ |
| C. $D_1$ from $D_1 = \beta P_1 = P_{11}$ | D. $D_1$ from $D_2 = \beta B_1 P_2 / B_2 = P_{21}$ |

Entry D reflects the fact that the narrow bandwidth device doesn't receive all of the power from the wide bandwidth device. If the power ratios from each condition are set in accordance with

$$P_{12}/P_{22} = P_{21}/P_{11}$$

then the UPCS square root of bandwidth relationship is the result, that is

$$\frac{P_2}{P_1} = \sqrt{\frac{B_2}{B_1}}.$$

This rule is set up to make power detection between two devices of differing bandwidth have the same interference area relative to each other. In the more ideal case, interference distances for collections of devices should be the same in this respect. Namely, a group of narrow bandwidth devices should have the same area over which their transmissions will be detected by the wide bandwidth devices as the area over which the wide bandwidth device transmissions would be detected by the narrow bandwidth devices. Making the case hold for single devices don't completely do this, but it is the intent.

Note 1: The interference area created by a collection of wide bandwidth devices is the union of the areas created by the individual devices. The interference area for wideband devices created by a collection of narrow bandwidth devices is slightly higher than the union of the individual areas, because the wideband devices sense the sum of the power from all narrow bandwidth devices in their frequency band.

Note 2: It would seem intuitively that it would be better to set a power ratio that would account for the fact that the UPCS rules have a detection threshold that is directly proportional to the bandwidth.

The assumption that the intent of equal interference range is achieved will be made and this bandwidth-power relationship will be investigated on this basis relative to the isochronous UPCS rules and further with respect to a modified set of asynchronous UPCS rules.

Assume the asynchronous UPCS rules are modified in such a way that the lockout condition of the backoff procedures is solved. With this modification, when a transmission burst ends, all devices within bandwidth $B_2$ stop transmission and all devices desiring access then contend. If a narrow bandwidth device (type $D_1$) wins contention and accesses, then all busy $D_1$ devices (those trying to access) within the

frequency range covered by the wide bandwidth devices (bandwidth $B_2$) can send for the allowed burst duration (some sort of intra-system notification would be needed). However, all must stop at the end of the burst duration and all devices (types 1 and 2) begin their backoff at the same time.

This is more favorable to wide bandwidth devices than the actual asynchronous rules since, in the actual rules, when more than one $D_1$ device on separate frequencies within $B_2$ is sending and is within range of device $D_2$, device $D_2$ does not sense a quiet period and thus cannot contend for the next access. Thus, whatever conclusion is drawn with this assumption, the actual asynchronous UPCS rules are less favorable to the wide bandwidth devices.

With this assumed modification of the asynchronous rules, a general case can be constructed covering both the asynchronous and isochronous rules.

Assume

A system of device type $D_1$ utilizing $n_1$ time divided channels of bandwidth $B_1$

A system of device type $D_2$ utilizing $n_2$ time divided channels of bandwidth $B_2$, $B_2 > B_1$

The LBT detection threshold = $hB_x$ where x is 1 or 2 and h is the proportionality constant which sets the threshold at the proper value (30 dB) above thermal noise.

The asynchronous rules permit any bandwidth above 0.5 MHz and $n_x$ is equal to 1(no time channelization). The maximum of $B_2$ is 1.25 MHz emission bandwidth in the isochronous UPCS rules and there are 8 channels at this bandwidth per 10 MHz sub-band.

Now, investigate the interference received by each type device from its own types and from the opposite types.

Let

$R_{12}$ = the device $D_2$ power level, as detected at device $D_1$, to device $D_1$ threshold level ratio and

$R_{11}$ = the device $D_1$ power level, as detected at $D_1$, to device $D_1$ threshold level ratio and

$R_{21}$ = the device $D_1$ power level to device $D_2$ threshold level ratio and

$R_{22}$ = the device $D_2$ power level to device $D_2$ threshold level ratio.

Device $D_1$ sees only the $D_2$ power level times $B_1/B_2$ because the monitoring bandwidth of device $D_1$ is narrower than the emission bandwidth of device $D_2$. Using this fact, setting the power level equal to $c_4B^{1/2}$ and setting the constant ratio $c_4/h = c_5$, the following results

$$R_{12} = c_5B_2^{-1/2} \qquad \text{Eq. A1-1}$$

$$R_{11} = c_5B_1^{-1/2} \qquad \text{Eq. A1-2}$$

$$R_{21} = c_5B_1^{-1/2}B_2^{-1} \qquad \text{Eq. A1-3}$$

$$R_{22} = c_5B_2^{-1/2} \qquad \text{Eq. A1-4}$$

Further, let

$A_{12}$ = The average area where the power level is above the LBT threshold of device $D_1$ because of device type $D_2$ transmissions and

$A_{11}$ = The average area where the power level is above the LBT threshold of device $D_1$ because of other device type $D_1$ transmissions and

$A_{21}$ = The average area where the power level is above the LBT threshold of device $D_2$ because of the device type $D_1$ transmissions and

$A_{22}$ = The average area where the power level is above the LBT threshold of device $D_2$ because of other device type $D_2$ transmissions.

## APPENDIX

If r is the distance between devices x and y, then the power-to-threshold value at distance r is

$R_{xy} = C_1 r^{\alpha}$, or

$r = (R_{xy}/C_1)^{1/\alpha}$ is the distance at which the ratio is $R_{xy}$.

Thus, the mean area in which the power level is above the threshold at device x due to the presence of a device y with power on is

$$A_{xy} = b_2 R_{xy}^{2/\alpha} \qquad \text{Eq. A1- 5}$$

where $b_2$ is a constant.

Further define

$K_{12}$ = the mean number of devices $D_2$ with power on (isochronous) or contending to turn power on (modified asynchronous) in which the power is detectable above the threshold by a device type $D_1$ and

$K_{11}$ = the mean number of other devices $D_1$ with power on (isochronous) or contending to turn power on (modified asynchronous) in which the power is detectable above the threshold by a device type $D_1$ and

$K_{21}$ = the mean number of devices $D_1$ with power on (isochronous) or contending to turn power on (modified asynchronous) in which the power is detectable above the threshold by a device type $D_2$,

$K_{22}$ = the mean number of other devices $D_2$ with power (isochronous) or contending to turn power on (modified asynchronous) in which the power is detectable above the threshold by a device type $D_2$.

In the case of the modified asynchronous rules it is assumed that when a device finds a channel busy, it will wait on the same channel until it gets an opportunity to access. Thus, $K_{xy}$ is the mean number of type y devices with which type x must contend, including the one currently transmitting. In the case of the isochronous rules, it is assumed that the device will search many channels for a vacant one, thus $K_{xy}$ is the actual number of devices of type y which type x can detect.

Now let

$N_1$ = the number of devices of type $D_1$ per unit area with power on or contending to turn power on and

$N_2$ = the number of devices of type $D_2$ per unit area with power on or contending to turn power on.

Then

$$K_{xy} = N_y A_{xy} = b_2 N_y R_{xy}^{2/\alpha} \qquad \text{Eq. A1- 6}$$

and with the constant $b_2 c_5 = c_6$

$$K_{12} = c_6 N_2 B_2^{-1/\alpha} \qquad \text{Eq. A1- 7}$$

$$K_{11} = c_6 N_1 B_1^{-1/\alpha} \qquad \text{Eq. A1- 8}$$

$$K_{21} = c_6 N_1 B_1^{1/\alpha} B_2^{-2/\alpha} \qquad \text{Eq. A1- 9}$$

$$K_{22} = c_6 N_2 B_2^{-1/\alpha} \qquad \text{Eq. A1- 10}$$

Define the spectrum usage or demand of the system of devices type x as $S_x$, then

$$S_x = N_x B_x / n_x \qquad \text{Eq. A1- 11}$$

is a reasonable definition. Then

$$N_x = S_x n_x / B_x. \qquad \text{Eq. A1- 12}$$

## APPENDIX

Comparative Advantage

If the ratio $K_{21}/K_{12}$ is greater than 1, then device type $D_1$ has an advantage in the sense that type $D_2$ will be prevented from accessing the channel by the LBT rule due to $D_1$ transmissions more often than will type $D_1$ be prevented by $D_2$ transmissions. Thus, this ratio is a measure of the comparative advantage of each device type.

The ratio $K_{21}/K_{22}$ is the ratio of the number of devices of type 1 (narrow bandwidth) to the number of devices of it own type with which a device of type 2 must contend. Thus, a large value for this ratio means that the narrow bandwidth devices have a worse effect on the wide bandwidth devices than would be the case if all devices were wide bandwidth.

From equations A1-7, A1-9 and A1-10, both these ratios are the same since $K_{12} = K_{22}$ and

$$\frac{K_{21}}{K_{12}} = \frac{K_{21}}{K_{22}} = \left(\frac{N_1}{N_2}\right)\left(\frac{B_1}{B_2}\right)^{1/\alpha}.$$

And, using equation A1-12

$$\frac{N_1}{N_2} = \frac{B_2 S_1 n_1}{B_1 S_2 n_2}$$, the ratio can be expressed as

$$\frac{K_{21}}{K_{12}} = \frac{K_{21}}{K_{22}} = \left(\frac{S_1 n_1}{S_2 n_2}\right)\left(\frac{B_2}{B_1}\right)^{(\alpha-1)/\alpha} \qquad \text{Eq. A1-13}$$

Asynchronous devices: This is a form applicable to the asynchronous UPCS case. In this case normally $n_1 = n_2 = 1$, and for equal spectrum usage $S_1 = S_2$. Thus, the first factor $(S_1 n_1/S_2 n_2)$ is usually 1 and the ratio of contending devices of type $D_1$ sensed by type $D_2$ to those of type $D_2$ sensed by type $D_1$ is proportional to the bandwidth ratio raised to a power a little less than 1. The asynchronous rules permit a minimum bandwidth of 500 kHz and the maximum bandwidth is about 8 MHz, thus a bandwidth ratio as high as 16 is permitted. With $\alpha = 4$ and $B_2/B_1 = 16$, the ratio is 8.

With equal throughput demand per system, a system of the highest bandwidth devices will see about 8 times as many devices of the lowest bandwidth than it would see if all devices were of the highest bandwidth. Likewise, it will experience 8 times as many devices of the opposite type with power on than the other type device will see of its type.

As an example, consider that the lower bandwidth system operates in a given area at 40% of maximum capacity and that a system of widest bandwidth devices are in the same area with a throughput demand for 40% of the capacity. The mean number of devices with power on experienced by the narrow bandwidth devices is about 0.4 narrow bandwidth device plus about 0.05 wide bandwidth devices. On the other hand, the wide bandwidth devices experience a mean of about 3.2 narrow bandwidth devices with power on plus about 0.4 wide bandwidth devices. It is clear that the wide bandwidth devices will not achieve their throughput demand; they will experience a condition equivalent to about 360% demand. The narrow bandwidth devices will experience a condition equivalent to about 45% throughput demand.

Thus, even improving the asynchronous procedures to eliminate the lockout condition will not permit the wide bandwidth devices to access the spectrum as often as can the narrow bandwidth devices, nor can the wide bandwidth devices access as freely as they could if all contending devices were wide bandwidth.

Isochronous devices: The ratios can be put in terms of the device signaling rate $\sigma_x$ to allow a better comparison of the bandwidth effect on isochronous devices. If each system has modulation efficiency ($e_x$) in BPS/Hz then

$\sigma_1 = e_1 B_1/n_1$ bits/sec. and

$\sigma_2 = e_2 B_2/n_2$ bits/sec., then

$$\frac{S_1 n_1}{S_2 n_2} = \frac{S_1 e_1 \sigma_2}{S_2 e_2 \sigma_1}\left(\frac{B_1}{B_2}\right).$$

The ratios can then be stated as

$$\frac{K_{21}}{K_{12}} = \frac{K_{21}}{K_{22}} = \frac{S_1 e_1 \sigma_2}{S_2 e_2 \sigma_1}\left(\frac{B_1}{B_2}\right)^{1/\alpha} \qquad \text{Eq. A1-14}$$

This indicates that with equal spectrum usage, signaling speeds and modulation efficiency, there is an advantage to the wide bandwidth system if part of the throughput load is carried by narrow bandwidth devices. However, this development was based on the assumption that the interference area from a group of narrow bandwidth devices is the union of the individual areas. The actual interference area is larger, thus the actual ratio is somewhat higher than the expression above and wide bandwidth devices have a weaker advantage than the equation shows. It can be assumed that the bandwidth ratio effect is about neutralized. Thus, the wide bandwidth devices are little affected if part of the throughput load is carried by narrow bandwidth devices and each type of device has approximately the same effect on the other type.

This would incdicate that improving the modulation efficiency improves access probability. However, normally an improvement in modulation efficiency results in a higher sensitivity to inteference. An assumption in the development here is that each system has the same sensitivity to interfernce of equal power density. Thus, improving the modulation efficiency may not result in an overall improvement since it increases the interference range of the receiver and will decrease frequency reuse.

Consider the case where the modulation efficiency, power density sensitivity and spectrum usage are the same. Here

$$\frac{K_{21}}{K_{12}} = \frac{K_{21}}{K_{22}} = \frac{\sigma_2}{\sigma_1}\left(\frac{B_1}{B_2}\right)^{1/\alpha}.$$

Thus, if the type 2 device must deliver a higher signaling speed than the type 1 devices it suffers an access disadvantage approximately proportional to the signaling speed ratio.

However, this assumes that the device with the higher signaling speed accesses one wider time slot (one channel of higher speed). If it is free to access multiple random time slots (multiple time channels) anywhere in a frame, it can achieve the necessary signaling speed this way; it only has to wait and access enough narrower channels within it's frequency bandwidth. However, to operate in this manner, the channel bandwidth should be sufficient to carry a large number of time channels so that devices only have to send on one frequency at one time.

The narrower bandwidth devices could also increase their signaling speed by accessing multiple frequency channels simultaneously. However, the requisite versatility is much more easily achieved with time divided channels. Thus, it is best to channelize in wide enough segments to permit high speed on each channel.

### A2. Necessary Power Level for the Modified Asynchronous Rules

Assume the UPCS asynchronous rules are modified as described in appendix A1 to remove the lockout condition. It will be shown here that the $B = P^{\alpha/2}$ relation is necessary to equalize the number of narrow bandwidth devices contending with wide bandwidth devices on the same interference area distance criteria used for the UPCS rules. That is, the assumption that the interference area of a collection of narrow bandwidth devices to a wideband device is the union of the individual interference areas. Define the power level ratios as before,

$R_{12}$ = the device $D_2$ power level, as detected at $D_1$, to device $D_1$ threshold level ratio and

$R_{11}$ = the device $D_1$ power level, as detected at $D_1$, to device $D_1$ threshold level ratio and

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$R_{21}$ = the device $D_1$ power level to device $D_2$ threshold level ratio and

$R_{22}$ = the device $D_2$ power level to device $D_2$ threshold level ratio.

Then the following is the case

$$R_{12} = \frac{P_2\left(\frac{B_1}{B_2}\right)}{hB_1} = \frac{P_2}{hB_2}$$

$$R_{11} = \frac{P_1}{hB_1}$$

$$R_{21} = \frac{P_1}{hB_2}$$

$$R_{22} = \frac{P_2}{hB_2} = R_{12}$$

Further, as before from equation A1-6,

$$K_{xy} = b_2 N_y R_{xy}^{2/\alpha}$$

Since the number of devices per unit area with information to send is proportional to 1/B. Then

$$N_1 = N_2 B_2 / B_1.$$

If $K_{12}$ is set equal to $K_{21}$, then, with equal throughput for each system, the number of type 1 devices contending with type 2 devices is the same as the number of type 2 devices contending with type 1 devices. When this is done, the result is

$$\frac{P_2}{P_1} = \left(\frac{B_2}{B_1}\right)^{\alpha/2}$$

which is the same as equation 4 and thus verifies the introductory statement.