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Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D. C. 20554

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OFFICE OF THE SECRETARY

In the Matter of:	)	
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Amendment of the Commission's	)	
Rules for Unlicensed Personal	)	
Communications Services	)	

PETITION FOR RULEMAKING

WIRELESS INFORMATION NETWORKS FORUM

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SUMMARY

The Wireless Information Networks Forum ("WINForum") is requesting that the Commission adopt a Notice of Proposed Rule Making to modify, in certain respects, the rules governing the operation of Unlicensed Personal Communications Services ("UPCS") devices. While the UPCS allocation has been tremendously successful, and continues to promise valuable advanced telecommunications options for the public, the industry now believes it is appropriate to reexamine some UPCS regulations in light of experience. As discussed below, this petition brings to bear the industry's development of a test protocol for UPCS devices, as well as implementation of commercial systems, and forecasts on future growth of the UPCS band. Based on this information, WINForum believes that the 1910-1920 MHz band should be made available for isochronous devices and that certain other minor modifications to the spectrum etiquette are warranted. WINForum's proposed changes are discussed in detail below.

Four years ago, the Commission allocated 20 MHz of spectrum exclusively to Unlicensed Personal Communications Services ("UPCS"). The band 1910-1920 MHz was allocated to "asynchronous" (*i.e.,* packet data) devices, while 1920-1930 MHz was allocated to "isochronous" devices, which use regular, periodic transmissions typical of circuit-switched communications. In the *Memorandum Opinion and Order* allocating UPCS spectrum, the Commission stated that "in the near future we will initiate a proceeding to consider allocation of additional spectrum to meet long term spectrum requirements for unlicensed PCS devices."[1] The Commission subsequently made an additional 10 MHz, at 2390-2400 MHz, available to asynchronous devices, but no additional spectrum was allocated to isochronous devices.

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[1] *Memorandum Opinion and Order*, GEN Docket 90-314, FCC 94-144 at 207.

Devices operating in the UPCS spectrum are required to comply with the "etiquette," which is the popular term for the requirements in Subpart D of Part 15. Among other things, the etiquette requires that a device monitor a channel before transmitting to minimize the chance of interfering with an existing communication on that channel. This is commonly known as the "listen before transmit" ("LBT") requirement. The purpose of the etiquette is to allow systems that use different air interfaces to coexist harmoniously in the same band. WINForum was instrumental in developing the etiquette and worked closely with the Commission during its incorporation into the Rules.

The UPCS allocation has been tremendously successful. Since allocation of the UPCS band, a number of isochronous systems have been developed by at least ten manufacturers, certified by the Commission, and marketed to the public. Based on market forecasts, over 1.5 million UPCS handsets will have been sold by 2002, at which time the UPCS handsets will account for more than half of all in-building wireless handsets sold. In contrast, to WINForum's knowledge, no asynchronous UPCS devices have been deployed. This apparently is not due to the lack of a market for unlicensed wireless data devices; there are a number of such devices operating in the Industrial, Scientific, and Medical ("ISM") bands under Section 15.247, and at least one system was certified for operation in the new Unlicensed National Information Infrastructure ("U-NII") spectrum less than a year after it was adopted by the Commission. Moreover, despite significant standards activity in wireless local area networks generally, no standards activities are currently directed at the asynchronous UPCS spectrum.

The lack of asynchronous UPCS devices, coupled with the significant asynchronous activity in the other bands, suggests to WINForum that the UPCS bands are less attractive than those other bands to unlicensed wireless data system manufacturers. This may be due to the

larger bandwidth and/or transmit power limits available in the other bands, as well as the constraints imposed by the asynchronous etiquette and, in the case of the 1910-1920 MHz band, the requirement that UPCS devices be coordinated with the incumbent fixed microwave systems through UTAM, Inc.

WINForum believes that it would be in the public interest to make the 1910-1920 MHz band available to isochronous UPCS devices, and to relax the access requirements for asynchronous UPCS devices operating in the 2390-2400 MHz band. Accordingly, WINForum proposes herein several changes to Subpart D, Part 15 of the Commission's Rules. The two basic elements to this proposal are:

- Allow isochronous devices to use the 1910-1920 MHz band as well as the existing 1920-1930 MHz band. The availability of 20 MHz for isochronous devices would come closer to satisfying the long-term spectrum needs envisioned for those devices and would make the total spectrum available to these devices comparable to that allocated to DECT in Europe (20 MHz) and PHS in Japan (23 MHz).
- Continue to allow asynchronous devices use of the 2390-2400 MHz band, but include in Subpart D an alternative set of access rules that does not require the LBT, which is viewed by some as an unnecessary and onerous requirement.[2] WINForum believes that this change would make the 2390-2400 MHz band (which has no fixed microwave incumbents) more attractive for some wireless packet data applications.

WINForum does not believe that any major changes should be made to the isochronous etiquette. Three different air interface standards have been developed for isochronous devices, and major changes in the isochronous etiquette (such as changes in the 1.25-MHz channelization) would result in the need for significant changes to those standards, with little accompanying benefit. Moreover, a detailed compliance test procedure for the etiquette has been developed by

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[2] *See Notice of Proposed Rule Making,* ET Docket 96-102, 11 FCC Rcd 7205 (1996). In that *Notice*, the Commission proposed to adopt the asynchronous UPCS etiquette for application to the spectrum that eventually became the U-NII bands. Some of the Comments filed in response to the Notice opposed the use of the asynchronous etiquette in the U-NII bands, and none supported it.

WINForum in cooperation with the Commission's Office of Engineering and Technology and the American National Standards Institute, and has been approved and has recently been published as an American National Standard. Equally important is the fact that a number of isochronous systems from different manufacturers are now operating successfully and in compliance with the isochronous etiquette.

However, WINForum also believes that several minor changes in the etiquette could be made which would improve it. Those changes, as well as the modifications to Subpart D associated with the general proposal outlined above, are detailed herein. WINForum respectfully requests that the Commission give serious consideration to this proposal and expeditiously issue a Notice of Proposed Rule Making consistent with the changes suggested here.

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The Wireless Information Networks Forum ("WINForum") hereby requests that the Commission adopt a Notice of Proposed Rule Making to modify, in certain respects, the rules governing the operation of Unlicensed Personal Communications Services ("UPCS") devices. While the UPCS allocation has been tremendously successful, and continues to promise valuable advanced telecommunications options for the public, the industry now believes it is appropriate to reexamine some UPCS regulations in light of experience. This petition brings to bear the industry's knowledge, as refined by the development of a test protocol for UPCS devices, the implementation of commercial systems, and joint forecasts on future growth of the UPCS band, to propose that the 1910-1920 MHz band be made available for isochronous devices and that the spectrum etiquette be modified in other minor respects. WINForum's proposed changes are discussed in detail below.

I. INTRODUCTION

In 1993, as part of its decision in the Second Report and Order in General Docket 90-314, ("Second R&O"), the Commission took the unprecedented step of allocating spectrum for the

exclusive use of unlicensed devices.[3] In allocating that spectrum, the Commission adopted a novel set of coexistence rules, collectively known as the "etiquette," which are codified in Subpart D, Part 15 of the Commission's Rules. Those rules require a device to monitor a channel before transmitting, thereby minimizing the likelihood of chronic interference among disparate systems. As the Commission is aware, WINForum was instrumental in developing those rules.

The original allocation for Unlicensed Personal Communications Services ("UPCS") in the Second R&O consisted of 40 MHz (1890-1930 MHz). Subsequently, in the 1994 Memorandum Opinion and Order ("MO&O"),[4] the UPCS allocation was reduced to 20 MHz, consisting of the 1910-1920 MHz band for "asynchronous" devices and the 1920-1930 MHz band for "isochronous" devices. At that time, the Commission noted that "in the near future we will initiate a proceeding to consider allocation of additional spectrum to meet long term spectrum requirements for unlicensed PCS devices."[5] In a subsequent decision, the Commission made the band 2390-2400 MHz available to asynchronous UPCS devices,[6] but no additional spectrum has yet been allocated for isochronous devices.

Since the UPCS allocation, WINForum has remained an active champion of UPCS and has, at the Commission's request and in cooperation with the Commission's Office of Engineering and Technology ("OET") and the American National Standards Institute ("ANSI") Committee on Electromagnetic Compatibility, developed a detailed compliance test standard for

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[3] See Second Report and Order, GEN Docket No. 90-314, 8 FCC Rcd 7700 (1993).

[4] Memorandum Opinion and Order, GEN Docket 90-314, FCC 94-144.

[5] MO&O at 207.

UPCS devices, which was recently published as an American National Standard.[7] That standard describes specific tests that must be performed to demonstrate compliance with Part 15, Subpart D of the Commission's rules. A number of WINForum member companies, as well as others, have also developed and are now marketing isochronous UPCS systems. Finally, the Telecommunications Industry Association ("TIA"), through its TR41.6 Engineering Subcommittee, has developed three different air interface standards for isochronous UPCS devices.

While the isochronous UPCS industry is enjoying a healthy early development, to WINForum's knowledge, not a single asynchronous UPCS device has been submitted to the Commission for certification. Although WINForum can only speculate as to the reasons for the lack of use of the asynchronous spectrum, it is likely that there are several factors at work. These include: (1) the availability of the Industrial, Scientific, and Medical (ISM) bands under Section 15.247, and more recently, the Unlicensed National Information Infrastructure ("U-NII") under Subpart E of Part 15 as more attractive alternatives; (2) the constraints associated with the asynchronous "etiquette;" and, (3) in the case of the 1910-1920 MHz band, inability to offer "nomadic" wireless data devices due to the potential for interference in some areas with the incumbent fixed operations.

Given the benefit of four years of experience with UPCS as well as other unlicensed technologies, WINForum believes that the time has come for the Commission to revisit the

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[6] Allocation of Spectrum Below 5 GHz Transferred from Federal Government Use, ET Docket No. 94-32, First Report and Order and Second Notice of Proposed Rulemaking, 10 FCC Rcd 4769 (1995).

[7] "American National Standard for Methods of Measurement of the Electromagnetic and Operational Compatibility of Unlicensed Personal Communications Services (UPCS) Devices," ANSI C63.17-1998, published by the Institute of Electrical and Electronics Engineers, New York, NY, 24 March 1998.

UPCS allocation and operating rules, and offers specific proposals herein to that effect. WINForum believes that adoption of these proposals will confer significant public benefits without the need to allocate any additional spectrum. The proposed changes to the Commission's Rules are confined to Subpart D of Part 15.

At the heart of this proposal are two elements. The first is to allow isochronous devices to use the 1910-1920 MHz band, which seems appropriate given the lack of asynchronous UPCS devices, and the other unlicensed spectrum options available to (and used by) asynchronous devices. The second is to relax the Commission's Rules for asynchronous devices operating in the 2390-2400 MHz band to make that band more practical and attractive for deployment of asynchronous systems. WINForum believes that these changes will result in better utilization of the UPCS spectrum by both isochronous and asynchronous devices.

II. BACKGROUND: ASYNCHRONOUS AND ISOCHRONOUS ETIQUETTES

Asynchronous devices are defined in Section 15.301 as "[d]evices that transmit RF energy at irregular time intervals, as typified by local area network data systems." Isochronous devices are defined as "[d]evices that transmit at a regular interval, typified by time-division voice systems." Although the requirements in Subpart D are often collectively termed the "etiquette," there are in fact two "etiquettes"—one for asynchronous devices and one for isochronous devices—and they are very different.

The asynchronous etiquette, as codified in Section 15.321, requires a device to monitor the frequency band over which it intends to transmit for at least 50 microseconds prior to transmission. If the monitored level is more than 32 dB above the thermal noise floor, the device

is not allowed to transmit. A single transmission burst from a device or a group of cooperating devices cannot exceed 10 milliseconds. Upon completion of a transmit burst, another access attempt may be made after a waiting time that is randomly-distributed between 50 and 750 microseconds. Each time an access attempt fails, the upper limit on this deference time doubles, up to a maximum of 12 milliseconds. Within a burst, an intra-burst gap between actual (continuous) transmissions of up to 25 microseconds is allowed; if the gap is longer, the monitoring procedure must be repeated.

The isochronous etiquette, as codified in Section 15.323, requires that a device confine its transmission to one of eight 1.25-MHz sub-bands, and have a frame duration that is either 10 milliseconds divided by an integer, or 20 milliseconds. Prior to transmission on a channel (frequency/timeslot combination), the device must monitor the channel and verify that the monitored power level meets several criteria. First, it may never exceed the "upper threshold," which is at most 50 dB above thermal noise. Second, it must be within 3 MHz of the upper or lower band edge (depending on whether the 26-dB emission bandwidth of the device is greater or less than 625 kHz), unless all channels within the first 3 MHz have monitored levels exceeding the "lower threshold." The lower threshold can be no more than 30 dB above thermal noise. This rule is often called the "packing rule" because it tends to pack wideband systems toward 1930 MHz and narrowband systems toward 1920 MHz. If all available channels within the first 3 MHz have monitored signal levels above the lower threshold, then the device must search for a channel in the 1.25-MHz sub-band immediately beyond the first 3 MHz. If there is a channel in that sub-band with a monitored level below the lower threshold, it must be used. If all available channels have monitored signal levels above the lower threshold, then the device must select the

least-interfered channel. To be allowed to operate in the least-interfered channel mode, the device must have at least 40 channels.

The isochronous etiquette is well-suited to "circuit switched" applications such as wireless telephony, where the traffic is typically time-bounded. For example, digitized voice packets must be transmitted and received, interference-free, at regular intervals to ensure high-quality reception. The isochronous etiquette provides reasonable assurance that a channel, once selected, will remain free of intermittent interference for a reasonable time interval (*e.g.,* many thousands of frames). This assurance is necessary because isochronous systems typically use a "dynamic channel selection" protocol to select a clear channel for the communication link. Retransmission of packets corrupted by interference usually is not an option for such systems, due to the rigid time-delay limits associated with time-bounded traffic.

In contrast, asynchronous systems carrying non-time-bounded traffic, such an Internet Protocol ("IP") exchanges supporting e-mail, file transfers, etc., are much less sensitive to variations in transmission delay. Moreover, data transfer protocols typically include error detection capabilities and positive and/or negative acknowledgment provisions whereby corrupted packets are retransmitted. The result of interference is therefore reduced throughput, as opposed to the degradation of link quality in the isochronous case. It might therefore be argued that asynchronous wireless systems which do not carry time-bounded traffic have less need for an interference-avoidance etiquette than do isochronous systems. In the asynchronous case, a collision, perhaps indicated by the lack of an acknowledgment, would be followed by a re-transmission after a random delay (to reduce the chance of a second collision).

III. THE 1910-1920 MHz BAND SHOULD BE MADE AVAILABLE TO ISOCHRONOUS DEVICES

As noted above, the isochronous UPCS market seems to be developing at a rate typical of a new industry. Currently, the most popular application seems to be wireless telephony systems for business environments. TIA, in fact, has recently completed work on three different air interface standards specifically for isochronous UPCS systems. As with their licensed counterparts, these UPCS systems facilitate communications and ultimately benefit the public. For example, customer calls can be quickly routed to sales personnel in large warehouse-format retail stores, minimizing delays and eliminating the traditional loudspeaker paging systems. Hospitals can use UPCS systems for immediate access to doctors and nurses when time is critical. Since UPCS systems use different spectrum than licensed systems, UPCS users incur no air time charges, and there is no need to make arrangements for spectrum-sharing with local cellular or PCS operators, which is attractive to businesses seeking a single solution that can be deployed nationwide.

Significant growth is projected for the burgeoning isochronous UPCS market in coming years. Attachment 1 shows the cumulative UPCS handset sales forecast through 2002,[8] which is a reasonable estimate of the expected embedded base. Based on this projection, there will be more than 1.5 million UPCS handsets in service in 2002, and UPCS handsets will account for more than half of all in-building wireless handsets. There currently are approximately ten companies with isochronous UPCS products, and the number is growing.

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[8] UPCS handset sales forecasts were taken from the Personal Communications Industry Association (PCIA) *1998 Wireless Market Portfolio – A Collection of Forecasts on the Wireless Industry*, pp. 95-96.

The spectrum needs for isochronous UPCS systems must be viewed in light of the fact that many UPCS systems will use multiple cells to provide seamless coverage of large areas, much like cellular and licensed PCS systems. The capacity of each cell is therefore limited by the degree to which channel can be re-used. Attachment 2 provides a detailed technical analysis of spectrum requirements and cell capacity for isochronous UPCS systems, and gives calculations of cell capacity for different assumptions about propagation, available spectrum, and usage restrictions in the Commission's Rules. It is clear from this analysis that in many situations, the additional 10 MHz of spectrum proposed to be made available herein would confer significant benefits on the users of UPCS systems—and therefore their customers—particularly in high-density facilities.

There also is a significant market for asynchronous wireless systems, such as wireless local area networks ("LANs"), although there are none currently deployed in the UPCS spectrum. Most wireless LANs operate in the ISM bands (902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz) under the spread spectrum provisions of Section 15.247 of the Commission's Rules. Committee 802.11 of the Institute of Electrical and Electronics Engineers ("IEEE 802.11") has developed interoperability standards for both direct sequence and frequency hopping systems in the ISM bands, and wireless LANs have been operating in those bands for a number of years. It is also interesting to note that, in the same year that the U-NII Rules for unlicensed operation near 5 GHz were adopted by the Commission (1997), the first product (a wireless LAN) was certified to operate under the new U-NII Rules and IEEE 802.11 began working to develop standards for wireless LANs in the U-NII bands. This contrasts markedly to the lack of any asynchronous UPCS devices or any efforts to develop standards for them, even

four years after the UPCS allocation, and serves to emphasize the point that there are a number of spectrum opportunities in the U.S. for non-UPCS asynchronous devices.

It might be argued that these same alternative spectrum opportunities are available to isochronous devices as well, and indeed, spread spectrum ISM-band isochronous devices for low-density environments, such as cordless telephones and small wireless business systems, have been available for a number of years. However, the lack of an etiquette for interference-management in unlicensed bands other than the UPCS band has tended to discourage the isochronous wireless market from reaching its full potential. This is clearly evidenced by the fact that it was not until after the UPCS allocation that a number of companies began work on large-scale wireless office systems, even though the ISM-band Rules of Section 15.247 had been available for nine years already.[9] Further, there are no industry standards for isochronous ISM-band devices.

This evidence supports WINForum's belief that the exclusive allocation of the 1910-1930 MHz band to unlicensed devices, combined with the interference management provided by an etiquette, are more important to isochronous systems carrying time-bounded traffic than they are to asynchronous systems with non-time-bounded traffic. For the latter, other considerations, such as the availability of more bandwidth and, in some cases, the higher transmit power limits, appear to make the ISM and U-NII bands more attractive. The asynchronous systems can manage sporadic interference by retransmission of errored packets, whereas the isochronous systems cannot. Isochronous systems must manage interference by avoiding it. While there are some telephony systems operating in the ISM bands under Section 15.247 that do this, their data

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[9] First Report and Order, GEN Docket No. 81-413, Adopted May 9, 1985, FCC 85-245.

rate is necessarily low so as to allow them to divide the band into enough channels for reliable interference-avoidance, and they are only suited to low-density applications.

In sum, the asynchronous interests in the unlicensed wireless industry seem to be focusing their efforts on the ISM and U-NII bands, to the exclusion of the UPCS bands, whereas the allocation of the UPCS spectrum clearly brought about the development of a new market for isochronous devices. WINForum, whose membership includes both asynchronous and isochronous interests, therefore proposes that the 1910-1920 MHz band, currently available exclusively for asynchronous devices, be made available for isochronous devices.

As a final point, it is noteworthy that in Europe, 20 MHz of spectrum has been allocated to Digital Enhanced Cordless Telephony ("DECT"), and in Japan, 23 MHz is allocated to the Personal Handyphone Service ("PHS"). Both DECT and PHS are similar, in technology and in application, to isochronous UPCS systems. Moreover, the cases of both DECT and PHS, the spectrum allocation is available exclusively for a single technology, whereas the UPCS spectrum is shared among multiple technologies, and their coexistence is managed by the etiquette. However, compliance with the etiquette exacts a price. It increases operational complexity, and as is clear from Attachment 2, it imposes a slight spectrum-efficiency penalty, even for a single system operating in isolation. Where there is actual coexistence of several different air interface technologies in the same vicinity, the spectrum-efficiency penalty increases because different systems that use different air interfaces do not share spectrum as efficiently as different systems that use the same air interface (as would be the case with multiple co-located DECT systems in Europe or PHS systems in Japan). It therefore seems reasonable that the spectrum available to isochronous UPCS applications in the U.S. should be at least comparable to that available for similar applications in Europe and Japan.

IV. THERE SHOULD BE ONLY MINOR CHANGES TO THE ISOCHRONOUS ETIQUETTE

WINForum does not believe that major changes to the isochronous etiquette are warranted. The basic framework of the isochronous etiquette consists of a frequency channelization structure (eight 1.25-MHz sub-bands) and the requirement that the frame be either 10 milliseconds divided by an integer or 20 milliseconds, as well as the listen-before-transmit ("LBT") requirement and its associated details. As noted above, TIA has developed air interface standards based on these rules, and a number of manufacturers now market systems that operate in compliance with these rules. In addition, the Commission, at its Equipment Evaluation and Authorization facility in Columbia, Maryland, has established an informal test bed for the isochronous etiquette by installing several systems that use different air interfaces. It is clear that the isochronous etiquette allows practical designs, and that the industry has expended considerable effort developing products and standards based on that etiquette.

WINForum therefore believes that the basic framework of the isochronous etiquette should be preserved. Specifically, the 1.25-MHz sub-band channelization, the frame duration requirements, and the channel access algorithm requirements should not be modified. At the same time, however, certain details of the isochronous etiquette would need to be modified to reflect the availability of the entire 1910-1930 MHz band for isochronous devices. In addition, there are several other minor modifications that WINForum believes would improve the etiquette. Some of these proposals are the result of discussions that occurred during development of ANSI C63.17, the test procedures for UPCS devices.

V. THERE SHOULD BE AN ALTERNATIVE TO THE "LISTEN BEFORE TRANSMIT" REQUIREMENT FOR ASYNCHRONOUS DEVICES IN THE 2390-2400 MHz BAND

In ET Docket 96-102, which resulted in the U-NII Rules, the Commission had proposed in the Notice of Proposed Rule Making ("NPRM") to adopt the UPCS asynchronous etiquette as operating rules for U-NII devices.[10] A number of commenting parties, including WINForum, voiced opposition to that proposal. Among the commenting parties, there was no support for adopting the UPCS asynchronous etiquette for the U-NII bands, and the Commission accordingly did not adopt it.

The opposition to the asynchronous etiquette in the U-NII proceeding has led WINForum to speculate that the asynchronous etiquette itself might conceivably be a barrier to use of the asynchronous UPCS spectrum by manufacturers. Moreover, WINForum believes that an interference-management etiquette is less critical for asynchronous systems that do not carry time-bounded traffic than for isochronous systems, or for asynchronous systems that carry time-bounded traffic. WINForum therefore proposes that an alternative set of rules be offered for asynchronous devices operating in the 2390-2400 MHz band. These rules would not require the LBT, but rather would simply impose a duty cycle limit to prevent any single system from dominating the band. This change would allow asynchronous devices to use the 2390-2400 MHz band without performing the LBT.

The specific proposal is that an asynchronous device using the 2390-2400 MHz band may either use the current asynchronous etiquette, as detailed in §15.321 of the Commission's Rules, or may use the alternative rules which would specify that: (1) the transmit duty cycle of any

individual device over any 1-second interval cannot exceed 25%, unless that device is a member of a group of cooperating devices; and (2) the aggregate transmit duty cycle of any group of cooperating devices over any 1-second interval cannot exceed 50%. "Cooperating devices" would be defined in §15.301 as:

> Cooperating Devices: A group of two or more devices among which there is RF communication that is coordinated either by a central control entity or by a distributed protocol. An example of a group of cooperating devices is a base station or access point and the portable units communicating with it.

VI. THE ANTENNA GAIN LIMIT FOR ALL UPCS DEVICES SHOULD BE INCREASED

The current antenna gain limit is 3 dBi. If the antenna gain exceeds this, the transmit power must be reduced 1 dB for each dB by which the antenna gain exceeds 3 dBi. WINForum proposes that the allowed antenna gain without a power backoff be increased to 6 dBi for all UPCS devices. The transmit power limit would be reduced by 1 dB for each dB by which the antenna gain exceeds 6 dBi. The intent of this proposal is not to foster "directional" antennas *per se* so much as to account for the fact that even simple low-gain antennas, especially when integrated into small portable devices, may sometimes have incidental lobes for which the gain exceeds 3 dBi. The 6 dBi limit, which is the same as that for spread spectrum devices operating in the ISM bands under §15.247, would serve to simplify design and testing.

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[10] *See Notice of Proposed Rule Making*, ET Docket No. 96-102, 11 FCC Rcd 7205 (1996).

VII. ANSI C63.17 SHOULD BE ADOPTED AS THE REQUIRED UPCS COMPLIANCE TEST PROCEDURE

With the encouragement and cooperation of the Commission's Office of Engineering and Technology, WINForum's WINTest Committee and ANSI Committee C63 have developed the recently-published standard ANSI C63.17, entitled "American National Standard for Methods of Measurement of the Electromagnetic and Operational Compatibility of Unlicensed Personal Communications Services (UPCS) Devices" (March 24, 1998). During that development, it was understood that once the test procedure was approved by ANSI and published, WINForum would petition the Commission for its adoption as the official UPCS compliance test procedure. WINForum hereby requests that ANSI C63.17 be formally adopted by the Commission.

VIII. WINFORUM REQUESTS THAT THE COMMISSION MAKE SEVERAL OTHER MINOR MODIFICATIONS IN THE UPCS RULES

During development of ANSI C63.17, many detailed technical discussions were held among industry and Commission representatives over a period of several years, and considerable supporting analyses was performed. As a by-product of that work, a number of desirable changes in the UPCS Rules emerged, which are detailed below. In addition, there are several other changes that should be made to support the proposals discussed above.

A. The "Peak Transmit Power" Definition in §15.301 Should Incorporate the Averaging Provisions of ANSI C63.17

WINForum proposes that the definition of "peak transmit power," in §15.301 be modified to read:

> Peak transmit power. The maximum transmit power averaged over a time interval of at most 30/B (where B is the emission bandwidth

> of the signal), or the transmission burst duration, whichever is less, under all conditions of modulation. Usually this parameter is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used.

This definition, in contrast to a peak envelope power ("PEP") definition, avoids penalizing modulation techniques with non-constant envelopes for instantaneous envelope variations, and yields a short-term average (over 30 modulation symbols or less) that more accurately reflects the interference potential of the signal being evaluated. A measurement procedure consistent with this definition is already incorporated into ANSI C63.17.

B. The Frequency Stability Requirement for Asynchronous Devices of §15.321(e) Should be Modified

In §15.321(e), the current frequency stability requirement for asynchronous devices is: "The frequency stability of the carrier frequency of intentional radiators operating in this section shall be ±10 ppm over 10 milliseconds or the interval between channel access monitoring, whichever is shorter," to be maintained over the standard temperature and supply voltage variations. WINForum proposes that this be modifed to read:

> (e) The emission limits of §15.321(d) shall be maintained over a temperature variation of –20° to +50° Celsius at normal supply voltage, and over a variation in primary supply voltage of 85 percent to 115 percent of the rated supply voltage at a temperature of 20 degrees Celsius. For devices operating under the provisions of (c) above, the monitoring system bandwidth must allow for the effects of temperature and supply voltage variations on the emissions. For equipment that is capable of operating only from a battery, the emission limit and monitoring bandwidth tests shall be performed using a new battery without any further requirement to vary supply voltage.

WINForum believes that for compliance purposes, any short-term (i.e., over a time interval of 10 milliseconds or less) instability in the frequency source can be subsumed by requirements related to the emission bandwidth, since transient frequency instability will result in a widening of the measured emission bandwidth.[11] Moreover, explicit measurement of the "carrier frequency" as a function of time for a short modulated burst is inherently problematic; it is difficult to separate the effects of the modulation from the effect of "carrier" instability on the observed power spectrum of the transmitted signal. Finally, from an interference perspective, what is important is that the emissions be confined to the intended band.

C. The Isochronous "Packing Rules" for Should be Modified to Reflect the Availability of the 1910-1920 MHz Band for Isochronous Devices

The "packing rules" for isochronous devices, as codified in §15.323(b), require that devices with emission bandwidths less than 625 kHz begin searching for a channel within 3 MHz of the lower edge of the isochronous band (currently 1920 MHz), while devices with bandwidths greater than 625 kHz must begin searching within 3 MHz of the upper band edge (1930 MHz). If the Commission makes the 1910-1920 MHz band available to isochronous devices in accordance with the above proposal, this requirement should be modified to reflect the fact that the entire 1910-1930 MHz band will be available to isochronous devices.

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[11] For asynchronous devices using the existing provisions of §15.321(b) and (c), the monitoring bandwidth requirement of §15.321(c)(5) will therefore automatically include the effects of transient frequency instability.

Doing so is complicated by the fact that in some locales, the entire 1910-1930 MHz band may not yet be available due to the presence of incumbent fixed microwave systems.[12] Therefore, WINForum proposes that the term "available band" be defined in §15.301 as follows:

> Available Band: A band (1910-1920 MHz or 1920-1930 MHz) is available to a coordinatable UPCS device in a particular location if that location has been coordinated by UTAM, Inc. for that band, and if the device is designed to use that band.

The packing requirement of §15.323(b) then would be modified to read:

> (b) Intentional radiators with an intended emission bandwidth less than 625 kHz shall start searching for an available time and spectrum window within 5 MHz of the lower edge of the lowest available band and search upward from that point. Devices with an intended emission bandwidth greater than 625 kHz shall start searching for an available time and spectrum window within 5 MHz of the upper edge of the highest available band and search downward from that point.

This would gracefully extend the packing rules to include the entire 1910-1930 MHz band when available to a device, and would apply equally as well to devices using only the 1910-1920 MHz band or the 1920-1930 MHz band. It therefore inherently accommodates existing isochronous devices that are designed for the 1920-1930 MHz band only. The proposed increase of the initial search window to 5 MHz reflects the eventual availability of 20 MHz, and corresponds to exactly four 1.25-MHz channels.

D. The Isochronous 3-Frequency Limit of §15.323(c)(5) Should become a 6-Frequency Limit

It is stipulated in §15.323c(5) that "No device or group of cooperating devices located within 1 meter of each other shall occupy more than three 1.25 MHz channels during any frame

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[12] The transition of the 1910-1930 MHz band is being managed by UTAM, Inc., as specified in §15.307.

period." The intent of this requirement is to prevent a single device or group of closely co-located devices (such as a base station or base station cluster) from blocking a large portion of the band.

However, at low traffic densities, such "blocking" will tend to be prevented due to the packing rules. As density increases and interference levels grow, a UPCS system will need to extend its search for clear channels further into the band, as dictated by the packing rules. The three-band limit will tend to frustrate this, and as shown in Attachment 2, will result in a loss of capacity (the number of simultaneous users per cell that can be served). WINForum therefore believes that the three-band limit should be modified to allow six 1.25-MHz channels to be used by a device or group of cooperating devices within 1 meter of each other. Attachment 2 shows the effect of the 3-channel limit, a 6-channel limit, and no limit.

E. Provisions for a Non-Random Wait Time Exceeding 150 Milliseconds Should be Added to §15.323(c)(6)

It is specified in §15.323(c)(6) that:

> (6) If the selected combined time and spectrum windows are unavailable, the device may either monitor and select different windows or seek to use the same windows after waiting an amount of time randomly chosen from a uniform random distribution between 10 and 150 milliseconds, commencing when the channel becomes available.

WINForum proposes that an option be added to this requirement which simply allows the device to wait for more than 150 milliseconds to re-attempt access, so that the device would be required to wait "an amount of time that exceeds 150 milliseconds, or is randomly chosen from a uniform random distribution between 10 and 150 milliseconds." The added option would integrate more

naturally into some air interface protocols, and avoid the requirement of generating a random number (as well as simplify the test), without compromising the intent of the requirement.

F. A "Sunset" Date Should be Specified for New Equipment Authorization of Asynchronous Devices in the 1910-1920 MHz Band

The existing asynchronous and isochronous etiquettes are not designed to allow asynchronous and isochronous devices operating to coexist in the same band at the same location. In fact, during the development of the etiquettes, WINForum's WINTech committee expended considerable effort attempting to develop an etiquette that could accommodate both types of devices in the same spectrum, but was unable to do so. WINForum therefore believes that for the Rule changes proposed herein to be complete, a date certain must be specified, after which no new equipment authorizations will be granted to asynchronous devices to operate in the 1910-1920 MHz band.

IX. CONCLUSION

WINForum believes that the changes proposed herein to Subpart D of Part 15 of the Commission's Rules would benefit the public by improving the utilization of the existing UPCS spectrum. The specific changes being proposed are in Attachment 3 to this Petition, shown as modifications to the existing Rules in Subpart D.

The spectrum opportunities for isochronous UPCS devices, for which the demand has already been demonstrated by market acceptance, and is expected to enjoy continued growth, would be expanded by making available to them the 1910-1920 MHz band, which remains unused by asynchronous devices. The Rules for the 2390-2400 MHz band, which is currently available to asynchronous UPCS devices, would be modified to simplify the access

requirements. WINForum believes that these changes would make the band more attractive for asynchronous devices, and would encourage new applications. Since, unlike the 1910-1920 MHz and 1920-1930 MHz bands, there are no fixed microwave incumbents in the 2390-2400 MHz band, that band is inherently suited to non-coordinatable ("nomadic") asynchronous devices. That band, with the Rule changes proposed here, would complement the ISM and U-NII bands already used by asynchronous unlicensed systems.

WINForum therefore respectfully request that the Commission issue a Notice of Proposed Rule Making consistent with the proposals presented herein. WINForum is prepared to discuss the proposals in detail with the Commission and other wireless industry members.

Respectfully submitted,

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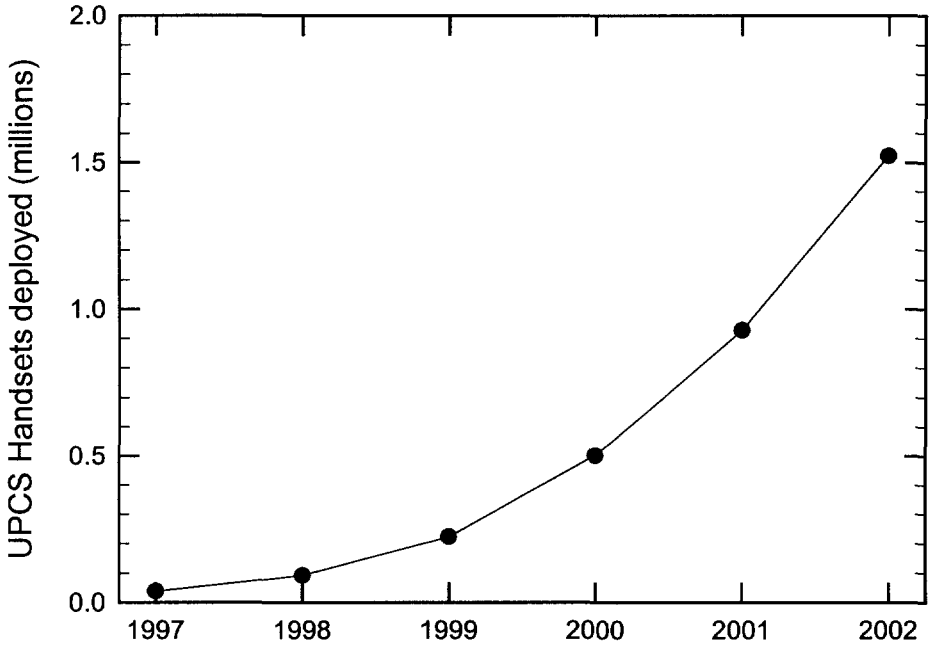
Dated: January 9, 1999

ATTACHMENT 1

CUMULATIVE ISOCHRONOUS UPCS HANDSET FORECAST



Based on UPCS handset sales forecasts were taken from the Personal Communications Industry Association (PCIA) *1998 Wireless Market Portfolio – A Collection of Forecasts on the Wireless Industry*, pp. 95-96.

ATTACHMENT 2

SPECTRUM REQUIREMENTS AND CELL CAPACITY FOR ISOCHRONOUS UPCS SYSTEMS

Jay Padgett
Lucent Technologies Bell Labs

EXECUTIVE SUMMARY

This paper discusses the relationship between the amount of spectrum available and cell capacity for multi-cell unlicensed PCS (UPCS) systems. The cell capacity is the average number of simultaneous voice connections per cell that can be supported while maintaining an acceptable link quality level.

The cell capacity depends not only on the available spectrum (currently 10 MHz), but on the propagation, the required carrier-to-interference ratio, the specific UPCS system architecture, and spectrum use constraints imposed by the FCC Rules. The effects on cell capacity of these factors is illustrated with an analysis of a system using the Personal Wireless Telecommunications (PWT) air interface standard, which is one of the standards developed for the UPCS band by the Telecommunications Industry Association (TIA). It is shown that the current FCC Rule that restricts a base station to three 1.25-MHz sub-bands reduces cell capacity.

A general capacity analysis, that does not depend on system architecture, is also provided. The result is an upper bound on available spectrum per cell, which does not account for limitations due to system architecture constraints or FCC restrictions. Using the ETSI model for indoor propagation, and accounting for adjacent-channel interference as well as interference from adjacent floors in multi-story buildings, the calculated available spectrum is 320 kHz per cell with the current 10 MHz allocation. Assuming roughly 100 kHz per active voice connection (which is typical of the digital wireless technologies used in UPCS systems), this would support 3.2 voice circuits per cell, on average. With an additional 10 MHz available, there would be 680 kHz per cell, which could support 6.8 connections per cell. Coincidentally, the trunk-limited capacity of a 12-channel PWT base station is 6 to 7 Erlangs (i.e., 6 to 7 circuits active, on average), at a 1% blocking probability.

It is concluded that the availability of an additional 10 MHz of spectrum would provide significant long-term benefits to the users of isochronous UPCS systems. In many cases, the additional spectrum would allow the system infrastructure (base stations and switch interface circuits) to be used more efficiently, since cell capacity will no longer be limited by interference, but rather by the architecture of the system itself. It is recommended that in addition to allocating an additional 10 MHz to isochronous UPCS, the FCC Rule that prohibits a base station from using more than three 1.25-MHz channels within a given

transmission frame [§15.323(c)(5)] be eliminated or at least relaxed to allow six 1.25-MHz channels to be used within a frame.

1. INTRODUCTION

Isochronous UPCS systems can provide wireless coverage over a large area with multiple small cells, each of which has a base station capable of carrying multiple circuits (simultaneous conversations). These systems operate in a manner very similar to that of outdoor cellular and PCS systems, executing handoffs between cells, location registration, paging for incoming calls, etc. Also like public cellular and PCS systems, these indoor unlicensed wireless systems depend on reuse of frequencies to achieve their capacity.

The purpose of this attachment is to explain the relationship between the average capacity per cell and the amount of spectrum available. It is shown that when adequate spectrum is available, cell capacity tends to be trunk-limited; that is, the average traffic load carried by a cell is determined by the circuit capacity of the base station. Conversely, if the spectrum allocation is not adequate, capacity will be interference-limited, and the full system resources cannot be used efficiently.

2. TRUNK-LIMITED CAPACITY

The trunk-limited capacity of a resource such as a UPCS base station is determined by the number of "servers" (usually voice circuits, or radio channels to carry voice circuits), and the desired "blocking probability" or grade of service (GoS). For a large number of traffic sources, the well-known Erlang B formula is often used. The finite-source counterpart of Erlang B is the Engset formula, which may be more appropriate in this case because of the relatively small number of servers. See chapter 3 of [1] for a complete discussion of the various traffic models.

As an example, consider a system operating under the Personal Wireless Telecommunications (PWT) standard developed by TIA for the UPCS band. The air interface uses time division multiple access (TDMA) with 12 duplex timeslots per radio carrier. Each radio channel therefore can carry 12 conversations, so a PWT base station with a single radio transceiver can be regarded as a 12-circuit server. For a 1% blocking probability, the corresponding offered load is 5.9 Erlangs[1] with the Erlang B formula. With the Engset formula, the blocking probability depends on the number of sources (wireless handsets) and the average load per handset. Table 1 shows the number of handsets per cell that can be accommodated at a 1% blocking probability for an average talk time per handset of 10, 15, and 20 minutes per hour. The third column is the traffic per handset multiplied by the number of handsets.

Table 1: *Engset 12-channel cell capacities for 12 servers and 1% blocking*

Usage/handset	Handsets	Average

[1] One Erlang equals 60 minutes of talk time per hour.

(min/hr)	per cell	Erlangs/cell
10	39	6.5
15	27	6.75
20	21	7.0

The trunk-limited capacity for a 12-channel base station therefore is on the order of 6 to 7 Erlangs per cell, depending on the usage per handset. Obviously, circuit capacity can be increased by adding another base station radio.

3. INTERFERENCE-LIMITED CAPACITY

3.1 The Reuse Concept

If the cell area is A and the traffic density is ρ Erlangs per unit area, then the traffic per cell is ρA Erlangs per cell, which represents the average number of active channels per cell. If there are a total of N channels (for a TDMA system, the number of frequencies multiplied by the number of time slots), then the reuse factor is:

$$R = \frac{\rho A}{N} , \tag{1}$$

which is the fraction of channels that, on average, are used in a given cell at a particular time. Clearly, maximizing the reuse R maximizes the capacity per cell (ρA), assuming N is fixed. This means that given the traffic density ρ, increasing R allows cell area to be increased, which reduces the number of base stations needed.

The reuse factor that can be achieved depends on the required carrier-to-interference ratio, and the propagation environment. As an example, the well-known formula for cellular systems, which relates the cell radius r to the distance d to the nearest cochannel cell, can be used (see [2]):

$$d/r = \sqrt{3K} . \tag{2}$$

This formula is based on hexagonal geometry, and assumes a regular frequency-reuse pattern with K different frequency groups. Clearly, $R = 1/K$. If the path loss varies as d^{γ}, then the carrier-to-interference ratio is:

$$\frac{C}{I} = \frac{1}{6}\left(\frac{d}{r}\right)^{\gamma} = \frac{(3/R)^{\gamma/2}}{6} \tag{3}$$

The "6" on the denominator reflects the assumption that interference is received for each of the 6 nearest cochannel cells. The concept is shown in Figure 1, using $K = 3$ as an example.

Interference to the center cell, which uses channel group 1, occurs only from the neighboring cells that use the same channel group.

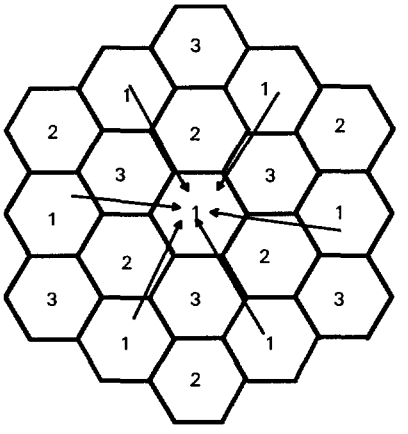


Figure 1: *Example of fixed channel assignments with 3 different channel groups*

Given that there is a maximum bit error rate for acceptable speech coder performance (typically on the order of 10^{-3} to 10^{-4}), there will be some minimum acceptable carrier-to-interference ratio β (including fade margin). From (3), the achievable reuse can be expressed in terms of β as:

$$R = \frac{3}{(6\beta)^{2/\gamma}} \tag{4}$$

As can be seen, the reuse factor depends on the required carrier-to-interference ratio β and the path loss exponent γ. The specific formula in (4) also depends on the assumed hexagonal geometry and the assumption of fixed channel assignments. While (4) provides a reasonable first approximation as well as a sanity check for computing the reuse of UPCS systems, those systems use dynamic channel assignment (DCA), and the actual reuse must be computed differently, as will be explained in detail shortly. However, it will be seen that even for systems using DCA, the reuse still varies inversely with $\beta^{2/\gamma}$.

3.2 Required Carrier-to-Interference Ratio

To determine β, two factors need to be considered. The first is the carrier-to-interference ratio required in a "static" situation, and the second is the margin that must be allowed for multipath fading. Figure 2 shows the bit error rate vs. E_b/N_0 for π/4 DQPSK (differential quadrature phase shift keying with a π/4 phase shift between symbols) and

FSK (frequency-shift keying) detected noncoherently, with the separation between the two symbol frequencies equal to the bit rate.[2] The π/4 DQPSK curve is based on the approximate formula [3]:

$$P_e \cong \frac{1}{2}\operatorname{erfc}\sqrt{0.5858\,E_b/N_0}\,, \tag{5}$$

where $\operatorname{erfc}(x) \equiv \frac{2}{\sqrt{\pi}}\int_x^{\infty} e^{-t^2}\,dt$ is the complementary error function. The FSK curve is $P_e = 0.5e^{-E_b/2N_0}$. In practice, minimum-shift keying (MSK) is often used, for which the frequency separation is half the bit rate. If MSK is envelope-detected (noncoherently detected), the theoretical performance will be about 3 dB worse in the range 10^{-3} to 10^{-4} than shown in Figure 2.[3] Most FSK receivers in digital cordless applications use limiter-discriminator detection, which should give performance approximating that of theoretical noncoherent detection, which requires $E_b/N_0 \cong 13.5\,\text{dB}$ at 10^{-3} and 15 dB at 10^{-4} (see [5], p. 231, Fig. 5-25).

[2] E_b is the received energy per bit and N_0 is the noise power spectral density.
[3] See [4], p. 313, Figure 5-4-6.

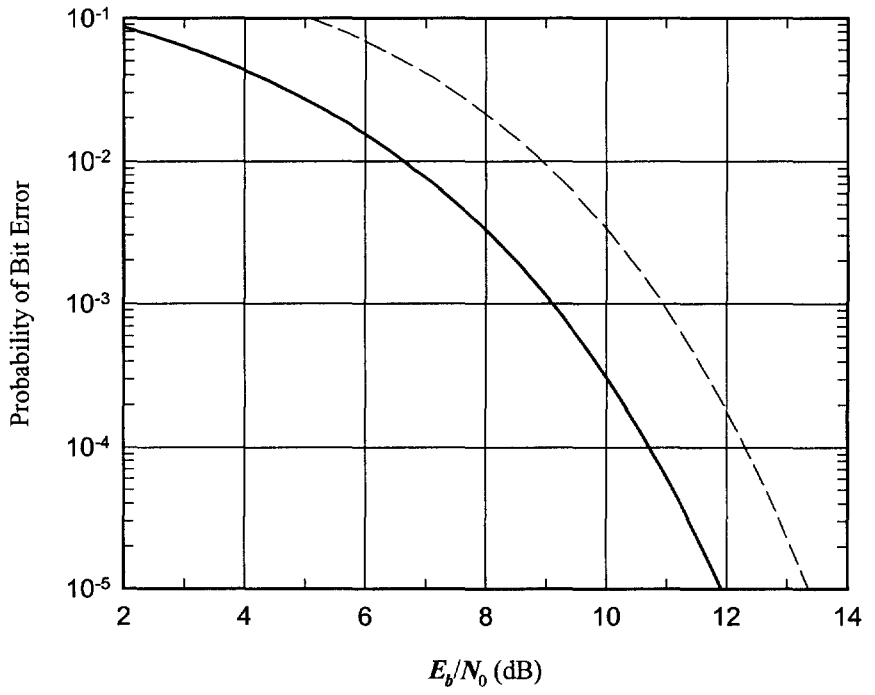


Figure 2: ***Bit error rate for π /4 DQPSK (solid) and noncoherently-detected orthogonal FSK (dashed)***

With a 4-level modulation, E_b/N_0 is 3 dB less than the carrier-to-interference ratio.[4] Therefore, accounting for an implementation loss of 1 to 2 dB, a carrier-to-interference ratio on the order of 14 to 15 dB in static conditions would seem a reasonable value for a general UPCS reuse calculation.

Unfortunately, conditions are normally not static due to multipath fading, and some additional margin must be allowed. The amount of margin depends on the fading characteristics and whether or not diversity is used. The effect of fading that is spectrally flat over the signal bandwidth is usually modeled as a Rayleigh-distributed signal envelope (exponentially-distributed power). Figure 3 shows the relationship between the fade margin and the probability that the carrier-to-interference ratio will fade below a "threshold" value under those conditions.

[4] This is because the carrier-to-interference ratio is E_s/N_0, where E_s is the energy per symbol and there are 2 bits per symbol with 4-level modulation.

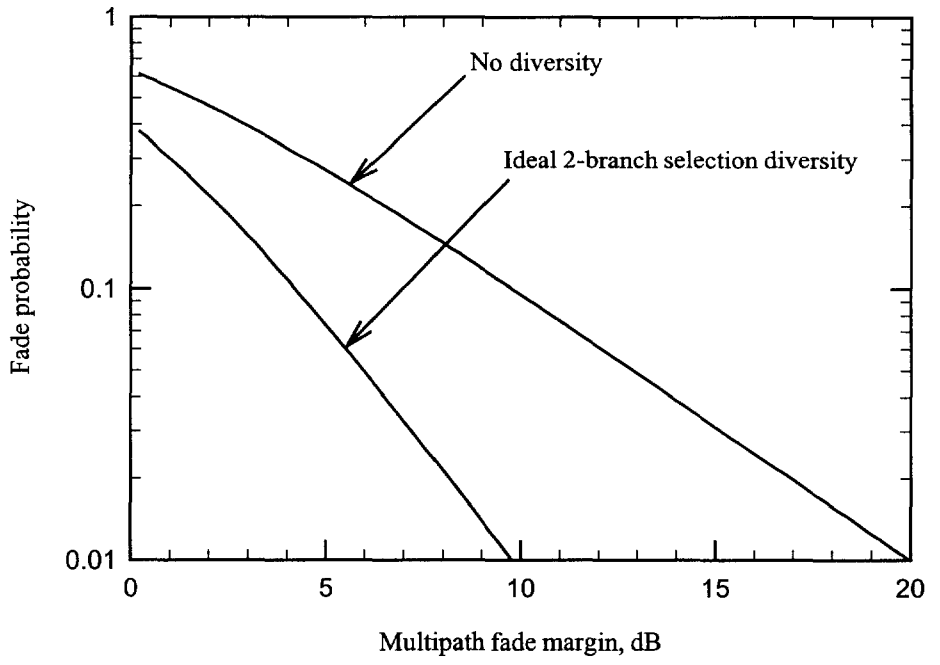


Figure 3: ***Fade probability vs. multipath margin for flat Rayleigh fading with no diversity and with ideal 2-branch selection diversity.***

As an example, if there is no diversity and the local mean carrier-to-interference ratio[5] is 20 dB above the threshold, there is a 1% probability that the multipath variations will drive the carrier-to-interference ratio below the threshold. With 2-branch diversity that operates fairly well, a margin on the order of 12 to 15 dB should give a fade probability in the desired range, 1 to 2 percent. The local mean carrier-to-interference ratio therefore should be in the range of 26 to 30 dB for good voice quality.

4. THE REUSE FACTOR WITH DYNAMIC CHANNEL ASSIGNMENT

4.1 Mathematical Model

For a system that uses DCA, the reuse factor can be calculated using the general approach of [6], which is summarized here for completeness. It is assumed that there are N channels, which may represent N distinct frequencies for a frequency-division multiple access (FDMA) system, or N frequency-timeslot combinations for a TDMA system. A wireless handset and its associated base station attempting to make a connection can use any of the N channels, subject to hardware limitations and the FCC Rules. Therefore, the transmitters using a particular channel tend to be distributed randomly over the service

[5] The "local mean" is the carrier-to-interference ratio with multipath variations averaged-out over a small area.

area, rather than being arranged in a predetermined pattern as in the fixed-channel case. The interference power received at a particular base or handset on a particular channel must therefore be modeled as a random variable, which will be denoted I. Of the channels available, there will be one which has the lowest interference power, denoted $I_{\min}$. If C represents the carrier (desired signal) power as before, the probability that there is no channel available with adequate carrier-to-interference ratio is:

$$P_0 = \Pr\left\{\frac{C}{I_{\min}} < \beta\right\}. \tag{6}$$

The problem is to find the reuse that can be achieved while maintaining P_0 at an acceptably low level, such as 1%.

It is assumed that if a transmitter and receiver are separated by a distance d, the signal power at the receiver is $\alpha d^{-\gamma}$. Thus, if the cell radius is r, the carrier power is

$$C = \alpha r^{-\gamma} \tag{7}$$

for a handset at the cell edge. Therefore, (6) becomes

$$P_0 = \Pr\left\{I_{\min} > \frac{\alpha r^{-\gamma}}{\beta}\right\}. \tag{8}$$

Assume there are M channels available (all N channels may not be available for various reasons discussed in more detail below), the probability in (8) is equal to the probability that the interference on all M available channels exceeds $\alpha r^{-\gamma}/\beta$. Assuming independence among the interference levels on the M channels, (8) becomes

$$P_0 = \left[\Pr\left\{I > \frac{\alpha r^{-\gamma}}{\beta}\right\}\right]^M, \tag{9}$$

where I is the interference power on an arbitrary channel. As noted above, I is random, and its distribution clearly will depend on the traffic density ρ and the total number of channels N, as well as the propagation parameters α and γ. Eq. (9) can be modified to show the reuse factor explicitly by dividing both sides of the inequality by $\alpha(\pi\ \rho/N)^{\gamma/2}$. The cell area is $A = \pi r^2$, so from (1), $\pi r^2\ \rho/N = R$, and:

$$\frac{\alpha r^{-\gamma}}{\alpha(\pi\,\rho/N)^{\gamma/2}} = \frac{1}{(\pi r^2\,\rho/N)^{\gamma/2}} = R^{-\gamma/2}. \tag{10}$$

Defining $Z \equiv \dfrac{I}{\alpha(\pi\rho/N)^{\gamma/2}}$, (9) becomes:

$$P_0 = \left[\Pr\left\{Z > \frac{1}{\beta R^{\gamma/2}}\right\}\right]^M. \tag{11}$$

Therefore, if the distribution of Z (which represents a normalized version of the interference power per channel) is known, P_0 can be calculated for a given value of the reuse factor R. As described in [6], the distribution of Z can be found via the Monte Carlo technique, or from the formula:

$$F_Z(z) = \Pr\{Z < z\} = 1 - \frac{1}{\pi}\sum_{k=1}^{\infty}\frac{\Gamma(k\nu)}{k!}\left[\frac{\Gamma(1-\nu)}{z^{\nu}}\right]^k \sin k\pi(1-\nu), \quad z > 0, \tag{12}$$

where $\nu = 2/\gamma$ and $\Gamma(\cdot)$ is the Gamma function. For the special case of $\gamma = 4$, (12) reduces to the closed form:

$$F_Z(z) = \operatorname{erfc}\left(\frac{\sqrt{\pi}}{2\sqrt{z}}\right), \quad z > 0 \quad \text{for } \gamma = 4. \tag{13}$$

Figure 4 shows the distribution of Z for $\gamma = 3$, 3.5, and 4, which represents the range of interest here. The upper limit on the sum was 1000, although a much small limit (e.g., 20) will suffice except at the lower tail of the distribution. The derivation of (12) is fairly complicated and is omitted here. However, (12) has been validated by comparison with Monte Carlo results.

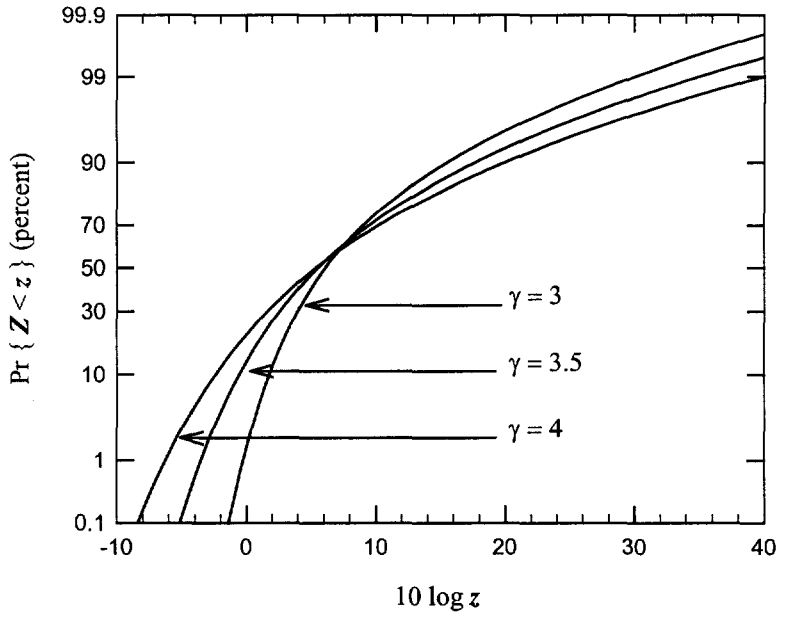


Figure 4: ***Cumulative distribution function (CDF) of the normalized interference power Z***

4.2 Application to UPCS Systems

A UPCS base station will have some maximum capacity, which is determined by the air interface and the base station hardware. For example, a PWT base station with a single radio can serve at most 12 handsets simultaneously. The same would be true for an FDMA system with 12 radios per base station. With random call attempts, the average load that can be carried by a single base station at a given blocking rate is determined by the usual teletraffic formulas, derived from queueing considerations, as discussed earlier. When the base station is part of a multi-cell system, reuse can become more limiting than base station resources.

The interference model summarized above can be used in conjunction with teletraffic models to determine whether trunking or reuse is the limiting factor. To do so, the Erlang B traffic model will be used. With Erlang B, if the resource (base station) has J circuits, and the offered load is a Erlangs, the probability the n circuits are occupied is:

$$p_n = \frac{a^n/n!}{\sum_{j=0}^{J} a^j/j!} \tag{14}$$

The circuit-limited blocking probability is p_J, the probability that all circuits are busy, so any new call attempt will be denied service.

With a PWT system, $J = 12$ timeslots for a single-radio base station, and there are 8 radio carriers (one per 1.25-MHz sub-band in the 1920-1930 MHz band), for a total of $N = 96$ possible channels. If n slots are occupied on a given base station, there are $12 - n$ slots available, or a total of $8 \times (12 - n)$ channels available.

Assume the offered load per cell is a Erlangs; that is $a = \rho A$, where A is the cell area and ρ is the traffic load density. From (1), $R = a/N$. Therefore, from (11), if n slots are occupied, the probability that the next call attempt cannot find a channel with the carrier-to-interference ratio above the threshold β is:

$$x_n = \left[\Pr\left\{ Z > \frac{1}{\beta (a/N)^{\gamma/2}} \right\} \right]^{8(12-n)} \tag{15}$$

so the total probability that a channel cannot be found with adequate C/I is:

$$\overline{P}_0 = \sum_{n=0}^{11} p_n x_n \,. \tag{16}$$

As with Erlang B, the circuit-limited blocking probability is p_{12}.

This model assumes that call attempts are not discouraged by inadequate C/I, so the state probabilities are the same as with the Erlang B model. For $\overline{P}_0 << 1$ this is a reasonable assumption, although the model could easily be modified to reflect an assumption that calls with inadequate C/I are blocked.

Table 2 shows the reuse calculated according to (4), and the average load/cell assuming 96 channels.[6]

Table 2: *Reuse and cell capacity calculated according to eq. (4) and the interference and circuit-blocking probabilities (96 channels, 12 circuits per base).*

	$\beta = 26$ dB				$\beta = 30$ dB			
	R	a (E)	$\overline{P}_0$ (%)	p_{12} (%)	R	a (E)	$\overline{P}_0$ (%)	p_{12} (%)
$\gamma = 3$	0.017	1.61	5.98	0.00	0.009	0.87	4.56	0.00
$\gamma = 3.5$	0.035	3.38	0.34	0.16	0.021	2.00	0.06	0.00
$\gamma = 4$	0.061	5.89	1.68	1.02	0.039	3.72	0.20	0.04

[6] These numbers do not account for the impact of the "3-frequency" rule, discussed below.

Table 3 shows the cell capacities, for the same combinations of parameters, that would give $\overline{P}_0 \cong 1\%$. Note how close these number are to those in Table 2, meaning that at least in the range of parameters of interest here, (4) provides a very good estimate of achievable reuse.[7] In all cases, capacity is reuse-limited, but for $\gamma = 4$ and $\beta = 26$ dB, just barely.

Table 3: *Cell capacities (Erlangs) for a 1% probability that C/I is below threshold (N = 96 channels, 12 circuits per cell).*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	1.5	0.82
3.5	3.6	2.2
4	5.6	4.1

If another 10 MHz of spectrum is made available, then $N = 192$ channels in this example. Clearly, with only 12 circuits per base, cell capacity will be trunk-limited for some cases ($\gamma = 3.5$ and 4 with $\beta = 26$ dB, and $\gamma = 4$ with $\beta = 30$ dB). Table 4 shows the corresponding cell capacities, assuming a base station capacity of 24 circuits (e.g., 2 PWT radios). The limit is taken as the point at which either $\overline{P}_0$ or p_{12} exceeds 1%. Note that capacity has more than doubled. The availability of more spectrum provides an effective "trunking efficiency" with regard to availability of clear channels. For example, with $\gamma =$ 4, reuse has increased 30%, and there is twice as much spectrum available, so cell capacity is 2.6 times what it is with 10 MHz. For $\gamma = 3.5$, the increase factor is 2.5.

The availability of additional spectrum accounts for a doubling of capacity. The additional increase is due to more efficient use of the spectrum because of (1) the larger base station circuit capacity assumed; and (2) the inherent "trunking efficiency" associated with the availability of more channel choices.

Table 4: *Cell capacities (Erlangs) for a 1% probability that C/I is below threshold (N = 192 channels, 24 circuits per cell).*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	3.6	1.9
3.5	9.0	5.6
4	14.6	10.8

[7] This does not mean that fixed frequency assignment will give a capacity comparable to that of DCA. See the note at the end of this paper for a brief discussion on cell capacities of fixed-frequency assignment and DCA systems.

4.3 Impact of the 3-Frequency Band Rule

The current FCC Rules for UPCS devices prohibit a single base station from using more than three 1.25-MHz frequency bands in a given frame, which reduces the reuse-limited capacity. If a base station already is using 3 bands, the number of channel choices for the next connection is reduced to 3/8 of what it would be otherwise. That is, the number of available channels becomes $3\times(12-n)$ rather than $8\times(12-n)$. To calculate the impact on reuse, the probability that three different bands are used, given that n connections are active, must be computed.

If there are sixteen 1.25-MHz frequency bands (as there would be with an additional 10 MHz), and n connections are active, there are 16^n different possible combinations of bands and connections. Of interest is the number of these combinations that use only 1 or 2 bands.

The number of unique band pairs is $C_{16,2}=16!/2!(16-2)!=120$ (where $C_{n,k}$ denotes the number of combinations of n things taken k at a time, or "n choose k"). For each of these pairs, there are 2^n assignments of bands to connections that use one or both bands in the pair; 2 of those use only one or the other of the two bands. Thus, there are 2^n-2 assignments that use both bands of the pair, and altogether $120\times(2^n-2)$ unique connection assignments that use exactly 2 bands. In addition, there are 16 combinations that use only one band (i.e., all n connections use the same band). Therefore, the probability that the n connections use only 1 or 2 bands is:

$$P_{<3}(n)=\frac{120(2^n-2)+16}{16^n}, \tag{17}$$

and the overall probability that if n slots are occupied, the next call attempt cannot find a channel with the carrier-to-interference ratio above the threshold β is:

$$x_n=P_{<3}(n)\left[\Pr\left\{Z>\frac{1}{\beta(a/N)^{\gamma/2}}\right\}\right]^{16(12-n)}+[1-P_{<3}(n)]\left[\Pr\left\{Z>\frac{1}{\beta(a/N)^{\gamma/2}}\right\}\right]^{3(12-n)}. \tag{18}$$

This expression is then used instead of (15) to compute the weighted-average probability of (16).

Figure 5 shows $\overline{P}_0$ vs. a using both (15), which assumes no 3-band limit, and (18), which accounts for the 3-band limit (dashed line).

It is reasonable to ask whether a larger band limit per base might be possible without significantly compromising capacity. To find out, (17) must be generalized to represent

the probability that K or fewer different bands are used, assuming the limit is $K + 1$. The approach is to determine the number of possible assignments of bands to connections that use K or fewer bands, then divide by the total number of possible assignments.

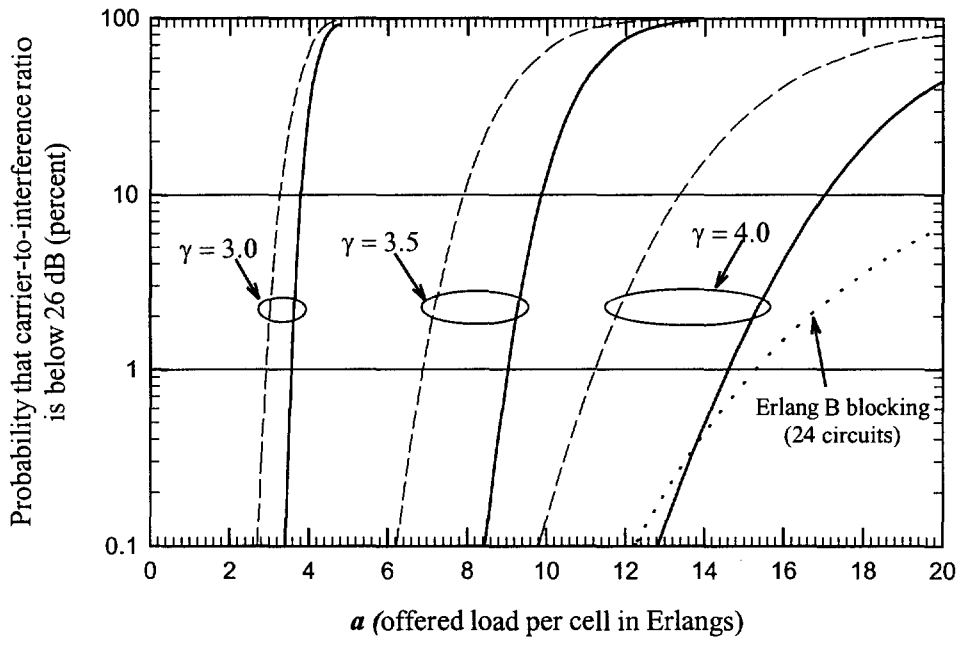


Figure 5: ***Probability that C/I is less than 26 dB assuming 192 channels (16 frequencies) and 24 available circuits per base station. The dashed lines show the effect of the 3-band rule.***

There are a total of k^n different possible assignments of n connections to a set of k specific bands, but only $y_k(n)$ of them use all k of the bands, where:

$$y_k(n) = k^n - \sum_{i=1}^{k-1} C_{k,i} y_i$$
$$y_1(n) = 1 \tag{19}$$

Since there are $C_{L,k}$ different combinations of k bands chosen from the entire set of L, there are $C_{L,k} y_k(n)$ different possible assignments of the n connections that use exactly k different bands. Since there are a total of L^n different possible assignments, the probability that an assignment uses K or fewer bands is:

$$P_{<K+1} = \frac{\sum_{k=1}^{K} C_{L,k} y_k(n)}{L^n} \tag{20}$$

and x_n then becomes

$$x_n = P_{<K}(n)\left[\Pr\left\{Z > \frac{1}{\beta(a/N)^{\gamma/2}}\right\}\right]^{16(12-n)} + \left[1 - P_{<K}(n)\right]\left[\Pr\left\{Z > \frac{1}{\beta(a/N)^{\gamma/2}}\right\}\right]^{K(12-n)} \quad (21)$$

Figure 6 shows the effect of a "6 band" limit, along with the unlimited and 3- band limit cases of Fig. 5.

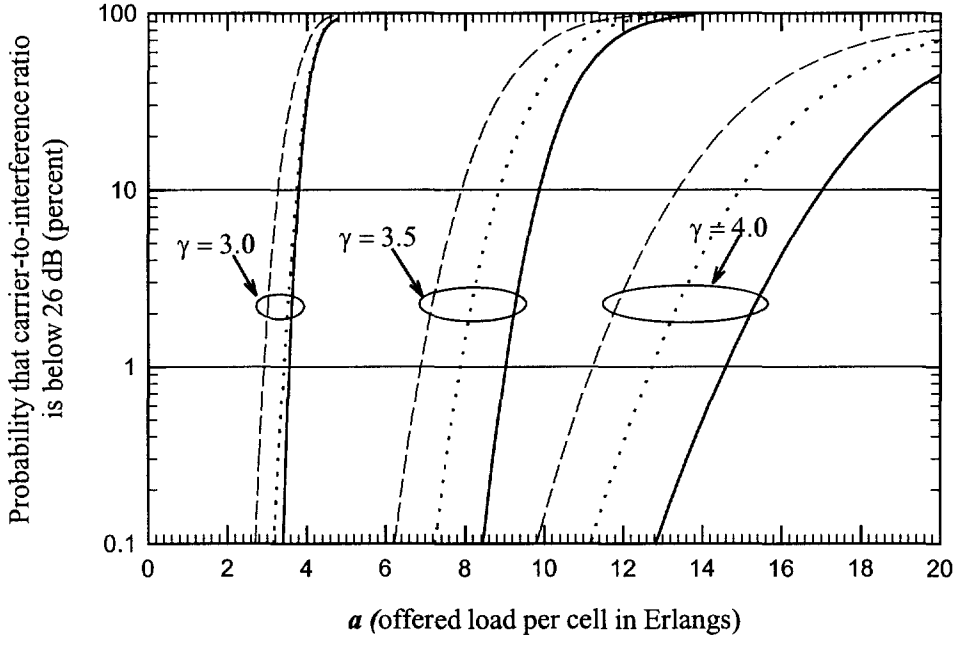


Figure 6: ***Same as Figure 5 except the effect of a 6-band limit per base station (dotted) has been added.***

Although the 6-band limit reduces capacity compared to the case in which there is no limit at all, it is an improvement over the existing 3-band limit, and may represent a reasonable compromise between single-system spectrum efficiency and coexistence safeguards.

4.4 General Capacity Limits

The above analysis used the PWT air interface as a specific example to explore the effect of spectrum available and band usage limits on the cell capacity of a UPCS system. The capacity was obviously affected by the system architecture (circuit capacity of a base station and the use of TDMA). Here, a general limit on capacity will be derived that is independent of those considerations. This limit is an upper bound on the capacity that can be achieved with a practical system, and it is based on the assumption that the least-

interfered of all N channels can be selected and used without limitations due to system implementation or FCC Rules.

From (11), if all N channels can be used,

$$P_0 = \left[\Pr\left\{ Z > \frac{1}{\beta R^{\gamma/2}} \right\} \right]^N \tag{22}$$

so

$$F_Z\left(\frac{1}{\beta R^{\gamma/2}} \right) = \Pr\left\{ Z < \frac{1}{\beta R^{\gamma/2}} \right\} = 1 - P_0^{1/N} \tag{23}$$

and

$$R = \left[\beta F_Z^{-1}\left(1 - P_0^{1/N}\right) \right]^{-2/\gamma} . \tag{24}$$

Hence, this upper bound on R can be easily calculated given N, P_0, β, γ, and the CDF $F_Z(\cdot)$, shown in Fig. 4. Tables 5 and 6 show R for $N = 96$ and 192. Although these numbers are taken from the PWT analysis, they are reasonable for a general analysis if it is assumed that each speech channel requires roughly 100 kHz. Moreover, as can be seen by comparing tables 5 and 6, R is relatively insensitive to N (this is true for large N).

Table 5: *Frequency reuse factor with 10 MHz of spectrum and unlimited channel access*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	0.016	0.009
3.5	0.042	0.025
4	0.079	0.050

Table 6: *Frequency reuse factor with 20 MHz of spectrum and unlimited channel access*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	0.017	0.009
3.5	0.045	0.027
4	0.089	0.056

If adjacent-channel and adjacent-floor interference are taken into account, these numbers will be somewhat reduced. The formula for the reduction is:[8]

$$\frac{R(A_{AC}, A_{AF})}{R(\infty,\infty)} = \frac{1}{1 + 2\times 10^{-A_{AC}/5\gamma} + 2\times 10^{-A_{AF}/5\gamma}}, \tag{25}$$

where A_{AC} and A_{AF} are the adjacent-channel attenuation and the adjacent-floor attenuation, respectively, in dB. Table 7 shows the reduction for A_{AC} = 30 dB and A_{AF} = 15 dB.

Table 7: *De-rating factors for reuse reduction with 15 dB adjacent-floor attenuation and 30 dB adjacent-channel attenuation*

$\gamma = 3$	$\gamma = 3.5$	$\gamma = 4$
0.81	0.76	0.70

This means that for γ = 3.5, for example, reuse (and therefore cell capacity) is reduced to 76% of the values shown in Tables 5 and 6.

4.5 Available Spectrum per Cell

The reuse factors, adjusted for adjacent-channel and adjacent-floor interference if appropriate, can be used to compute the effective spectrum available per cell, which is simply the reuse factor multiplied by the total available spectrum. Tables 8 and 9 show the result for the existing 10 MHz, and the proposed total of 20 MHz, respectively.

Table 8: *Average available spectrum per cell (kHz) with 10 MHz of spectrum and unlimited channel access (A_{AC} = 30 dB, A_{AF} = 15 dB)*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	140	75
3.5	320	200
4	550	350

[8] See [6], eq. (18).

Table 9: *Average available spectrum per cell (kHz) with 20 MHz of spectrum and unlimited channel access (A_{AC} = 30 dB, A_{AF} = 15 dB)*

$\beta \rightarrow$	26 dB	30 dB
$\gamma = 3$	280	150
3.5	680	410
4	1240	780

The advantage of cell capacity expressed in terms of available spectrum, as in Tables 8 and 9, is that it does not presume any particular system implementation. For purposes of computing reuse per (22)-(24), it assumes that a 1.25-MHz sub-band can accommodate 12 voice channels (i.e., roughly 100 kHz per voice channel, which is typical for UPCS technologies), but the results are relatively insensitive to that assumption. The actual capacity that a given system can achieve will likely be somewhat less, due to limitations in base station circuit capacity, system mechanics, and FCC rules.

5. CONCLUSIONS

This paper has provided a detailed analysis of cell capacity for isochronous UPCS systems. While the PWT air interface was used in some of the calculations for illustrative purposes, the principles demonstrated by the analysis apply generally. Moreover, a general analysis was provided that gives an upper bound on achievable cell capacity.

Cell capacity (expressed as available spectrum per cell, or as Erlangs per cell) was seen to vary significantly as a function of the path loss exponent γ. Inside buildings, γ is typically expected to be between 3 and 4, with $\gamma = 3$ representing a fairly open environment with good propagation and $\gamma = 4$ representing a more cluttered environment in which path loss accumulates more quickly with distance. The ETSI indoor propagation model uses $\gamma = 3.5$ (see [7], page 42, E3.1). With this value of γ, which may in some sense represent a "typical" office environment, the current 10 MHz supports roughly 320 kHz of spectrum per cell on average, or enough for three simultaneous voice connections, assuming a *C/I* requirement of 26 dB. With 20 MHz, the spectrum per cell would increase to about 680 MHz, which would support more than 6 voice connections, on average. In that case, the full capacity of a 12-channel PWT base station could be used.

For $\gamma = 3$, reuse is very poor, and even with 20 MHz of spectrum, the reuse-limited capacity of a cell is less than 3 Erlangs. What this means is that with low values of γ, systematic channel reuse is not very practical over a limited area. However, under such conditions, the benefit of the additional spectrum is very great, because the total system capacity may be limited to the number of available RF channels. Again using PWT as an example, with 10 MHz (96 channels), 16 cells with 5 Erlangs each could be supported

without channel reuse (the 96 channels can support 80 Erlangs with 1% blocking). With 20 MHz (192 channels), the total capacity without reuse increases to 172 Erlangs, which would support 34 cells at 5 E each.

Finally, it must be remembered that the UPCS spectrum is not dedicated to a single air interface, but rather shared among different air interfaces. This involves some inherent inefficiencies. The additional spectrum would make harmonious coexistence of different air interfaces much easier in high-density situations.

Clearly, there is no "hard" number on the spectrum required for isochronous UPCS systems. For some situations (low densities, poor propagation), the current 10 MHz is adequate, at least for a single air interface that is not attempting to coexist with a system that uses a different UPCS air interface. At the other extreme, there will undoubtedly be situations in which even 20 MHz will not be enough to meet the nominal wireless communications needs (high densities, large numbers of users, good propagation, other UPCS systems nearby). However, in many cases, the additional 10 MHz may allow more efficient use of system resources, improve performance, and facilitate coexistence with other systems using different air interfaces.

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NOTE: Fixed Frequency Assignment vs. DCA

For completeness, the capacity difference between a fixed-frequency system and a dynamic channel assignment (DCA) system is explained here. UPCS systems use dynamic channel assignment, as required by the FCC etiquette.

With fixed frequency assignment, N channels are effectively divided into K groups, and each cell is assigned on of the groups in such a way that the distance between cochannel cells satisfies (2). For a hexagonal geometry, there is a constraint that $K = i^2 + ij + j^2$, where i and j are integers. Thus, K can only take on the values 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, and so on.

A cell may use only its assigned channels. Assume, for example, that $K = 16$ (corresponding to $R = 0.0625$). With a total of $N = 96$ channels, each cell has access to 6 channels, so its trunk-limited capacity must be computed on the basis of 6 circuits. At a 1% GOS, the capacity is about 1.8 E/cell. Thus, on average, only about 30% of the channels carry traffic at any given time, which represents a rather inefficient use of spectrum.

By contrast, a DCA system with 12 circuits per base and $R = 1/16$ has a reuse-limited cell capacity of 6 Erlangs/cell and also a trunk-limited capacity of about 6 E. The DCA system has more than 3 times the capacity of the fixed frequency system. The reason is that a cell can select channels from the entire pool as needed to serve local traffic peaks.

The reuse calculations from (4) are relatively close to those obtained for DCA from the method of [6], despite the fact that different channel assignment mechanisms were assumed. The reason is that (4) assumes all 6 first-tier (nearest) cochannel cells are transmitting, which is a necessary assumption for the purposes of frequency planning (i.e., worst-case). In essence, fixed frequency assignment requires that a large margin be built into the reuse, which results in less efficient spectrum utilization.

ATTACHMENT 3

Specific Changes Proposed to Subpart D

(Proposed additions underlined, proposed deletions struck through)

Proposed Additions or Changes to §15.301

( ) Available band. A band (1910-1920 MHz or 1920-1930 MHz) is available to a coordinatable PCS device in a particular location if that location has been coordinated by UTAM, Inc. for that band, and if the device is designed to use that band.

( ) Cooperating Devices. A group of two or more devices among which there is RF communication that is coordinated either by a central control entity or by a distributed protocol. An example of a group of cooperating devices is a base station or access point and the portable units communicating with it.

(f) Peak transmit power. The ~~peak~~ maximum transmit power averaged over a time interval of at most 30/B (where B is the emission bandwidth of the signal), or the transmission burst duration, whichever is less, ~~output as measured over an interval of time equal to the frame rate or transmission burst duration of the device~~ under all conditions of modulation. Usually this parameter is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used.

Proposed Changes to §15.319

(a) The ~~1910-1920 MHz and~~ 2390-2400 MHz band~~s~~ is~~are~~ limited to use by asynchronous devices under the requirements of Section 15.321. The 1920-1930 MHz sub-band is limited to use by isochronous devices under the requirements of Section 15.323. The 1910-1920 MHz band is available to isochronous devices under the requirements of Section 15.323. That band is also available to asynchronous devices under the requirements of Section 15.321 (a) - (f) until [TBD].

(e) The peak transmit power shall be reduced by the amount in decibels that the maximum directional gain of the antenna exceeds 6~~3~~ dBi.

Proposed Changes and Additions to §15.321

(a) Prior to [TBD], o~~O~~peration of asynchronous devices shall be contained within either or both the 1910-1920 MHz and 2390-2400 MHz bands. After [TBD], new equipment authorization of asynchronous devices is limited to the 2390-2400 MHz band. ~~The emission bandwidth of any intentional radiator operating in these bands shall be no less than 500 kHz.~~

(b) The emission bandwidth of any intentional radiator operating in these bands under this Section shall be no less than 500 kHz. -All systems of less than 2.5 MHz emission bandwidth shall start searching for an available spectrum window within 3 MHz of the band edge at 1910~~,~~ or 1920 MHz (only for equipment authorized before [TBD]), or 2390~~,~~ or 2400 MHz, while systems of more than 2.5 MHz emission bandwidth will first occupy the center half of the band. Devices with an emission bandwidth of less than 1.0 MHz may not occupy the center half of the sub-band if other spectrum is available.

(e) ~~The requirements in this Section~~The emission limits of §15.321(d)~~The frequency stability of the carrier frequency of intentional radiators operating in this section shall be ± 10 ppm over 10 milliseconds or the interval between channel access monitoring, whichever is shorter. The frequency stability~~ shall be maintained over a temperature variation of -20° to +50° Celsius at normal supply voltage, and over a variation in the primary supply voltage of 85 percent to 115 percent of the rated supply voltage at a temperature of 20 degrees Celsius. For devices operating under the provisions of (c) above, the monitoring system bandwidth must allow for the effects of temperature and supply voltage variations on the emissions. -For equipment that is capable of operating only from a battery, the ~~frequency stability~~emission limit and monitoring bandwidth tests shall be performed using a new battery without any further requirement to vary supply voltage.

(h) As an alternative to requirements (b) and (c) of this Section, asynchronous devices may operate in the 2390-2400 MHz band under the following requirements:

(1) The transmit duty cycle of any individual device over any 1-second interval must not exceed 25%, unless it is a member of a group of cooperating devices.

(2) The aggregate transmit duty cycle of any group of cooperating devices over any 1-second interval must not exceed 50%.

Proposed Changes to §15.323

Section 15.323 Specific requirements for isochronous devices operating in the 1910~~1920~~-1930 MHz ~~sub~~-band.

(a) Operation shall be contained within one of sixteen~~eight~~ 1.25 MHz channels starting with 1910-1911.25~~1920-1921.25~~ MHz and ending with 1928.75-1930 MHz. Further sub-division of a

1.25 MHz channel is permitted with a reduced power level, as specified in Section 15.319(c), but in no event shall the emission bandwidth be less than 50 kHz.

(b) Intentional radiators with an intended emission bandwidth less than 625 kHz shall start searching for an available time and spectrum window within 5~~3~~ MHz of the ~~sub-band edge at 1920 MHz~~ lower edge of the available band(s) and search upward from that point. Devices with an intended emission bandwidth greater than 625 kHz shall start searching for an available time and spectrum window within 5~~3~~ MHz of the upper~~sub-band~~ edge of the available band(s)~~at 1930 MHz~~ and search downward from that point.

(c) (5) If access to spectrum is not available as determined by the above, and a minimum of 40 duplex system access channels are defined for the system, the time and spectrum windows with the lowest power level below a monitoring threshold of 50 dB above the thermal noise power determined for the emission bandwidth may be accessed. A device utilizing the provisions of this paragraph must have monitored all access channels defined for its system within the last 10 seconds and must verify, within the 20 milliseconds (40 milliseconds for devices designed to use a 20 millisecond frame period) immediately preceding actual channel access that the detected power of the selected time and spectrum windows is no higher than the previously detected value. The power measurement resolution for this comparison must be accurate to within 6 dB. No device or group of cooperating devices located within 1 meter of each other shall occupy more than ~~three~~ six 1.25 MHz channels during any frame period. Devices in an operational state that are utilizing the provision of this section are not required to use the search provisions of (b) above.

(c) (6) If the selected combined time and spectrum windows are unavailable, the device may either monitor and select different windows or seek to use the same windows after waiting an amount of time that exceeds 150 milliseconds, or is randomly chosen from a uniform random distribution between 10 and 150 milliseconds, commencing when the channel becomes available.