IEEE P802.11
Wireless LANs

Proposal for a Wireless Personal Area Network Medium Access Control and Physical Layer Protocol

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Abstract

The following proposal is provided in response to the Call For Proposals [ref: doc.: IEEE 802.11-98/199] by the IEEE 802.11 Wireless Personal Area Network Study Group. The intention of this proposal is to provide the Study Group a benchmark on disclosure such that the group will begin to communicate more freely and that the IEEE 802.11 Working Group can begin to understand the WPAN applications and the impact on protocols used.

This proposal was originally written in response to a vertical application AMP Wireless Systems reviewed in September 1997.

This WPAN application had to be capable of providing a communications environment in which multiple devices, either mobile worker tools, or devices that provide gateway services to wide area network (WAN), can autonomously attach themselves to each other and communicate in a peer-to-peer mode. Overlap from, and interaction between adjacent WPANs will be frequent and should be considered in the proposed network architecture. While some level of RF interference may be unavoidable, and only resolved by additional physical separation, the communications integrity of the WPAN must be maintained, preventing the inadvertent transfer of data between WPANs. If a hub function is required for the attachment and coordination of the RF components of the WPAN, the failure of the hub device should not result in the loss of connectivity between the remaining devices.

Since these devices are intended to provide productivity enhancements for the users, the communications architecture must be designed to minimize the amount of time that users devote to activities related to interfacing with the communications networks and devices. The communications protocol and applications software must be consistent with this approach. Furthermore, since most of the devices utilized by the mobile work force are small and require battery power, all communications devices must be designed with power efficiency and size as key considerations.

The WPAN Technical Guidelines and/or Functional Requirements may not be addressable by the following MAC & PHY Layer Proposal but we wanted to disseminate our approach anyway.

Note: We anticipate using other higher OSI layer standards to enable WPANs e.g., Wearable Computers w/ Power Management via Smart Battery Specification (SBS), Advanced Configuration and Power Interface (ACPI), etc.

AMP WIRELESS SYSTEMS

1. Purpose

The proposed Wireless Body LAN is a wireless local area network intended to support up to 16 devices which are carried by the operator, or in close proximity to the operator.

2. Summary

frequency:	2400 MHz ISM band
spreading:	slow frequency hopping
maximum transmit power:	0.75 mW
effective operating range:	15 meters
channel bandwidth:	150 kHz
number of channels:	556
bit rate:	40 kbps
modulation:	Manchester FSK
sleep mode duty cycle:	between 10:1 and 100:1 depending upon device

3. Physical Layer

We propose using the 2400 MHz ISM band with a maximum device power output of 0.75 mW. This should provide a range of about 15 meters, including 15 dB margin for Rayleigh fading and 12 dB margin for 95% confidence interval. Under free space conditions the interference range of this device may be more than one kilometer.

Background manmade noise at 2400 MHz is expected to be minimal, with the exception of noise generated by other ISM band devices. Specifically, under certain scenarios it is possible that as many as a hundred Body LAN systems could be operating within 200 meters, with the strong likelihood that these devices will all interfere with each other.

The recommended spreading technique is slow frequency hopping, with a subscriber device transmitting one block of data on each channel.

A bandwidth of 150 kHz is recommended to take advantage of inexpensive IF filters developed for consumer FM radios. This permits 556 channels across the 2400 MHz ISM band.

A bit rate of 40 kbps is suggested, using Manchester FSK. This modulation technique is very simple to demodulate and can use an AC coupled radio, permitting a very inexpensive radio and modem combination. A bit rate of 40 kbps is proposed to minimize device power consumption.

3.1 Interference From Other Body LANs

Provided that the other Body LANs are uniformly distributed over the available channels, the probability of collision with other Body LANs on a given hop can be calculated. Since there is no synchronization between Body LANs, when a user's radio hops to a given frequency it could interfere with two hops by another user.

The probability of sole use of the frequency is given by:

$P_s=(1-2/n)^{m-1}$ n= number of channels

m= number of Body LANs transmitting simultaneously

	100 Body LANs	*30 Body LANs*
556 channels	*0.6999*	*0.8975*

3.2 Pseudo-random Hopping Sequences

Number the channels from 1 through 556. Each BodyLAN during attachment selects at random a number "m" between 1 and 556. This number "m" is used for the remainder of the day's operation.

next channel = (last channel + m) modulo 557

If next channel = 0 or 1, repeat the next channel calculation (0 is an invalid channel number).

Since 557 is a prime number, it has no common factors with the number "m", and the probability of selecting any channel between 2 and 556 will be a uniform distribution. All channels will be covered before the pattern repeats.

Channel 1 is reserved for attachment.

4.

Error Detection and Correction Coding

4.1 Characterization of the 2.4 GHz Channel

Figure 1 shows signal amplitude for a typical wideband Rayleigh channel plotted against frequency and distance. It can be seen from the diagram that as an individual moves spatially or as his radio hops through the spectrum, he will experience Rayleigh fading. Note that the Rayleigh fading is very similar in both space and frequency, and that because of the frequency selective nature of the channel a very simple mechanism for avoiding a multipath fade is to hop to a different frequency within the channel.

Figure 1 Rayleigh Fading Amplitude Plotted Against Frequency and Distance

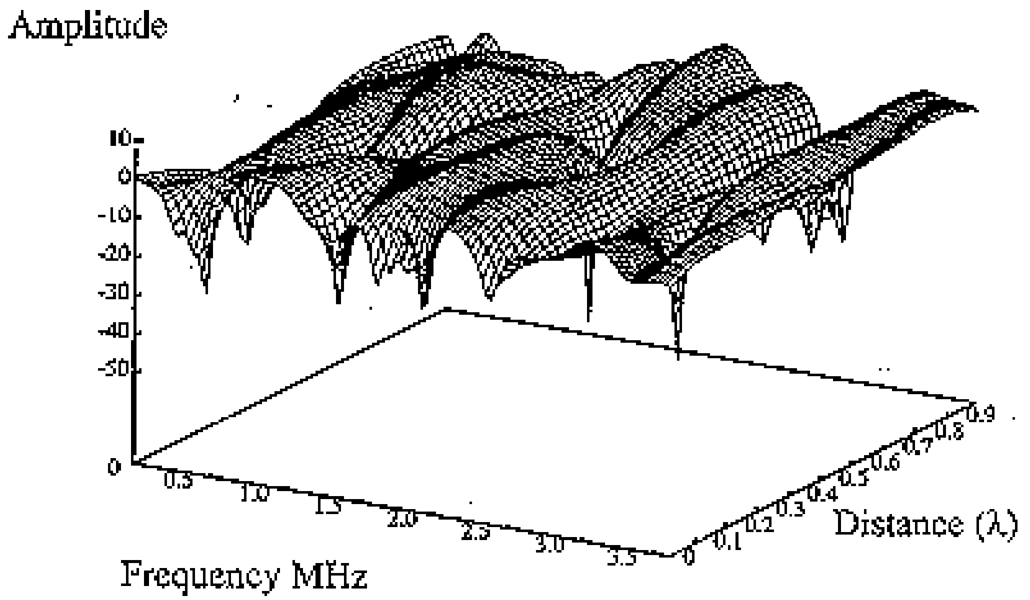


Figure 2 shows signal amplitude plotted against frequency for a 160 MHz “window” of spectrum at 2.6 GHz. Figures 3 and 4 show the same spectrum in greater detail. It can be seen from these diagrams that for the majority of hops, a 150 kHz slice of spectrum will be within a few dB of the median signal level -- only rarely will the desired spectrum be in a fade.

Figure 2 – 160 MHz Window at 2.6 GHz

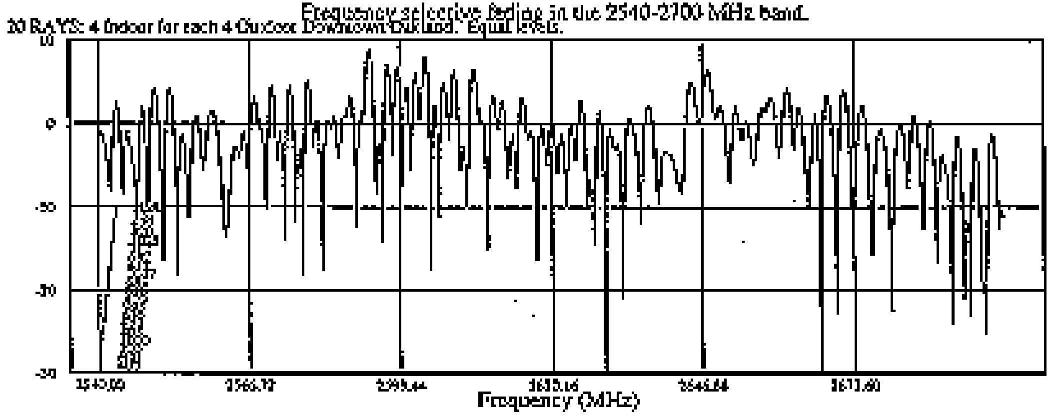


Figure 3 – 3 MHz Window at 2.6 GHz

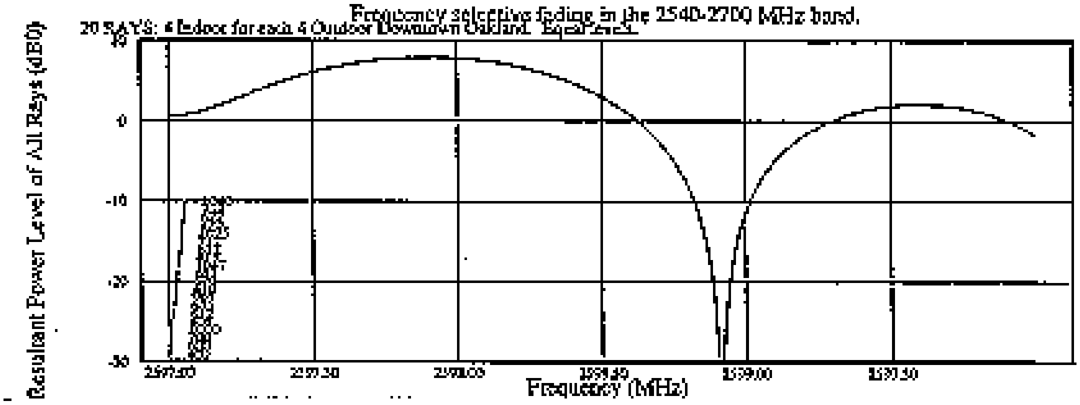
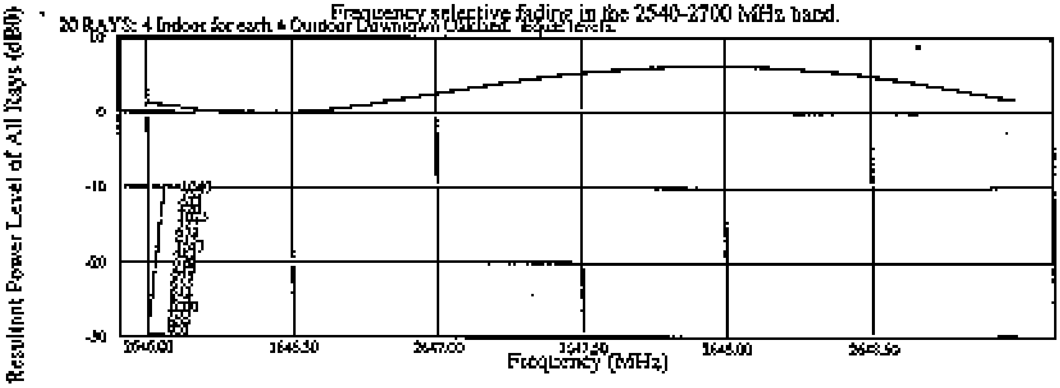


Figure 4 — 3 MHz Window at 2.6 GHz



For a Rayleigh-faded signal, a general rule of thumb is that 10% of the time the signal envelope will be 10 dB below the median level, 1% of the time it will be 20 dB below the median level, and 0.1% of the time it will be 30 dB below the median.

4.2 Error Detection and Correction Coding Strategy

Slow frequency hopping provides a very simple mechanism for avoiding the negative effects of multipath fading. With the expected Rayleigh fading margin of 27 dB, fewer than one hop in a hundred should be affected by Rayleigh fading. If a hop is affected, the block is lost and can be retransmitted on the next hop. It then becomes necessary to correct only for Gaussian bit errors, and to provide a robust error detection strategy. These can be done with linear codes which can be implemented in shift registers, reducing the data latency and substantially simplifying the implementation relative to using more complex block codes such as the Reed Solomon (63,45) code.

The Reed Solomon block code will handle about a 2% bit error rate (9 bits out of 378) in AWGN, while a constraint length 7 convolutional code will handle about a 14% bit error rate (2 bits out of 14) in the same environment, with an enormous reduction in complexity. The main strength of the Reed Solomon code is in a fading environment, where it can correct a maximum fade of 54 bits out of 378 (14%). The convolutional code can be implemented simply in serial logic using a shift register and a few gates.

The recommended error detection and correction coding strategy is to use a convolutional code for error correction, and a cyclic redundancy code (CRC) for error detection. This is coupled with a 27 dB margin for Rayleigh fading, and the ability to avoid a deep fade on one channel by retransmitting on the next hop at a different frequency, which hopefully will be unaffected by the fade.

5.

Proposed Body LAN System Protocol

5.1 Physical Layer

The radio will transmit 40 Kbps Manchester modulation at a maximum power level of 0.75 mW. The spectrum between 2400 MHz and 2483.5 MHz will be divided into 556 simplex channels spaced 150 KHz apart, and numbered 1 through 556.

5.2 Medium Access Layer

5.2.1 Attachment

Attachment would be made simpler if one of the devices has a bar code scanner; that device (refered to as the "lead device") would take the lead during the attachment process.

It is assumed that each device has an electronic serial number which is specified by a bar code label. To attach a device, the operator will put both the lead device and the device to be attached in the attachment mode (perhaps by invoking an attachment screen on the lead device, and by power cycling the device to be attached). In the attachment mode, both the lead device and the device to be attached will go to a channel reserved for attachment (channel 1), where the lead device will send a single block message to the device to be attached, requesting attachment and indicating the device electronic serial number, new port address, hopping sequence "m", and first hop frequency. The device to be attached will acknowledge this message then move to the specified frequency, where it will camp and wait for a beacon message.

5.2.2 Frequency Hopping

All devices in the Body LAN network will hop in unison over the 555 hopping channels, in a pseudo random sequence which ensures that in 555 hops each channel will be hit exactly once. Prior to the first attachment, the lead device will select at random a number "m" between 1 and 556. The first channel in the hopping sequence is always channel 2. Subsequent channels are determined by adding the selected number "m" modulo 557, i.e.

$f_{n+1} = (f_n + m)$ modulo 557 m is a number selected at random $1 \leq m \leq 556$

if $f_{n+1} = 0$ or 1, a new f_{n+1} is calculated $(2 \leq f_{n+1} \leq 556)$

5.2.3

Data Formats

5.2.3.1 Message Blocks

Messages are formatted into blocks as shown below:

20	15	270 + 270	32 + 32	14
PR	SYNC	DATA	CRC 32	T

653 bits/17ms

The preamble sequence is all ones, which in Manchester modulation translates into an alternating sequence of ones and zeroes which is optimum for clock recovery.

The sync sequence is a 15 bit PN sequence '000100110101111'. The data field is 270 bits. Error detection is provided by a CRC32, which has a probability of undetected error of 2.3×10^{-10} .

Error correction is provided by a rate one half constraint length seven convolutional code, which is capable of correcting two bit errors over a span of 14 bits (7 data and 7 parity). This code can be easily implemented with shift registers and majority logic decoding, so is amenable to implementation in ASIC. It was adopted by NASA for their Planetary Standard, and was used in the Voyageur mission. At the end of the data block are 14 tail bits required to flush the convolutional encoder shift register.

Messages larger than 270 bits are formatted into a series of data blocks for transmission, each block including an 8 bit sequence number. The maximum message length is 8640 bytes.

5.2.3.2 Beacon Message

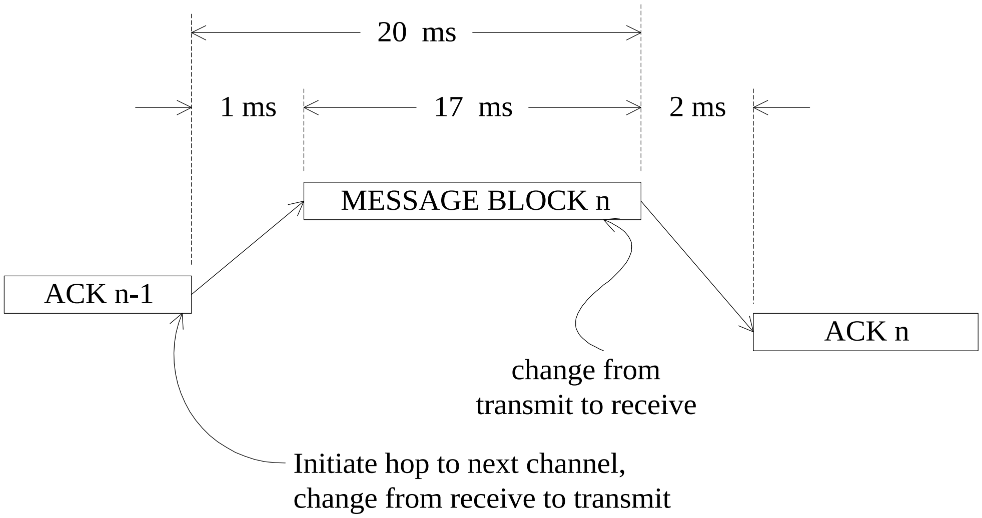
The Beacon format is shown below

20	15	20 + 20	32 + 32	14
PR	SYNC	DATA	CRC 32	T

153bits / 4ms

The Beacon message is a shortened form of a standard message block

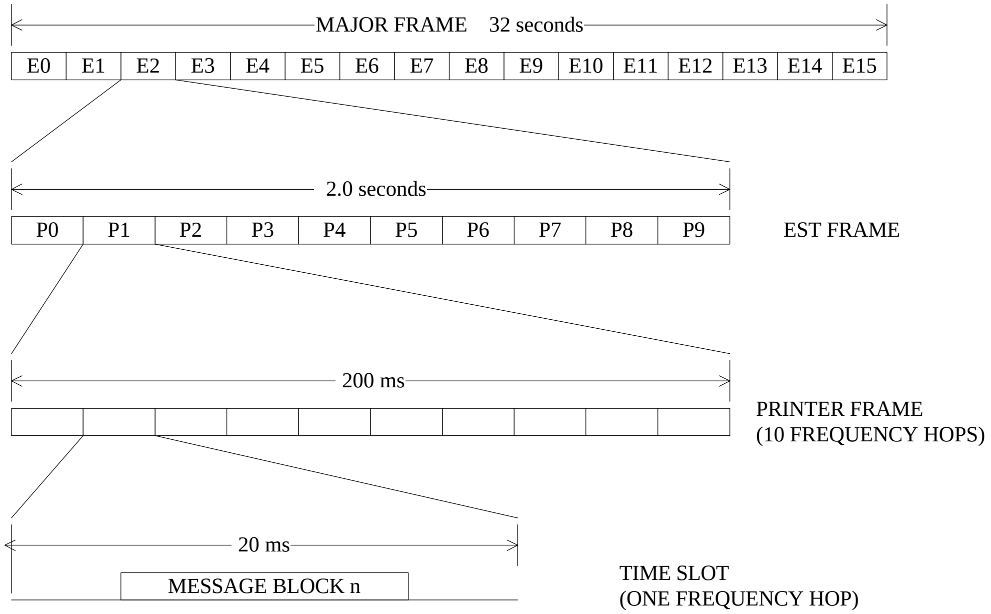
5.2.4 Time Slot Structure



Each time slot is 20 ms in length, as shown in the diagram above. The time slot begins with a 1 ms guard period while the radios hop to the next channel, and perhaps from receive to transmit. After the message block is another 2 ms guard period permitting a device to change from transmit to receive. The ACK refers only to the preceding message block.

5.2.5 Frame Structure

The protocol frame structure is shown in the diagram below:



A major frame is 32 seconds and consists of 16 EST sleep cycles. Each EST sleep cycle is 2.0 seconds and consists of 10 printer sleep cycles. A printer sleep cycle is 200 ms in duration and consists of 10 time slots, each of 20 ms duration.

A beacon message is transmitted in the first slot of each EST frame. The first beacon message in each major frame is transmitted in the first time slot of EST frame 0, by the Body LAN device with port address 0. Subsequent beacon messages are transmitted by devices with port addresses 1 through 15.

5.2.6 Sleep Mode

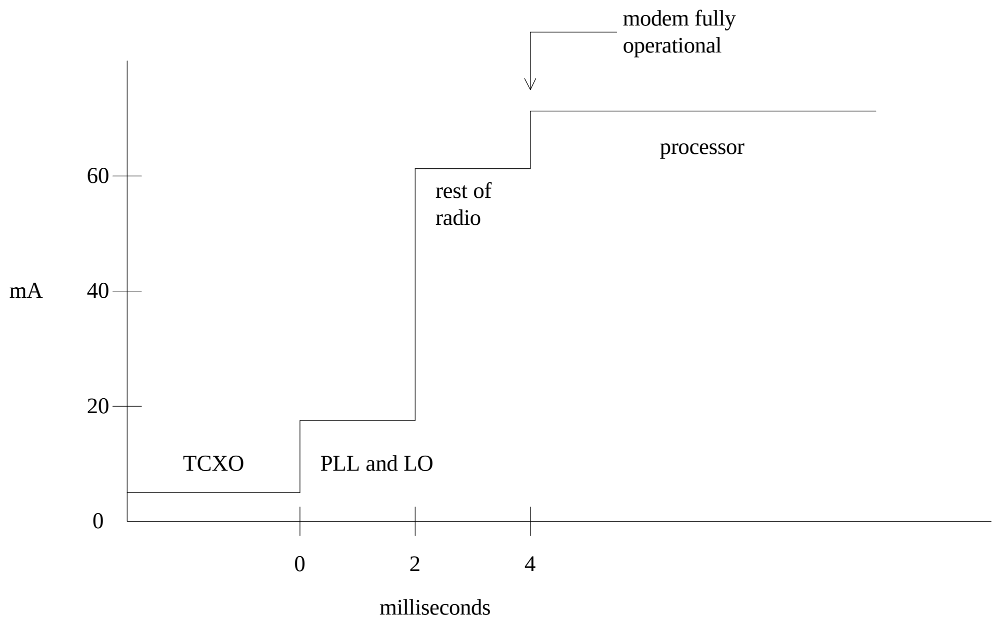
Devices in the Body LAN will be divided into 3 classes based on their battery requirements.

Class 1: devices such as the EST which must be in the sleep mode as much as possible. Target sleep mode duty cycle is 100:1.

Class 2: devices such as the printer which cannot tolerate long access delays, and which will wake up from the sleep mode more frequently. Target sleep mode duty cycle is 10:1.

Class 3: devices such as a mobile radio, which will not be put in the sleep mode, but will receive continuously.

The following diagram shows the expected radio modem power consumption when waking up to receive or transmit a beacon message:



The expected wake up time from sleep mode is 4 ms. In sleep mode the modem will have only the crystal oscillator and wakeup timer circuit operating, with a current consumption of about 3-5 mA. The processor wakes up at time 0 shown on the diagram and turns on the phase locked loop and local oscillator, then goes back to sleep. Two milliseconds later, it wakes up to turn on the remainder of the radio, then goes back to sleep again. Two milliseconds later, it wakes up again to a fully functional radio.

Since a beacon message is 4 ms in duration, power consumption should be limited to an average of about 6 ms at full current, then return to sleep mode. The EST should be able to achieve approximately 300:1 power savings with a beacon cycle of 2.0 seconds. The EST will wake up only for the beacon at the start of an EST frame. To minimize latency when printing, class 2 devices will be required to wake up from sleep mode every 200 ms, or 10 times each beacon interval. These devices, including the printer, will wake up and be prepared to receive a message in the first time slot of a printer frame.

5.2.7 Channel Contention

The channel contention algorithm is a version of slotted ALOHA with refinements to support the sleep modes. If a device detects a message transmission during a time slot, it may not begin a message transmission in the next time slot, even if it detects that the last message block has been transmitted and acknowledged. This provides a one time slot busy hang time to protect against the situation where the block is ACK'd but the ACK is not received by the sender, and the block is retransmitted.

The second time slot after the end of a message is available for transmission, provided that it is not reserved for a beacon transmission.

If the first block of a transmission is not ACK'd (indicating the possibility of a collision), the device selects at random one of the next three time slots and retransmits the block.

A message to a class 1 device (i.e. EST) should be initiated in the first slot after a beacon message. Messages to class 2 or class 3 devices may not be initiated in this time slot.

A message to a class 2 device (i.e. printer) may be initiated in the first time slot of printer frames P1 to P7 (P0 is reserved for beacon messages).

A message to a class 3 device (i.e. mobile radio) may be initiated at any time the class 1 and 2 devices can normally be expected to be sleeping.

The second time slot after the end of a message can be used to initiate a transmission to any class of device.

Blocks are acknowledged during the same time slot; if a block is not acknowledged, it is retransmitted in the time slot following.