interfering with digital receivers. Investigations by NTIA[7] of several interference cases have identified two types of radar transmitter interference into digital receivers: receiver front-end overload caused by the radar transmitter fundamental frequency and radar transmitter spurious emissions into the bandwidth of the digital receiver. Based on these studies it was determined that the effect of radar pulsed emissions into digital receivers are a function of the coupling mechanism (front-end overload or spurious emissions), radar pulse train characteristics (peak amplitude, pulse width and the number of transmitted pulses), and the effect of the environment on the pulsed emissions (multiple coupling paths). In addition, the digital signal format (e.g., modulation type, multi-level signaling) and special signal processing circuitry (e.g., error correction coding, bit interleaving) influence the effects of the radar emissions.

SPECTRUM MONITORING

As stated in the Notice, as part of the spectrum etiquette procedures, the NII/SUPERNet devices must incorporate a listen-before-transmit feature and a search for available spectrum window (channel) feature. The listen-before-transmit feature requires the NII/SUPERNet device to monitor the channel for at least 50 microseconds (μsec) prior to data transmission with a maximum reaction time (integration time) on the order of 40 μsec. Other than starting the available channel search at the band edge, the details of the available channel search feature are not specified.

The technique of searching for an available channel can be a very effective technique in mitigating mutual interference with radar systems. However, to be effective it must be implemented to adequately detect typical radar signal characteristics. If the monitor period and reaction time proposed in the Notice are used in the available channel search, it will be ineffective in detecting radar use of the channel and in avoiding mutual interference with radars. Using the characteristics in Table A-1 of Appendix A, typical radar inter-pulse periods range from 10 to 1000 μsec. To effectively detect the pulsed radar signals in the band, a monitor period of at least 1 millisecond (msec) and a integration time of less than about 1 μsec would be required.

Because of the duration of the antenna scan rate and narrow beamwidth it is unlikely that the available channel search feature will detect a mainbeam radar signal. To be effective in detecting radar signals, the listen-before-talk and available spectrum search features (hereinafter referred to as the NII/SUPERNet spectrum monitoring system) must also have the ability to detect peak signals, not average signals during the spectrum monitoring period.

To further reduce the likelihood of mutual interference a technique of switching to an alternative frequency when a radar signal is detected could also be employed in the NII/SUPERNet spectrum monitoring system design. Switching to an alternate frequency would significantly reduce the mutual interference between radar systems and NII/SUPERNet devices.

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[7] NTIA 94-313 *supra* note 5; NTIA Report 90-260 *supra* note 2.

DETECTION OF RADAR SIGNALS

When the received signal from a radar transmitter operating in the 5150-5350 MHz and 5725-5875 MHz bands exceeds the spectrum monitoring threshold level, that frequency will be declared unavailable for data transmission. Radar transmitters operating in the 5 GHz frequency range have the ability to tune over a large frequency range and employ a wide transmitter bandwidth. This could result in the spectrum monitoring system declaring a channel as unavailable for NII/SUPERNet data transmission, thereby reducing the performance of the system.

The threshold level for the spectrum monitoring system is specified in the Notice, as not to be more than 32 dB above the thermal noise power of the receiver. This threshold level represents an interference-to-noise ratio (I/N) criteria for the NII/SUPERNet spectrum monitoring system receiver. The radar transmitter interference power level at the input to the spectrum monitoring system receiver is obtained using the following equation:

$$I = P_T + G_T + G_R - L_S - L_B - L_P$$

where

I is the radar transmitter on-tune interference power level at the input of the NII/SUPERNet spectrum monitoring system receiver (dBm);
P_T is the radar peak transmitter power (dBm);
G_T is the radar transmitter antenna gain (dBi);
G_R is the antenna gain of the NII/SUPERNet spectrum monitoring system antenna (dBi);
L_S is the radar coupling/insertion losses (dB);
L_B is the building attenuation losses (dB);
L_P is the propagation loss between the radar system and the NII/SUPERNet spectrum monitoring system.

The NII/SUPERNet spectrum monitoring system receiver noise power can be calculated using the following equation:

$$N = -114 + 10\log(BW) + NF$$

where

N is the NII/SUPERNet spectrum monitoring system receiver noise power (dBm);
BW is the NII/SUPERNet spectrum monitoring system receiver bandwidth (MHz);
NF is the NII/SUPERNet spectrum monitoring system receiver noise figure (dB).

Nominal characteristics for the ground-based radar transmitter and the NII/SUPERNet spectrum monitoring system receiver are given in Table B-1.

TABLE B-1. Nominal Characteristics for Ground-Based Radar Example

PARAMETER	VALUE
Radar Transmitter Peak Power	90 dBm
Radar Transmitter Emission Bandwidth	54 MHz
Radar Transmitter Median Sidelobe Antenna Gain	-8 dBi
Radar Transmitter Antenna Height	15 m
Radar Coupling/Insertion Losses	2 dB
NII/SUPERNet Spectrum Monitoring System Receiver Bandwidth	25 MHz
NII/SUPERNet Spectrum Monitoring System Receiver Noise Figure	0 dB
NII/SUPERNet Spectrum Monitoring System Receiver Antenna Gain	0 dBi
NII/SUPERNet Spectrum Monitoring System Receiver Antenna Height	15 m
Building Attenuation Losses	5 dB[8]

Many of the radars operating in the 5 GHz frequency range are used for the detection and tracking of airborne targets. The antenna mainbeam for these antennas will therefore be positioned above the horizon (e.g., reducing the effects of ground clutter). The NII/SUPERNet devices will therefore be illuminated by the sidelobes of the radar antenna not the mainbeam. The antenna gain for these radars will vary with time as the radar antenna rotates or scans in frequency, and can be described by a Gaussian distribution. In this analysis, the radar antenna gain is represented as a Gaussian distribution having a mean of -17 dBi and a standard deviation of 9 dB.[9]

Combining the equations for the interfering radar transmitter power and the NII/SUPERNet spectrum monitoring system receiver noise power yields:

$$I/N = P_T + G_T + G_R - L_S - L_B - L_P - N$$

Solving the equation above for the propagation loss between the radar transmitter and the

[8] U.S. Department of Commerce, National Telecommunications and Information Administration, NTIA Technical Memorandum 92-155, *Preliminary Building Attenuation Model* (May 1992).

[9] Electromagnetic Compatibility Analysis Center, ECAC-TN-74-07, *A Median Gain Model for Rotating Radar Antennas* (February 1974).

NII/SUPERNet monitoring system receiver results in the following equation:

$$L_P = P_T + G_T + G_R - L_S - L_B - N - I/N$$

The equation above gives the minimum propagation loss required for detection of a radar signal. Using the characteristics given in Table B-1 and the inverse mode of a smooth-earth propagation model, the maximum distance for detection of a radar signal is found to be:

$$D_{det} = 20 \text{ km}$$

If the distance between the NII/SUPERNet spectrum monitoring system receiver and the ground-based radar transmitter is greater than 20 km, the spectrum monitoring system will be less likely to detect the radar signal. However, if the distance separation between the NII/SUPERNet spectrum monitoring system receiver is less than 20 km, the radar signal can be detected and the frequency avoidance technique discussed in the previous section can be employed to mitigate mutual interference. The detection distance for airborne radar transmitters will be greater than the value calculated for ground-based radars.

RECEIVER SELECTIVITY CHARACTERISTICS

Receiver front-end overload (receiver desensitization) is a phenomenon that occurs when a low-noise, high gain, amplifier is located at the front-end of a digital receiver and is subjected to a strong signal from an external source (e.g., a high EIRP radar). When this condition occurs, the amplifier will not only gain compress at the frequency of the overloading signal, but also at all other frequencies in the amplifier's gain response band.[10] As it can be seen in Figures A-2 through A-5 of Appendix A, signal levels as high as -5 dBm (Figure A-4), which can cause front-end overload, are encountered in some portions of the 5725-5850 MHz band.

To mitigate the effects of front-end overload caused by adjacent-band high EIRP radar transmitters the NII/SUPERNet receiver design should include a filter with RF selectivity characteristics that significantly attenuate the radar transmitter's fundamental frequency. However, in the case of co-channel interference from high EIRP radar transmitters, receiver filtering will not reduce the effects of front-end overload. A peak signal limiter in the receiver front-end could also be employed to reduce the effects of front-end overload. When front-end overload occurs in a digital receiver, the performance degradation will be manifested as an increase in BER for slight gain compression, to a loss of synchronization for severe (long recovery time) gain compression. In general, the distance at which front-end overload from a radar transmitter occurs will vary depending

[10] If the input signal level at the amplifier does not exceed the threshold value, then the output gain of the amplifier will remain at its nominal design level. However, if the input signal level to the amplifier exceeds a critical threshold, then the gain characteristic of the amplifier will be reduced.

on the EIRP of the radar.

ROBUST RECEIVER DESIGN

To mitigate the effects of radar transmitter spurious emissions that degrade BER performance of a digital receiver a robust receiver design should be implemented. Typically the BER requirements for digital systems that transmit at high data rates as described in the Notice (20 - 25 Mbps) are on the order of 10^{-5} to 10^{-6}. If the pulse density from the high EIRP radar transmitters is high, it may be difficult to achieve the required BER unless additional signal processing is incorporated in the NII/SUPERNet receiver design. An error-correction algorithm, for example, may be incorporated to improve the receiver BER by adding code bits to the information bit sequence. The High Performance Radio Local Area Network (HIPERLAN) standard developed by the European Telecommunications Standards Institute (ETSI) employs forward error correction to enhance the basic bit error rate of the system.

Error correction coding is designed to correct independent errors. In the case of radar pulses, bit errors can be clustered together in bursts. To improve the performance of error correction, bit interleaving can also be employed. The use of bit interleaving is a way of enhancing the random-error correcting capabilities of a code, so that it is also useful in a burst interference environment. Many packet data systems similar to the NII/SUPERNet devices employ an error detection with retransmission protocol, called automatic repeat request (ARQ) error detection to mitigate the effects of burst interference.

SUMMARY

The technique of monitoring a channel before transmitting and searching for an available channel can be very effective techniques for minimizing mutual interference with radar systems, if implemented to adequately consider typical radar characteristics.

If the distance between the NII/SUPERNet spectrum monitoring system receiver and the ground-based radar transmitter is greater than 20 km, the spectrum monitoring system will be less likely to detect a ground-based radar signal. However, if the distance separation between the NII/SUPERNet spectrum monitoring system receiver is less than approximately 20 km, the radar signal can be detected and spectrum monitoring frequency avoidance techniques need to be employed.

Manufacturers of NII/SUPERNet devices should consider the radar characteristic described above in the design of their equipment to reduce the possibility of interference. Implementation of a robust receiver design to reduce the vulnerability of interference from high EIRP radar systems is essential. Such features as peak signal limiters, high efficiency error correction, bit interleaving, and error detection with retransmission protocols have proven useful in a number of similar situations. Experience has shown that digital systems operating in or adjacent to bands used by high EIRP radar systems must employ adequate receiver RF selectivity to achieve satisfactory system performance.

Receiver standards, either regulatory or industry developed, would be appropriate. Such technical considerations, as described above, incorporated early in the design of the NII/SUPERNet receivers would make them more compatible with high EIRP radar transmitters.

APPENDIX C
AGGREGATE EFFECTS ON RADIODETERMINATION SYSTEM PERFORMANCE

AGGREGATE EFFECTS ON RADIOLOCATION SYSTEM PERFORMANCE

Spectrum sharing between radar systems and NII/SUPERNet devices will generally have to consider two types of interference: 1) interference from a radar transmitter to the NII/SUPERNet receiver (discussed in Appendix B) and 2) the power-sum aggregate effects of a large number of NII/SUPERNet transmitters to a radar receiver. The difference in the effective radiated power of a radar transmitter (110 dBW) and the NII/SUPERNet transmitters (-10 dBW) is extremely large. For co-frequency use, such situations assure that the effects of interference from a radar transmitter to a NII/SUPERNet receiver will dominate over the reverse situation, making interference from a single NII/SUPERNet transmitter to a radar receiver highly unlikely. However, in areas where large numbers of NII/SUPERNet transmitters are used, the power-sum aggregate effects to a radar receiver must be taken into consideration.

NTIA used a computer program to estimate the power-sum aggregation at a terrestrial receiver from a distribution of co-channel terrestrial transmitters.[11] Using this capability an analysis to compute the power-sum aggregate emission level at a ground-based radar receiver for various numbers of NII/SUPERNet transmitters was performed. A ground-based radar was considered in this analysis because it represents the largest category of radars operating in the 5 GHz frequency range. Nominal characteristics for the NII/SUPERNet transmitter and the radar receiver are given in Table C-1.

TABLE C-1. Nominal Characteristics for NII/SUPERNet Transmitter and Radar Receiver

PARAMETER	VALUE
NII/SUPERNet Transmitter EIRP	-10 dBW
NII/SUPERNet Transmitter Antenna Height	15 m
Number of NII/SUPERNet Channels	14
NII/SUPERNet Device Duty Factor	50%
Radar Transmitter R.M.S. Sidelobe Antenna Gain	9 dBi
Radar Receiver Antenna Height	15 m
Radar Coupling/Insertion Losses	2 dB

[11] U.S. Department of Commerce, NTIA TM-89-139, *Single and Aggregate Emission Level Models for Interference Analysis* (March 1989).

Radar Receiver Bandwidth	25 MHz
Radar Receiver Noise Figure	5 dB
Building Attenuation Losses	5 dB

The scenario considered in this analysis was based on a population of NII/SUPERNet devices distributed in a series of concentric rings around the radar using an inner ring distance of 20 km and an outer ring distance of 30 km. The program automatically assigns the number of rings, ring separation, and number of transmitters per ring, for a symmetric distribution. A distance of 20 km was chosen for the inner ring distance based on the calculations in Appendix B. The results of the aggregate interference analysis are presented in Table C-2.

TABLE C-2. Aggregate Co-Channel Interference Levels from NII/SUPERNet Transmitters

Number of Active On-Tune NII/SUPERNet Transmitters	Aggregate Interference Level (dBm)	Interference-to-Noise (dB)
500	-115	-20
1,000	-112	-17
5,000	-105	-10
10,000	-102	-7
50,000	-95	0
100,000	-92	3

The number of active on-tune NII/SUPERNet transmitters given in Table C-2 range from 500 to 100,000. It should be noted that this analysis assumes all NII/SUPERNet transmitters have an antenna height of 15 m. However, in many instances the NII/SUPERNet transmitters will be located in multi-floor office buildings. This will increase the chance of an NII/SUPERNet transmitter being in the mainbeam of a radar, thus raising the aggregate interference levels shown in Table C-2. Furthermore, depending on the extent of the outdoor community network use, the aggregate interference levels computed above could increase significantly.

Table C-2 also gives the corresponding interference-to-noise ratio (I/N) for various numbers of NII/SUPERNet transmitters. The receiver noise power for the radar was calculated using the following equation:

$$N = -114 + 10 \log (BW) + NF$$

where

N is the radar receiver noise power (dBm);
BW is the radar receiver bandwidth (MHz);

NF is the radar receiver noise figure (dB).

Using a conservative criteria of I/N = -10 dB for the radar receiver protection threshold, the results in Table C-2 show that it would require the aggregate-sum of 5,000 NII/SUPERNet transmitters to exceed this threshold causing possible performance degradation to the radar system.

SINGLE-ENTRY AND AGGREGATE EFFECTS ON ADJACENT BAND RADIONAVIGATION SYSTEM PERFORMANCE

Spectrum sharing between NII/SUPERNet devices and adjacent band radionavigation systems will consider both single-entry and aggregate interference effects. The adjacent band radionavigation system considered in this analysis is the MLS that operates in the 5000-5150 MHz band. The NII/SUPERNet transmitter and MLS receiver characteristics[12] used in the analysis are given in Table C-3

TABLE C-3. Nominal Characteristics for NII/SUPERNet Transmitter and MLS Receiver

PARAMETER	VALUE
NII/SUPERNet Transmitter EIRP	-10 dBW
NII/SUPERNet Transmitter Bandwidth	25 MHz
NII/SUPERNet Transmitter Antenna Height	15m
Number of NII/SUPERNet Channels	14
NII/SUPERNet Out-of-Band Emissions	-50 dB
NII/SUPERNet Device Duty Factor	50%
MLS Receiver Bandwidth	150 kHz
MLS Co-Channel C/I Protection Criteria	25 dB
MLS Adjacent Channel C/I Protection Criteria	-20.5 dB
MLS Minimum Signal Strength	-95 dBm
MLS Antenna Gain	0 dBi
MLS Frequency Selectivity	> 40 dB (5.092-5.250 GHz) > 75 dB (> 5.250 GHz)

Single -Entry Interference Effects

[12] ICAO Standards and Recommended Practices relating to MLS Airborne Receivers, Annex 10; CAP 208.

In the Notice, the Commission is proposing to require that all emissions ocurring from NII/SUPERNet devices outside of the 5150-5350 MHz and 5725-5875 MHz bands be attenuated by at least 50 dB or to the radiated emission limits set forth in Section 15.209[13], whichever is the lesser attenuation. In addition the Commission is proposing that any emissions ocurring in the restricted bands[14] comply with the radiated emission limits set forth in Section 15.209. The Commission believes that these out-of-band emission limits will provide sufficient protection against harmful interference to adjacent band and harmonically related radio operations. Moreover, the Commission is proposing to amend Section 15.205 to delete the listing of 5150-5250 MHz as a restricted band.[15]

The out-of-band emission limit of 50 dB for the NII/SUPERNet transmitter signals below 5150 MHz and MLS receiver selectivity characteristic of greater than 40 dB attenuation for signals between 5092-5250 MHz from Table C-3 will be used to determine if single-entry adjacent band interference exists. Using these values it can be seen that the out-of-band emissions from a NII/SUPERNet transmitter will be 10 dB below the specifed MLS receiver attenuation. Therefore interference from a single adjacent band NII/SUPERNet transmitter will not cause interference to an MLS receiver.

Aggregate Interference Effects

NTIA has developed a program to estimate the power-sum aggregation into an aircraft receiver.[16] The program computes the power-sum aggregate interference at an airborne receiver by modeling the emitter distribution and integrating their collective effect under free-space propagation. The user specifies the aircraft altitude, the emitter density, the emission level, and the emission frequency. Using these values, the program determines the number of emitters in the field-of-view of the aircraft and computes the aggregate power-sum into the aircraft receiver.

The scenario considered in this analysis used a landing aircraft altitude of 50 ft, and an emitter distribution radius of 10 km. Building attenuation losses (5 dB) and receiver insertion/cable losses (2 dB) are also included in the analysis.

The analysis will consider the effects of both in-band aggregate spurious emissions and adjacent channel aggregate interference from the NII/SUPERNet transmitters. For aggregate in-band

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[13] *See* 47 C.F.R. § 15.209.

[14] *See* C.F.R. Section 15.205.

[15] Only spurious Part 15 emissions are permitted in restricted band. Restricted bands are those allocated for services involving safety-of-life or for services that are required by the nature of their operations to use signals received at very low received levels. See First Report and Order, GEN. Docket No. 87-389, 4 FCC Rcd. 3493 (1989).

[16] NTIA TM-89-139, *supra* note 11.

spurious emissions the out-of-band emission level of 50 dB proposed by the Commission will be used. Since the model assumes co-frequency operation, the adjacent channel aggregate interference level will include a factor for the frequency dependent rejection (FDR) in the analysis. FDR is the attenuation of the NII/SUPERNet transmitter signal power by the MLS receiver because of on-tune and off-frequency rejection. The on-tune rejection (23 dB) occurs because of the limited bandwidth of a MLS receiver with respect to the NII/SUPERNet emission bandwidth. The off-frequency rejection (40 dB) is the rejection provided by the MLS receiver selectivity for frequencies below 5150 MHz. The results of the aggregate interference analysis are presented in Table C-4.

TABLE C-4. Aggregate Interference Levels from Adjacent Band NII/SUPERNet Transmitters

Number of Active Adjacent Band NII/SUPERNet Transmitters	Aggregate In-Band Spurious Emission Interference Level (dBm)	C/I (dB)	Aggregate Adjacent Channel Interference Level (dBm)	C/I (dB)
500	-137	45	-139	47
1,000	-134	42	-136	44
5,000	-127	35	-129	37
10,000	-123	31	-126	34
50,000	-116	24	-119	27
100,000	-113	21	-116	24

The number of active adjacent band NII/SUPERNet transmitters given in Table C-4 range from 500 to 100,000. Above 100,000 represents a worst-case scenario insofar as it corresponds to a mature system in an urban environment operating at its peak traffic load. It is anticipated that the number of NII/SUPERNet transmitters in rural areas will be much less.

Interference to the MLS receiver will be assessed in terms of carrier-to-interfernce (C/I) ratio as given in Table C-4. The C/I represents the number of dB by which the power level of the desired signal "C" at the input of the MLS receiver exceeds the aggregate power level of the undesired signal "I" at the same point in the receiver. The C/I ratios calculated in this analysis do not include the effects of signal processing performed by the MLS receiver. The desired signal used in this analysis was the value of minimum signal strength of -95 dBm specified in Table C-3.

Using a co-channel C/I protection criteria of 25 dB and an adjacent channel protection criteria of -20 dB, the results in Table C-4 indicate that even for high numbers of active NII/SUPERNet transmitters the calculated C/I values are above the C/I protection criteria specified for the MLS receiver. Depending on the extent of the outdoor community network use, the aggregate interference levels computed in Table C-4 could increase significantly.

SUMMARY

The results indicate that as the NII/SUPERNet devices proliferate, the power-sum aggregation of emission from co-channel NII/SUPERNet transmitter can degrade the operational performance of a ground-based radar system. However, if the NII/SUPERNet devices employ a spectrum monitoring procedure as discussed earlier, co-frequency use with radars can be minimized, reducing the effects of aggregate interference. The results also indicate that the aggregate effect of NII/SUPERNet transmitters will not cause interference to radionavigation sytems operating in the adjacent band. The levels of potentially interfering emissions will alos depend on the ratio of indoor to outdoor use. Depending on the extent of outdoor community network use, the aggregate interference levels computed in this analysis could increase significantly. The out-of-band emission limit of 50 dB proposed by the Commission for the NII/SUPERNet transmitters appears to be reasonable and should preclude interference to adjacent band radionavigation systems. This value for the out-of-band emissions is consistent with other digital and unlicensed standards.

APPENDIX D
PROPOSED BANDS FOR NII/SUPERNet OPERATIONS

SPECTRUM REQUIREMENTS OF NII/SUPERNet DEVICES

In the Notice, the Commission seeks comment on whether 350 MHz of spectrum is necessary to support the proposed NII/SUPERNet operations. The WINForum petition for rule making, provided a spectrum requirements analysis that estimated the amount of spectrum needed for broadband wireless networks.[17] The estimate of spectrum requirements included both voice and data applications and ranged from 194 MHz (low density environment) to 388 MHz (high density environment).[18] Without examining each of the parameters used in determining the spectrum requirements, there is one parameter that must be addressed in more detail, the modulation efficiency.

The type of modulation used is a major factor in the development of spectrum requirements. The WINForum spectrum requirements analysis uses a modulation efficiency of 1 bit per second per Hertz of bandwidth (b/s/Hz) , corresponding to a 2-level modulation scheme. This means that one data bit is transmitted per symbol. Although easy to implement and relatively inexpensive, two-level modulation schemes are not spectrally efficient.

As discussed in the next section, multi-level digital modulation techniques are currently being employed in wireless applications and are able to transmit two, three, or four bits per symbol. Transmitting more bits per symbol makes it possible to greatly increase the amount of data transmitted in a given bandwidth. Bandwidth efficiencies of between 2 to 4 b/s/Hz are currently achievable at a reasonable cost and would reduce the spectrum requirements of the NII/SUPERNet devices. For example, if a 4-level modulation scheme were used by the NII/SUPERNet devices, twice as much data can be transmitted as compared to a 2-level modulation scheme, in essence reducing the spectrum requirements from the 350 MHz proposed by the Commission to 175 MHz.

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[17] *See* WINForum Petition, at A-1.

[18] Low density and high density are used to denote environments in which the walls are present or absent.

The choice of digital modulation technique is influenced by error performance, spectral characteristics, implementation complexity, and other factors peculiar to the specific application. Binary modulation schemes provide good error performance and are simple to implement, but they lack the bandwidth efficiency required for most practical applications. Hence the recent emphasis has been on multi-level modulation schemes that provide the necessary bandwidth efficiency. The use of spectrum efficient multi-level modulations techniques as well as improvements in digital signal processing should be included in the spectrum requirements analysis for the NII/SUPERNet devices. For example, if a 4-level modulation scheme were employed, the spectrum requirements for the NII/SUPERNet devices could be satisfied by 175 to 200 MHz. Moreover, using digital modulation techniques that are more spectrally efficient will have the added benefit of allowing more users in a given geographic area.

BANDWIDTH EFFICIENCY OF NII/SUPERNet DEVICES

In the Notice, the Commission requests comment on whether a minimum bandwidth efficiency should be specified for the NII/SUPERNet devices. Bandwidth efficiency is expressed in bits per second per Hertz of bandwidth (b/s/Hz). Two broad classes of digital modulation are constant-envelope and linear modulation. Constant-envelope modulation schemes include Frequency Shift Keying (FSK) and Minimum Shift Keying (MSK). Linear modulation schemes such as Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM), which use linear power amplifiers, can achieve bandwidth efficiencies of greater than 1 b/s/Hz. Linear modulation schemes have the property that increasing the modulation level increases the bandwidth efficiency. Table D-1 compares various digital modulation techniques on the basis of their theoretical and practical bandwidth efficiencies.

TABLE D-1. Performance of Digital Modulation Schemes*

Modulation Technique	Bits per Symbol	Theoretical Required Bandwidth (Hz)[19]	C/N (dB)	E_b/N_0 (dB)	Theoretical Bandwidth Efficiency (b/s/Hz)	Practical Bandwidth Efficiency (b/s/Hz)
2-level PSK (BPSK)	1	R	11.7	10.6	1	0.75
4-level PSK (QPSK)	2	R/2	13.6	10.6	2	1.5
8-level PSK	3	R/3	18.8	14.0	3	2.25
8-level QAM	3	R/3	13.6	10.6	3	2.25

[19] R is the data rate of the system in bits per second.

16-level PSK	4	R/4	24.3	18.3	4	3
16-level QAM	4	R/4	20.5	14.5	4	3

* BER of 10^{-6} was assumed

Multi-level modulation techniques have made steady progress in digital applications in recent years. The use of multi-level modulation schemes makes it possible to greatly increase the amount of data carried in a given bandwidth. Today 16-level PSK systems, which transmit four bits per symbol, are quite common. However, an increase in the number of modulation levels used must be traded off with a higher required transmit power.

As stated above, 16-level modulation schemes are common place today resulting in a bandwidth efficiency of 4 b/s/Hz. The U.S. digital cellular systems TIA/EIA[20] IS-136 interim standard recommends using B/4 Differential Quadrature Phase Shift Keying (B/4 DQPSK) with a bandwidth efficiency of 2 b/s/Hz. Moreover, one of the modulation schemes that is being considered for the HIPERLAN standard is B/4 DQPSK.

Providing a throughput of 25 Mbps in a 25 MHz channel, which corresponds to a bandwidth efficiency of 1 b/s/Hz, as suggested in the Notice is spectrally inefficient. In the Notice it is proposed that there should be some value of minimum bandwidth efficiency applicable to the NII/SUPERNet devices. Given the technology that is currently available, a bandwidth efficiency of between 2 to 4 b/s/Hz appears to be obtainable at a reasonable cost. Bandwidth efficiencies in this range are a good compromise between spectrum efficiency and cost.

The adoption of a strict bandwidth efficiency at the outset of an emerging service may have a dampening effect on its rapid implenentation. A more practical approach may be the adoption of effective bandwidth efficiency requirements that would come into effect at a future date. This would help to achieve both goals, that of fostering rapid development of NII/SUPERNet devices, while also promoting more spectrum efficient operations as the technology matures.

PROPOSED USE OF THE 5150-5350 MHz BAND

The harmonization of U.S. spectrum allocations with European spectrum allocations is considered a highly desirable objective and a benefit to U.S. manufacturing. In response to the Apple and WINForum petitions for rulemaking, many of the commenting parties supported adoption of standards that will allow for compatibility with the HIPERLAN standard developed by ETSI. The HIPERLAN standard includes 150 MHz of spectrum allocated at 5150-5300 MHz.

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[20] Telecommunications Industry Association/Electronic Industries Association (TIA/EIA) is an advisory group that develops standards and prepares publications used by the telecommunications industry.

The HIPERLAN standard has been under development in Europe for 5 years. At this time the standard has not been approved and implemented, but some European countries have allocated 5150-5250 MHz (100 MHz) for such systems while other countries have allocated 5150-5300 MHz (150 MHz). The 5150-5350 MHz band proposed for NII/SUPERNet devices is intended to be equivalent to the HIPERLAN allocation. To maintain global compatibility an allocation of 5150-5350 MHz for NII/SUPERNet operations in the U.S. would seem appropriate.

In order to promote sharing with NII/SUPERNet devices and future aeronautical radionavigation safety-of-life systems in the 5000-5250 MHz frequency range a band segmentation approach should be employed, where the lower power indoor NII/SUPERNet devices would operate in the 5150-5250 MHz band segment. The EIRP limit of -10 dBW proposed by the Commission seems reasonable for short range communications (50 to 100 meters). The outdoor longer range community network links would then be restricted to the upper segment 5250-5350 MHz. The indoor NII/SUPERNet devices would also be permitted to operate in the 5250-5350 MHz band segment. For the outdoor community network links a maximum path length of 1 to 2 km consistent with the HIPERLAN system would seem to be a good compromise between satisfying the campus-type network requirements and limiting interference to other users. A transmitter power of 1 W and an antenna gain of 6 dBi could be used for these links providing adequate margin for fading and other link imperfections.

PROPOSED USE OF THE 5725-5875 MHz BAND

In the Notice, the Commission states that they are not proposing to accommodate the higher power longer range community networks in the 5150-5350 MHz band, because permitting such high power operations would not allow spectrum sharing among multiple users. However, the Commission still believes there is merit in the concept of longer range community networks and they are seeking comment on whether the community network operations should be permitted in the 5725-5875 MHz band.

A band segmentation approach similar to that used in the 5150-5350 MHz band will also be used in the 5725-5875 MHz band. In the 5725-5850 MHz band, the outdoor longer range community network operations would be permitted with a maximum path length of 1 to 2 km. As stated earlier a transmitter power of 1 W and an antenna gain of 6 dBi would be sufficient for these links. The lower power indoor NII/SUPERNet devices would also be permitted in this band segment and would operate with an EIRP limit of -10 dBW.

The upper band segment (5850-5875 MHz) would then be limited to the lower power indoor NII/SUPERNet devices with an EIRP limit of -10 dBW. Restricting the community network operations to the 5725-5850 MHz band segment preserves the opportunity to accomodate the Dedicated Short Range Communications (DSRC) which is an integral component of the Intelligent Transportation System (ITS) services by limiting the use of this band segment to indoor NII/SUPERNet devices. Limiting the 5850-5875 MHz to indoor operations will also faciliatte sharing with the military's transportable satellite earth stations that operate in the 5850-6425 MHz

band.

ALTERNATE BANDS FOR COMMUNITY NETWORK OPERATIONS

The preceeding pargaraphs addressed the community network operations permitting a maximum link distance of 1 to 2 km. However, even longer range community network links (e.g., 10 to 15 km) in the 5725-5875 MHz band have been proposed. Although the 5725-5850 MHz portion of this band is a potential candidate for such operations, examining the compatibility with the existing radar environment is much more complex. As indicated in Figure A-1 of Appendix A, the distribution of frequency assignments is much less in the 5150-5350 MHz band (71 assignments) as compared to the 5725-5875 MHz band (288 assignments). Since the 5725-5875 MHz band is more heavily used by radars, the signal levels encountered will be significantly higher as shown in Figures A-2 and A-4 of Appendix A. The higher concentration of radar transmitters will also increase the likelihood of mutual interference with NII/SUPERNet devices. Based on the analysis performed in Appendix C, as the NII/SUPERNet devices proliferate the aggregate interference levels encountered by radar receivers will increase, causing performance degradation to radar systems in the immediate vicinity. Successful operation of community network links will depend on geographic separation from the high-power radar systems operating in the band. All efforts should be made to avoid operating community network links near the following military test ranges:

1) Weapons and Tactics Center, Nellis AFB Nevada;
2) Air Force Eastern Test Range, Patrick AFB, Florida;
3) Pacific Missile Test Center, Pt. Mugu, California;
4) Army Electronic Proving Ground, Ft. Huachuca, Arizona;
5) White Sands Missile Range, Las Cruces, New Mexico.

Further complicating the situation in the 5725-5875 MHz band is the on-going rule making proceeding in ET Docket No. 96-8 that proposes to eliminate the limit on directional gain antennas, thus authorizing long range unlicensed links using spread spectrum techniques in the 5725-5875 MHz band. At this point in time, the compatability analyses of these long range links with the existing radar environment have not been completed by NTIA or others proposing the NII/SUPERNet devices or spread spectrum systems. The NII/SUPERNet rule making should proceed except that any possible action on long range community network links in the 5725-5850 MHz band be deferred for a further Notice of Proposed Rulemaking. The primary concern is that if community network operations are permitted with no EIRP limits, the 5725-5875 MHz band could become a *de facto* unlicensed point-to-point microwave band.

A great deal of emphasis has been on unlicensed equipment to support community networking operations. However, longer range community network operations (e.g., greater that 1 to 2 km) could be supported by licensed equipment in the 18, 23, or 38 GHz bands, where spectrum and equipment are readily available. Due to the specific nature of applications and technology used at these frequencies, costs and required installation time are kept at very low levels compared with more traditional microwave systems. Estimates range from less than $20,000 - $25,000 per 18 GHz

hop to less than $15,000 per hop in the higher bands. In contrast, current unlicensed DS-1 (T1) radios typically cost $18,000 per hop. Moreover, licensed equipment in the price range is capable of operating at twice the capacity as the unlicensed equipment and is available for even higher speed applications.[21]

SUMMARY

The justification for the requirement for 350 MHz of spectrum for the NII/SUPERNet devices appears to be based on a spectrum efficiency of 1 b/s/Hz. If a more spectrum efficient modulation scheme, such as B/4 DQPSK with a theoretical bandwidth efficiency of 2 b/s/Hz, were employed in the design of the NII/SUPERNet devices the stated spectrum requirements could be satisfied in less than 200 MHz. Employing spectrum efficient modulation techniques in the NII/SUPERNet design would benefit all users by allowing more devices to operate in the same geographic area. The European HIPERLAN standard has 150 MHz allocated in the 5150-5300 MHz band. To maintain global compatibility an allocation of 5150-5350 MHz for U.S. NII/SUPERNet operations would seem appropriate. However, to protect the development of the next generation of air traffic control systems it is recommended that community network operations should not be permitted in the 5150-5250 MHz band segment. Similarly, to reduce the potential impact on communication systems supporting the Intelligent Transportation System and the military's transportable satelllite earth stations, it is recommended that community network operations should not be permitted in the 5850-5875 MHz band segment. In the 5250-5350 MHz and 5725-5850 MHz bands community network operations having communication ranges of 1 to 2 km comparable to those allowed by the European HIPERLAN system should be permitted. The emphasis has been on unlicensed equipment to support community networking operation. However, the compatibility of the longer range community network operations in the 5 GHz frequency range has not been addressed. The longer range community network operations could be supported by licensed equipment in the 18, 23, or 38 GHz bands, where spectrum and equipment are readily available.

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[21] Telecommunications Industry Association comments in response to ET Docket No. 96-102, at 7.