IEEE 802.11
Wireless Access Method and Physical Layer Specifications

A Packet Delivery and Relay Strategy for the Foundation MAC

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Abstract: The current Foundation MAC [1] requires a precise definition of the mechanism by which packets are relayed between stations in a BSS. This paper addresses 11.5, "Will the AP provide relay of packets to other devices within a BSS." This paper proposes a comprehensive strategy for packet delivery and relay for a wireless LAN with an Access Point. The proposed relay and delivery mechanism would significantly improve the reliability of RF coverage within a BSS. The current Foundation MAC specifies packet relay only in support of power management and does not specify how to prevent packets arriving out-of-order at a destination station. The proposed strategy in this submission supports both power management and peer-to-peer communications and also prevents out-of-order packets. This strategy is also fully compatible with the Foundation MAC's channel access protocol as specified in [1]. The authors would like to see this strategy included in the Foundation MAC specification.

Introduction

This paper proposes an affirmative answer to IEEE 802.11 MAC issue number 11.5, "Will an AP provide relay of packets to other devices within a BSS?" which was raised in [2]. However, packet relay between stations within a BSS is only one aspect of a much broader packet delivery problem. The authors feel the Foundation MAC needs to specify an overall packet delivery strategy in a wireless LAN.

The general packet delivery strategy must address three areas:

1. Transport of packets between a wireless station and the wireline network attached to the AP.

2. Peer-to-peer communications (i.e., packet delivery between two wireless stations).

3. Packet delivery to power savings stations.

To solve the first problem, a packet destined for a wireline address must be directed toward the access point where the packet can then be forwarded on to the attached wireline infrastructure. In the reverse direction, the access point must forward packets originating on the wireline network to the appropriate destination wireless station.

The second problem concerns the delivery of packets from one wireless station to another wireless station, where both stations belong to the same BSS. An RF link between a given station and the AP can be guaranteed via synchronization and registration requirements. However, an RF link cannot be guaranteed between two wireless stations.

If two stations are both in range of the AP but happen to be out of range of each other, the current Foundation MAC does not precisely specify how these two stations will communicate. The Foundation MAC does not specify how packets are delivered between two stations that belong to the same BSS, but are out of range of each other.

A peer-to-peer packet relay mechanism would significantly improve RF coverage reliability. If two stations are out of range of each other, some relay mechanism will be required to deliver packets between the two devices.

However, if two wireless stations are within range of each other, the most efficient solution is to allow the two stations to directly communicate with no intervention by another station or AP. AP relay of packets involves significant channel overhead that is best used only when necessary. Allowing direct peer-to-peer communication, when possible, will minimize the total channel overhead occupied by the packet delivery mechanism.

The third item deals with the problem of delivering packets to and from devices exercising power management. Wireless stations may periodically enter the "sleep" state (i.e., turn off their transceivers) in order to conserve power. A station which is asleep can neither transmit nor receive, and therefore cannot participate in any communications activity with the AP or another wireless station. If a station transmits a packet to a sleeping station, a relay mechanism should step in and attempt to deliver the packet at some later time when the destination is awake.

The Foundation MAC mentions relay as it relates to the power management strategy, but does not specify relay in support of peer-to-peer communications. The Foundation MAC currently mentions that the Access Point will buffer packets destined for wireless stations that are in power saving polling (PSP) mode or power saving non-polling (PSNP) mode.

If peer-to-peer communications is allowed in conjunction with relay, then the packet delivery strategy must be designed to prevent packets arriving out of order at a destination. The Foundation MAC's packet buffering strategy is not specified in a way that will prevent out-of-order packets. For example, if a station operating in a power saving mode is allowed to accept packets from stations other than the AP, then packets can easily arrive out of order. Consider a station that wishes to transmit several packets to an asleep station (either in PSNP or a PSP) and the AP buffers the first of these packets. Suppose the destination wakes up in time to accept the second packet directly from the source station. When the AP transmits the first packet down to the destination station, the two packets will have arrived out of order.

This submission proposes a comprehensive packet delivery / relay strategy for wireless LANs with an AP. The proposed strategy will support both peer-to-peer communications and power management. This strategy will handle 1) packet delivery between wireless stations, 2) packet delivery between a wireless station and the wireline network, and 3) packet delivery to power saving stations. The strategy will also prevent packets from arriving at the destination station out of order. The proposed strategy specifies relay on a packet by packet basis and is therefore fully compatible with the Foundation MAC's CSMA/CA access procedure.

The authors would like to see this packet delivery strategy incorporated into the Foundation MAC specification.

The Packet Delivery / Relay Problem

The packet delivery problem is governed by the following constraints.

1. The source station typically has no knowledge of whether the destination of its packet is an address on the wireline network or another wireless station. It would be an unreasonable burden to require the source stations to track whether the destination is on the wireline or in the microcell. The Access Point should be charged with knowing whether a packet is addressed to the attached wireline network or another wireless station within the BSS.

2. If the destination of a packet is another wireless station, the source wireless station does not know whether the destination station is within communication range or not.

3. The Access Point will not know whether the source and destination of a packet transmission are in range of each other. This and the previous point indicate that no a priori knowledge exists about the RF connectivity within a BSS.

4. If the destination of a packet is another wireless station, the source wireless station does not know whether the destination station is asleep. To require a wireless station to track the sleep status of its destination stations would not work: When the wireless station itself goes to sleep, it would miss any sleep status indications transmitted by the other wireless stations. The Access Point should be charged with tracking the sleep status of the wireless stations registered to its BSS.

Assuming a packet relay mechanism is in place, a packet transmitted by a wireless station may be destined for one of the following:

1. An address on the wireline network. In this case, the AP must buffer and acknowledge the packet. The AP must then forward the packet to the wireline network.

2. Another station within the BSS, but asleep. In this case, the AP must also buffer and acknowledge this packet. The AP must retransmit (forward) the packet to the destination station at a later time determined by the power management strategy of the destination station.

3. Another station within the BSS, awake, and in range of the source station. In this case, an efficient solution is for the AP to let the destination station accept and acknowledge the packet provided packets will arrive in order.

4. Another station within the BSS, awake, but out of range of the source station. In this case, the AP would ideally accept and acknowledge reception of the packet. The AP would then deliver the packet to the destination station as soon as possible.

When a wireless station hears a packet transmission destined for himself, the source of the packet can be one of the following:

1. On the wireline network: In this case, the AP is transmitting the packet.

2. Another wireless station transmitting the packet directly to the station.

3. Another wireless station, but the AP is transmitting (relaying) the packet to the station.

A packet relay strategy which supports both peer-to-peer communications and power management must handle the above complications. In addition, the following requirements must be met:

1. The relay mechanism must provide a reasonably efficient means of relay between a source station and a destination station under the cases where the destination station is either asleep or out of range of the source station.

2. Packets must be delivered in the order in which they are transmitted by the source station.

3. A method must be in place to determine when the AP should step in to buffer the packets or let the destination station receive and acknowledge the packet.

4. The relay mechanism must be designed to avoid the case where the destination station and the AP both attempt to acknowledge the same frame at the same time (thereby causing a collision). This case is caused by the invocation of relay even though the destination station actually heard the transmission.

5. The relay mechanism must provide an acknowledgment strategy that informs the sending station that either the packet is being accepted by the access point or the packet is being accepted by the destination station.

6. The relay mechanism must provide an acknowledgment strategy which informs the station that the packet reached (or did not reach) the destination wireless station. If the AP was unable to relay a packet to the destination station (i.e., the destination

station moved out of the BSS), then the source station should not transmit any more packets destined for that destination station. (If the destination is on the wireline network, the source wireless station need not be informed of final delivery to the destination address.)

7. The delivery mechanism must be compatible with and integrated into the power management strategy. For example, stations should not enter the sleep state when in the middle of a "conversation" with another device. To do otherwise would cause additional (and unecessary) delays in packet delivery.

8. The relay mechanism must support the possibility of a changing RF environment: The relay strategy must handle the situation where the destination station moves within range of the source station (or wakes up) in the middle of the relay and delivery process.

Overview of Proposed Packet Delivery / Relay Strategy

This section provides a quick overview of the proposed packet delivery and relay strategy. The details of the strategy are discussed in the sections to follow. The discussion assumes that packets are fragmented into smaller "fragments" for transmission over the RF. Furthermore, the fragments are assumed to be acknowledged one "window" at a time. The details of the strategy can easily be modified for the case where packet fragmentation and fragment windowing are not used. Assuming single fragment packets in the following discussion will handle the case where fragmentation and fragment windowing are not in use.

When a wireless station has a packet to transmit, it will simply attempt to transmit the first fragment window according to the channel access protocol. The source wireless station will not need to know if the destination is another wireless station or an address on the wireline network. If the destination is another wireless station, the source station will not need to know whether the destination is awake or asleep or in range.

After transmitting the first fragment window, the source station will wait for an acknowledgment. If the destination of the packet is another wireless station that is awake and in range, the destination station will send an acknowledgment directly back to the source station. In this case, no access point intervention is necessary. If the destination is an address on the wireline network, the access point will accept and acknowledge the packet. However, if the destination is another wireless station that is either asleep or out of range, access point intervention will be required to deliver the packet.

If the destination station is awake and out of range of the source, the proposed strategy is one where the source station requests relay from the access point via an indication in the header of the packet requiring delivery. If the destination station is awake, the access point will not know whether the source and destination station are in range of each other. The source station will first attempt to transmit the first fragment window directly to the destination station. If no acknowledgment is received after some configurable number of attempts, the station will set the "relay" bit in the header of the packet. The relay bit indicates to the AP that the source station is requesting the AP to accept and buffer the packet for relay. After receiving the entire packet, the AP will acknowledge the source and indicate that relay is being performed. The AP will then forward the packet on to the destination station. When the AP receives the final acknowledgment from the destination station, the AP will then send an "End-to-End" acknowledgment to the source station to indicate that the packet successfully reached its destination.

If the destination station is asleep, the access point should accept the first fragment window and acknowledge the source station. The access point's acknowledgment will indicate that relay is being performed. The source station should then transmit the remaining fragments of the packet directly to the access point. (The access point will be charged with knowing when a device is asleep or awake.) After receiving the entire packet, the AP will wait until the destination station is awake and forward the packet on to the destination. When the AP receives the final acknowledgment from the destination station, the AP will then send an "End-to-End" acknowledgment to the source station to indicate that the packet successfully reached its destination.

Once the AP accepts the relayed packet from the source station, the source station is forbidden from transmitting any more packets to that destination until it receives the End-to-End acknowledgment from the AP. The purpose of this requirement is to prevent an out-of-order packet condition if the destination happens to hear the second packet directly from the source before the AP can deliver the first packet.

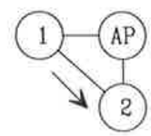
To properly route packets within a microcell, packet headers will contain an "access point" bit and a "relay" bit in addition to the packet's source and destination. The "access point" bit indicates whether a packet or acknowledgment is being transmitted by the access point or a wireless station. The "relay bit" will be used to indicate whether a packet or acknowledgment is involved in the relay process. The AP and relay bits are discussed further below.

Packet Delivery Between Two Awake Stations in a BSS

When a source station has a packet to transmit, it will simply transmit the first window of fragments. If the destination of a station's transmission is another station within the BSS and is within range and awake, the destination station will acknowledge the source station. Upon receipt of the acknowledgment of the first fragment window, the source station can continue sending the remaining fragments of the packet directly to the destination station. The access point will not need to intervene when two awake stations can directly communicate.

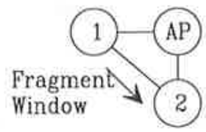
Figure 1 below shows a packet being delivered between two awake stations. In these and other figures, a BSS is shown as a collection of connected circles. The circles denote the stations in the BSS. A line connecting two stations indicates an RF connection between the two stations. Note in Figure 1 that neither the relay bit nor the AP bit is set in any of the transmissions since relay is not used.

Transmission to an awake station within range:

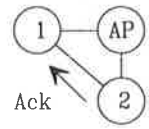


Source station transmits each fragment window

1) Station 1 sends each fragment window destined for station 2:
2) Station 2 sends ack to device 1.
3) Repeat until entire packet is delivered to station 2.



Step 1 Fragment Header:
Type=DATA
Source=Station 1
Dest=Station 2
Relay=0
AP=0



Step 2 Fragment Header:
Type=ACK
Source=Station 2
Dest=Station 1
Relay=0
AP=0

Figure 1: Packet delivered between two awake wireless stations in range of each other.

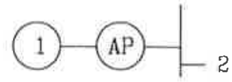
However, if the destination address happens to be a wireline address, the AP will accept and acknowledge the packet. If the destination station is either out of range or asleep, the source station will not receive an acknowledgment and relay will be required. These cases are discussed below.

Packet Delivery Between a Wireless Station and an Address on the Wireline Network

The access point will be charged with knowing whether the destination of a transmission is on the wire or is another wireless station within its BSS. The wireless stations need not know whether the destination of their packets are on the wire or in the BSS. If the AP hears a transmission destined for a wireline address, the AP must accept and acknowledge the transmission.

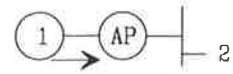
Figure 2 below shows the steps involved in delivering a packet from a wireless station to a wireline address. Note that the relay bit is not set in any of the transmissions since relay over the RF is not required.

Transmissions from a wireless station to the wireline network

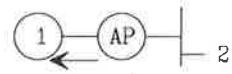


Step A: Source station transmits first frag. window: Access point buffers+acks.

1) Station 1 sends first fragment window destined for address 2. Station 1 does not know address 2 is on the wire.
2) Access point accepts and acknowledges. Ack has AP=1, and Relay=0, informing device 1 that the AP is forwarding the packet to the address on the wire. Relay=0 tells station 1 that an ETE packet is not required after the packet makes it to the destination.



Fragment Window



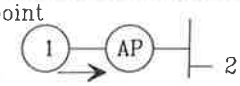
Acknowledgment

Step 1 Fragment Header:
Type=DATA
Source=Station 1
Dest=Station 2
Relay=0
AP=0

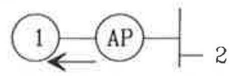
Step 2 Fragment Header:
Type=ACK
Source=Station 2
Dest=Station 1
Relay=0
AP=1

Step B: Ship remainder of packet up to the access point

3) Station 1 sends each fragment window to the access point exactly as done in step 1.
4) Access point acknowledges each fragment window exactly as done in step 1.
5) Repeat until entire packet is delivered to the access point.



Fragment Window



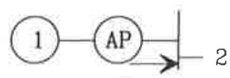
Acknowledgment

Step 3 Fragment Header:
Type=DATA
Source=Station 1
Dest=Station 2
Relay=0
AP=0

Step 4 Fragment Header:
Type=ACK
Source=Station 2
Dest=Station 1
Relay=0
AP=1

Step C: Access point forwards entire packet on to the wire.

6) Access point forwards the packet to the wire connection.
7) Note that no End to End packet is required.

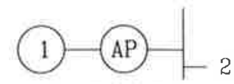


Packet

Figure 2: Packet delivered from a wireless station to the wireline network.

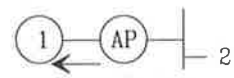
Figure 3 below shows the steps involved in delivering a packet from the wireline network to a wireless station. Note that the relay bit is not set in any of the transmissions since an RF relay is not being performed.

Transmissions from the wireline network to a wireless station



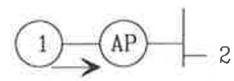
Access point forwards fragments to wireless station

1) Access point sends each fragment window from address 2 destined for station 1. AP=1, Relay=0 tells station 1 that address 2 is on the wire.
2) Station 1 sends an acknowledgment of each fragment window to the access point.
3) Repeat until entire packet is delivered to station 1.



Fragment Window

Step 1 Fragment Header:
Type=DATA
Source=Station 2
Dest=Station 1
Relay=0
AP=1



Acknowledgment

Step 2 Fragment Header:
Type = ACK
Source = Station 1
Dest = Station 2
Relay = 0
AP = 0

Figure 3: Packet delivered from the wireline network to a wireless station

Packet Relay to Awake Stations

The relay mechanism is one by which the source station requests relay after some number of failed attempts to transmit the first fragment window of a packet. The source station uses a *relay bit* in the fragment header to tell the Access Point to receive all fragments of a packet. The Access Point then relays on a packet by packet basis followed by an end-to-end acknowledgment of each packet.

This procedure is as follows. Let station 1 be the source station, and let station 2 be the destination station which is out of range of station 1. Both station 1 and station 2 are registered with the Access Point and hence, are both within range of the Access Point. Both stations 1 and 2 are awake.

- Station 1 transmits the first window of fragments of a packet destined for station 2. Since station 2 is out of range of station 1, no acknowledgment is sent and station 1 will try again to transmit the first window of fragments for some configurable number *num_attempts_before_relay* of retransmission attempts. (*num_attempts_before_relay* can be 1 to allow relay to be requested immediately after the first failed attempt. Also, *num_attempts_before_relay* must not be large in a way that the packet lifetime timer for the packet expires before the packet can be delivered to the access point for relay).
- After the predetermined number of transmission attempts, station 1 will retransmit the first window of fragments with the relay bit in the fragment headers turned on. This relay bit tells the Access Point that station 1 wants the Access Point to receive this packet for relay on to the destination.

- As soon as the access point receives the first fragments of the packet requiring relay, the access point will set a lifetime timer for the incoming fragments. If the entire packet is not received before the lifetime timer expires (i.e., *packet_lifetime*), the access point will discard the incomplete packet. (This requirement should be true for any station receiving fragments from another station: if the entire packet is not received within a *packet_lifetime* of receiving the first fragment, the station should discard the incomplete packet. The purpose is to prevent receiving stations from waiting to receive more fragments of a packet that has already been discarded by the sending station.)

- Station 1 then continues to send all remaining fragment windows of that packet to the Access Point. The Access Point will acknowledge each fragment window with the following information contained in the acknowledgment header: relay bit = 1, Access Point bit = 1, source station = station 2, destination station = station 1. Setting the relay bit to 1 indicates that the Access Point has accepted the packet for later relay. (If station 2 was on the wire and the Access Point failed to hear the first *num_attempts_before_relay* attempts by station 1, station 1 will request relay to station 2. In this case, the Access Point will accept the fragments, but will set the relay bit to zero to indicate that the destination was on the wireline network.)

- After the Access Point receives all fragments of the packet destined for station 2, the Access Point must then relay that packet on to station 2. Immediately following its last acknowledgment to station 1, the Access Point will then begin the process of transmitting the fragments of the packet to station 2.

- As soon as the Access Point receives the final fragment from station 1, the Access Point will reset the packet lifetime timer for that packet. The Access Point will then have another *packet_lifetime* to forward the entire packet to station 2. If the Access Point fails to forward the entire packet to station 2 within a *packet_lifetime*, the Access Point must discard the packet.

- The fragment headers of the packet being transmitted (relayed) from the Access Point to station 2 must contain the following information: relay bit = 1, Access Point bit = 1, source = 1, and destination = 2, sequence number = same as that received from station 1. These settings allow station 2 to properly execute its packet sequencing algorithm. I.e., station 2 will understand that the packet it is receiving originated from station 1 even though the Access Point is the current transmitter. Station 2 must then update its sequencing information for station 1, not the Access Point.

- When station 2 receives station 1's packet from the Access Point, station 2 must address its acknowledgments as follows: The relay bit = 1, source station = 2, destination station = 1, and Access Point bit = 0. A relay bit = 1 and an AP bit = 0 prevents station 1 from picking up this acknowledgment, thereby preventing any confusion at station 1 should station 1 happen to hear any of station 2's acknowledgments. (The rules on accepting packets are summarized below.)

- When the Access Point receives from station 2 the final acknowledgment indicating that the packet was successfully received by station 2, the Access Point must inform station 1 that the packet finally arrived at station 2. The Access Point transmits to station 1 an "End-to-End" (ETE) packet that tells station 1 that its packet has been successfully delivered. The ETE packet that informs station 1 that its packet was successful is addressed as follows: source = 2, destination = 1, Access Point = 1, relay = 1. The ETE packet consists of a header with no payload. The ETE packet should be allocated its own opcode to distinquish it from other packet types.

- If the Access Point is unable to transmit the data packet to station 2 within a *packet_lifetime* (i.e., station 2 has, for example, left the microcell), the Access Point must also transmit an ETE packet to station 1 informing station 1 that station 2 is unreachable by the Access Point. Except for the setting of the relay bit, the ETE packet in this case is identical to the ETE packet when the packet was successful. If station 1's packet reached station 2, the relay bit in the ETE packet is set to 1. If station 1's packet failed to reach station 2, the relay bit in the ETE packet is set to 0. If the ETE packet indicates that station 1's packet failed to reach station 2, station 1 must then remove from its queue any packets bound for station 2.

- After the Access Point receives the packet for relay from station 1, station 1 must not transmit any more packets to station 2 until it receives the ETE packet from the Access Point. After receiving the ETE acknowledgment, station 1 is free to transmit (as per the channel access protocol in use) any more packets that it may have in its queue.

- Station 1 must acknowledge receipt of the ETE packet. Station 1 will send an ETE acknowledgment, a frame with its own opcode to distinguish it from the normal (one-hop) acknowledgments. If station 1 fails to acknowledge the ETE packet, the Access Point will retransmit the ETE packet (as per the channel access protocol) until station 1 sends an acknowledgment or until the packet lifetime for the ETE packet expires. (I.e., the ETE packet is sent as any other packet would be sent.) Station 1's acknowledgment of the ETE packet is addressed as follows: source = 1, destination = 2, Access Point = 0, relay = 1. The sequence number of the ETE acknowledgment contains the sequence number of the packet that was being relayed.

- If station 1 does not receive the ETE packet after a time-out period (called *ETE_timeout*), then station 1 should assume station 2 is unreachable and remove from its queue any packets bound for station 2. Station 1 can then transmit more packets if it desires. The ETE time-out period *ETE_timeout* is measured from the instant that station 1 receives the final acknowledgment verifying that the packet was successfully delivered to the Access Point (the first hop).

- Relay of a packet can be requested only on the first window of fragments. If some fragments of the first window of a packet are acknowledged by the destination station, the source station will not be allowed to set the relay bit on any of the remaining fragments of the packet. This requirement prevents the Access Point from having to relay an incomplete packet.

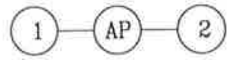
- If a source station requires the Access Point to relay a packet to a particular destination station, it is likely that the next packet destined for that station will also need to be relayed. To optimize the relay strategy, we can allow the source station to automatically request relay to a particular station for some time period following the first successful relay to that station.

(A relay becomes successful as soon as the ETE packet is received by the sending station.) This time period is called *continue_relay_request*. When that time period expired, the source station would revert back to the relay-by-request strategy described above. This timer should not be set if the packet was relayed because the destination was asleep - if the source station receives an acknowledgment from the AP, with both the AP and relay bits set, in response to a packet without relay requested then the destination is assumed to be asleep.

Figure 4 below shows a sample transaction between two wireless stations (stations 1 and station 2) that are out of range of each other. In this figure, the circles with numbers represent wireless stations. The circle with an AP represents the Access Point. The lines represent an RF communication link.

In step A of Figure 4, the first window of fragments is sent without station 1 knowing if station 2 is within range. Station 2 sends no acknowledgment back to station 1. In step B, station 1 turns on the relay bit in the fragment headers to request that the Access Point accept and relay the fragments to station 2. Station 1 then ships the entire packet up to the Access Point. In step C, the Access Point sends the packet to station 2. In step D, the Access Point sends the ETE packet to station 1 to inform station 1 whether its packet was successfully delivered to station 2. In step E, station 1 acknowledges receipt of the ETE packet.

Relay by Request to an Awake Station:



Step A: Source station attempts to transmit first fragment window

1) Station 1 sends first fragment window destined for Station 2:
2) Station 2 supposed to send ack but does not.
3) Repeat *num_attempts_before_relay* − 1 times

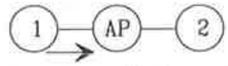
Fragment Window followed by no ack.

Step 1 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=0
AP=0

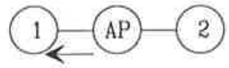
Step 2 Header:
(If Station 2 hears Station 1)
Type=ACK
Source=station 2
Dest=station 1
Relay=0
AP=0

Step B: Ship entire packet up to the access point

4) Station 1 sends each fragment window to the access point with relay bit set: Purpose is to request relay from the access point.
5) Access point acknowledges each fragment window. Relay=1 tells station 1 to wait for ETE pkt following the successful delivery to station 2.
6) Repeat until entire packet is delivered to the access point.



Fragment Window with relay bit set.



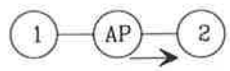
Acknowledgment (after SIFS)

Step 4 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=1
AP=0

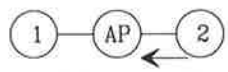
Step 5 Header:
Type=ACK
Source=station 2
Dest=station 1
Relay=1
AP=1

Step C: Access point sends entire packet to destination station

7) Access point sends each fragment to station 2. Relay bit and AP bit=1 to indicate a packet relayed by AP.
8) Station 2 acknowledges the access point after each window: relay=1 and AP=0 prevents station 1 from accepting the ack.
9) Repeat until entire packet is deliverd to station 2. (or until the access point gives up on the packet).



Fragment Window



Acknowledgment (after SIFS)

Step 7 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=1
AP=1

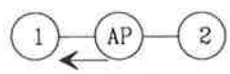
Step 8 Header:
Type=ACK
Source=station 2
Dest=station 1
Relay=1
AP=0

Step D: Access point sends End to End Packet to source station

10) Access point must send ETE Packet to station 1 with relay bit = 1 to indicate that station 1's packet was successfully delivered to device 2.

OR

11) Access point must send ETE Packet to station 1 with relay bit = 0 to indicate that station 1's packet was not delivered to station 2.



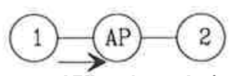
ETE Packet

Step 10 header:
(Pkt successful)
Type=ETE
Source=statoin 2
Dest=station 1
Relay=1
AP=1

Step 11 Header:
(Pkt unsuccessful)
Type=ETE
Source=station 2
Dest=station 1
Relay=0
AP=1

Step E: Station 1 must acknowledge the ETE packet

12) Station 1 sends ETE Acknowledgment to AP.
13) Station 1 is now free to transmit more packets.
14) If station 1's packet never made it to station 2, station 1 will flush its queue of all packets destined for station 2.



ETE Acknowledgment

Step 12 header:
Type=ETE ACK
Source=station 1
Dest=station 2
Relay=1
AP=0

Figure 4: Relay by Request to an Awake Station.

Since a wireless station does not know if a destination is on the wireline network, it is possible for a source station to request relay to a station which happens to be on the wire. This case may occur if the source station was unable to deliver the first fragment window to the Access Point after *num_attempts_before_relay* attempts. Figure 5 shows how this situation is handled.

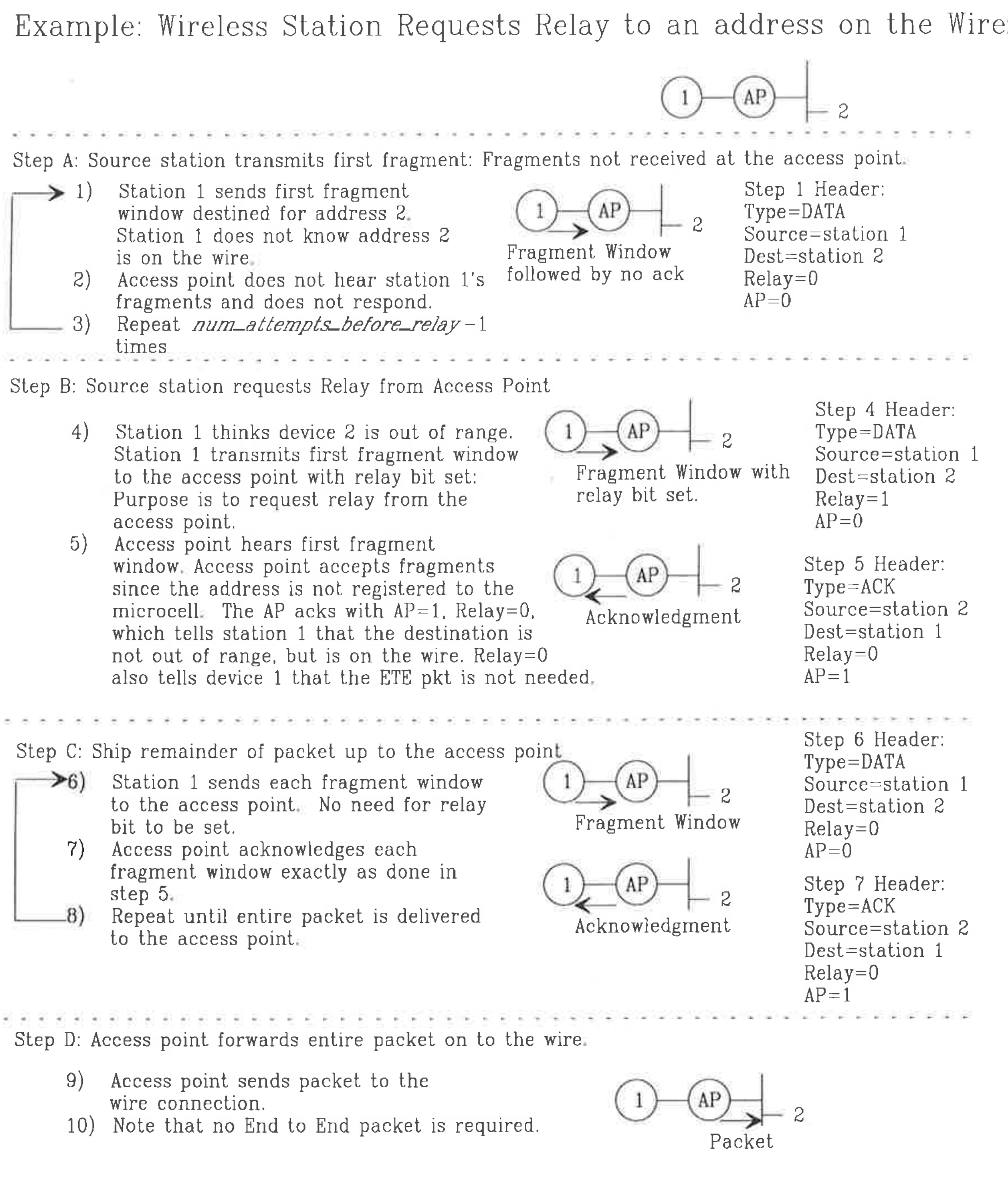


Figure 5: Example: Wireless Station Requests Relay to an Address on the Wireline Network

Packet Relay to Sleeping Stations

The packet relay and delivery strategy must make provisions for sleeping stations. When a station is asleep, it is unable to monitor and receive packets from the RF channel. This proposal assumes the Access Point will keep track of which stations in the network are asleep. However, the sending station will not know in advance whether its destination station is asleep or awake. (The sending station also does not know whether the destination is a wireless station or an address on the wireline network).

To permit the wireless stations to avoid having to know whether its destination is asleep, the Access Point will keep track of which stations are asleep and which stations are awake. The Access Point must monitor all incoming fragments to determine if the destination of the fragment is registered to the microcell or not. Of the destinations that are registered in the microcell, the Access Point must determine whether the destination is asleep. If the Access Point believes that a destination station is asleep, the Access Point will receive and buffer any fragments destined for that sleeping station. The Access Point will retransmit those fragments at a later time when the destination station is awake.

When the Access Point receives the first window of fragments destined for a sleeping station, the AP will send an acknowledgment that contains the following information: source station = destination that is asleep; destination station = source station sending the packet; Access Point bit = 1; relay bit = 1.

However, before actually acknowledging the first window of fragments bound for an asleep station, the Access Point will monitor the channel for the SIFS interval to determine whether the destination station has started to acknowledge the packet. If the AP mistakenly thinks the destination is alseep, the destination may attempt to acknowledge the first fragment window. If no acknowledgment is heard, the Access Point will send its acknowledgment to the source station after the PIFS interval has expired. This strategy prevents both the AP and the destination station from simultaneously acknowledging the fragment window.

Figure 6, below, shows station 1 transmitting to station 2. The AP believes station 2 is asleep and prepares to send its acknowledgment after the PIFS interval. If station 2 was actually awake, station 2 would have acknowledged in the SIFS interval, causing the AP to discard its prepared acknowledgment to station 1. In Figure 6, station 2 was asleep and did not acknowledge after the SIFS interval. Hence, the AP accepts the packet from station 1 and acknowledges in the PIFS interval.

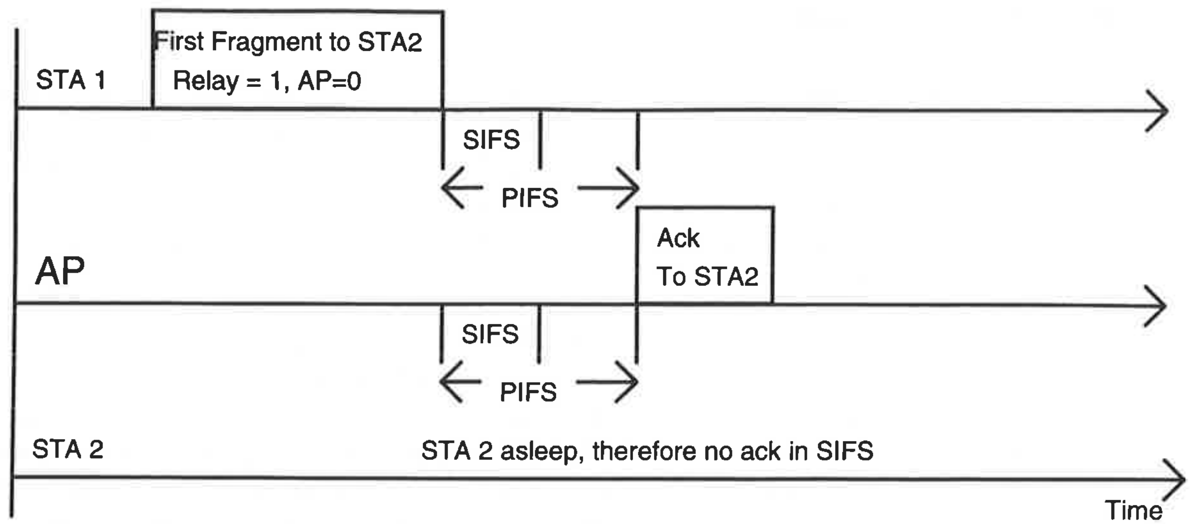


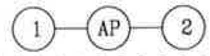
Figure 6: Preventing simultaneous acknowledgments

The source station receiving the acknowledgment from the Access Point will see that the both the Access Point and relay bits are set to 1 indicating that the Access Point is accepting the packet for later relay. The source station must then send the next window of fragments with the relay bit set, exactly as if relay is being requested. Since the first window of fragments were accepted by the Access Point, the source station will finish sending the remaining fragments of the packet to the Access Point. Setting the relay bit ensures that the remainder of the packet will go through the Access Point in case the destination should wake up in time to hear the last set of fragments of the packet. This plan avoids the extra overhead and possible confusion that may result from attempting to relay partial packets.

As in the relay mechanism described above, once the packet has been delivered to the Access Point, the source station is forbidden from transmitting any more packets until an ETE packet is received by the Access Point. When the acknowledgment has both AP and relay bits set to one, the source station knows that the Access Point is relaying the packet and that the station must wait for the ETE packet. (If the AP bit = 1, but the relay bit = 0, the station knows that the Access Point is forwarding the packet onto the wireline network and no ETE packet will be sent.) If no ETE packet is received after a suitable time-out (*ETE_timeout*), the source station will throw out all packets destined for the destination station. The source station will then be allowed to transmit any other packets it may have according to the channel access rules.

Figure 7, below, shows the steps by which a packet is transmitted from a source wireless station to a sleeping wireless station. The contents of the frame headers are shown at each step in the transaction.

Relay to a Sleeping Station:



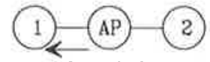
Step A: Source station transmits first frag. window: Access point buffers+acks.

1) Station 1 sends first fragment window destined for station 2. Station 1 does not know station 2 is asleep.

Fragment Window

Step 1 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=0
AP=0

2) Station 2 is asleep: Access point accepts and acknowledges. Ack has both AP and Relay bits set, informing station 1 that the AP is relaying to an asleep station. Relay=1 tells station 1 to wait for the ETE Ack following the successful delivery to the AP.

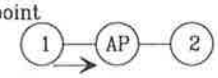


Acknowledgment (after PIFS)

Step 2 Header:
Type=ACK
Source=station 2
Dest=station 1
Relay=1
AP=1

Step B: Ship remainder of packet up to the access point

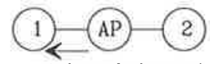
3) Station 1 sends each fragment window to the access point with relay bit set: Remainder of packet is sent as if packet needs relay. Relay=1 and AP=0 keeps station 2 from accepting the fragments should station 2 wake up in the middle of the transaction.



Fragment Window with relay bit set.

Step 3 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=1
AP=0

4) Access point acknowledges each fragment window.



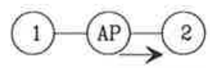
Acknowledgment (after SIFS)

Step 4 Header:
Type=ACK
Source=station 2
Dest=station 1
Relay=1
AP=1

5) Repeat until entire packet is delivered to the access point.

Step C: Access point sends entire packet to destination station after wakeup.

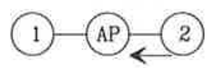
6) Access point waits until the the destination station is awake.



Fragment Window

Step 7 Header:
Type=DATA
Source=station 1
Dest=station 2
Relay=1
AP=1

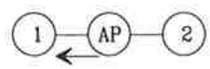
7) Access point sends each fragment to station 2.
8) Station 2 acknowledges the access point after each window.
9) Repeat until entire packet is deliverd to station 2. (or until the access point gives up on the packet).



Acknowledgment (after SIFS)

Step 8 Header:
Type=ACK
Source=station 2
Dest=station 1
Relay=1
AP=0

Step D: Access point sends End to End Packet to source station



ETE Packet

10) Access point must send ETE Packet to station 1 with relay bit = 1 to indicate that station 1's packet was successfully delivered to station 2.

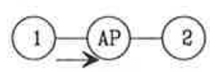
OR

11) Access point must send ETE Packet to station 1 with relay bit = 0 to indicate that station 1's packet was not delivered to station 2..

Step 10 header:
(Pkt successful)
Type=ETE
Source=station 2
Dest=station 1
Relay=1
AP=1

Step 11 Header:
(Pkt unsuccessful)
Type=ETE
Source=station 2
Dest=station 1
Relay=0
AP=1

Step E: Station 1 must acknowledge the ETE packet



ETE Acknowledgment

12) Station 1 sends ETE Acknowledgment to AP.
13) Station 1 is now free to transmit more packets.
14) If station 1's packet never made it to station 2, station 1 will flush its queue of all packets destined for station 2.

Step 12 header:
Type=ETE ACK
Source=station 2
Dest=station 1
Relay=1
AP=0

Figure 7: Relay to a Sleeping Station

Packet Timers

The above discussion proposes the use of several timers to assist in the delivery process. This section summarizes how these timers are used.

The first timer is a packet lifetime timer which is used to limit the amount of time a packet will spend at a particular device. When a station or access point receives a packet from its host device, the packet lifetime timer will start counting. The station must complete transmission of that packet (either to the destination station or to the access point) before the packet lifetime timer reaches some time-out value (called *packet_lifetime*). When the access point receives from a station a packet requiring relay to another station, the access point will start a packet lifetime timer for that packet as soon as all fragments of that packet are received at the device.

Another use of the lifetime timer is to prevent stations from waiting indefinitely for more fragments of a packet from another station. We propose that as soon as a station receives the first fragment of a multi-fragment packet, the station should start the lifetime timer for that packet. If all fragments of that packet have not been received by the *packet_lifetime*, the receiving station should discard the incomplete packet. If all fragments have not been received by a *packet_lifetime* of receiving the first fragment, the source station will have given up on transmitting the remainder of that packet. Hence, the receiving station should give up on receiving the packet.

The second timer mentioned in the previous sections was an End-to-End (ETE) timer, which serves two purposes. First this timer sets an interval during which the source of a relayed packet is not allowed to transmit more packets to the destination of the relayed packet. Second, this timer is used to prevent a station from waiting indefinitely for the AP to indicate that the station's packet was relayed to its destination.

A source station sets an ETE timer as soon as the station receives the final acknowledgment from the AP indicating that all fragments of the packet requiring relay have been completely received by the AP. The source station will learn whether its packet is being relayed by observing the relay bit in the acknowledgment sent back from the AP. If the relay bit in the AP's acknowledgment is set to true, the destination of the packet is either a sleeping station or an out-of-range station. If the relay bit is set to false in the AP's acknowledgment, then the destination of the packet was a wireline station.

When the source station sets an ETE timer, that station is forbidden from transmitting any more packets to the destination until one of two things happens: an ETE packet is received from the AP or the ETE timer expires. This requirement prevents packets from arriving out of order at the destination station. If the source station transmitted any more packets before the AP was able to relay the first packet, the forthcoming packets might arrive at the destination before the first packet.

As soon as the AP receives the final ack from the destination of the relayed packet, the AP must transmit an ETE packet back to the source of the packet. The AP must indicate in the ETE packet whether the AP was successful in delivering the relayed packet to the destination station. The relay bit in the ETE packet indicates success or failure of the relayed packet.

If the source station fails to receive the ETE packet from the AP before the ETE timer expires, or if the source station receives an ETE packet indicating relay failure, the source station must discard all of its packets that are destined for that destination station. This requirement prevents the source station from wasting its channel access on packets for a destination to which the AP is unable to relay.

Packet Addressing Rules

To properly route packets within the microcell, the relay and access point bits are used to address a data packet as follows:

- A data packet that is being transmitted by the source wireless station will have the Access Point bit set to zero to indicate that the packet is being transmitted by the source wireless station and not the Access Point. The relay bit will normally be set to zero unless the source wireless station requests relay from the Access Point as discussed above.
- A data packet that has originated from the wireline network and is being transmitted by the Access Point will have the source address of the wireline station, not the Access Point. The Access Point bit will be set to one to indicate that the Access Point is currently transmitting the packet. The relay bit will be set to zero to indicate that the packet originated from the wireline network, not another wireless station.
- A data packet that has originated from a wireless station and is being relayed by the Access Point will have the source address of the source wireless station, not the Access Point. The Access Point bit will be set to one to indicate that the Access Point is currently transmitting the packet. The relay bit will be set to one to indicate that the packet originated from another wireless station, not the wireline network.

Rules for a Wireless Station on Accepting Packets and Acknowledgments

To properly route packets from a source station to a destination station, the following three rules govern whether a wireless station may accept a frame.

- (Destination must be equal to your own) OR (Destination must equal the broadcast / multicast address)

  AND

- (Relay bit = 0) OR (Access Point bit = 1)

  AND

- BSS-ID and ESS-ID = that of your own. (I.e., the packet must have originated from the microcell to which you belong.)

When a wireless station receives a data frame, the following list indicates the meaning of the relay and Access Point bits given that the destination of the fragment matches that of the wireless station:

- Relay bit = 0, Access point bit = 0: The data packet is being transmitted by a source wireless station and is intended for the wireless station listed in the destination field of the frame.
- Relay bit = 0, Access point bit = 1: The data packet is being transmitted by the Access Point and the source station is on the wireline network.
- Relay bit = 1, Access point bit = 0: The wireless station listed in the destination field is not allowed to accept this fragment. A data fragment with these settings is being transmitted by a source wireless station who is requesting the Access Point to buffer this fragment and send it to the destination wireless station at a later time.
- Relay bit = 1, Access point bit = 1: The data packet is being relayed by the Access Point to the destination wireless station. In this case, the destination wireless station must set the relay bit in its acknowledgment to 1 so that the acknowledgment is directed towards the Access Point.

When a wireless station receives an acknowledgment, the following list indicates the meaning of the relay and Access Point bits given that the destination of the acknowledgment matches that of the wireless station:

- Relay bit = 0, Access point bit = 0: The acknowledgment is being sent by the destination wireless station back to the source wireless station.
- Relay bit = 0, Access point bit = 1: This acknowledgment indicates that the Access Point is acknowledging a packet that was destined for the wireline network.
- Relay bit = 1, Access point bit = 0: The station listed in the destination field is not allowed to accept this acknowledgment. An acknowledgment with these settings is being transmitted to the Access Point by the final destination of a relayed packet.
- Relay bit = 1, Access point bit = 1: An acknowledgment with these settings is being transmitted by the Access Point to indicate that the packet is being accepted by the Access Point (not the final destination) for later relay to another wireless station.

Rules for the Access Point on Accepting Packets and Acknowledgments

The Access Point must live by the following rules: The Access Point will accept only those packets whose ESS-ID and BSS-ID is equal to that of the Access Point (i.e., packets that originated from within the microcell and not, for example, from a co-located microcell). Of the incoming frames with the correct ESS-ID and BSS-ID, the Access Point will accept the following:

- Destination is not registered in the microcell. In this case, the destination is assumed to be on the wireline network. The Access Point will send an acknowledgment containing the following header information: source = the wireline destination address, destination = wireless station, Access Point bit = 1, relay bit = 0.

OR

- Destination is registered in the microcell, but is asleep. In this case, the Access Point must accept the packet and retransmit the packet to the destination station according to the power management section. The Access Point will acknowledge this packet as follows: source = destination wireless station, destination = source wireless station, Access Point bit = 1, relay bit = 1.

OR

- Relay bit is 1. In this case, a wireless station is requesting relay to another station.

Compatibility with the Foundation MAC's CSMA/CA Access Procedure

The above delivery strategy is fully compatible with the Foundation MAC's channel access procedure as discussed in [1]. The above delivery strategy basically specifies the routing of packets from one station to another within a BSS. We propose a minor addition to the AP's use of the PIFS time spacing as defined in [1].

Our proposed modification was mentioned in an earlier section and concerns which inter-frame spacing the AP should use to acknowledge reception of a packet requiring relay to a station the AP believes is alseep. As described in [1], frames are normally acknowledged following the SIFS interval.

However, when a source station transmits a first fragment window to another station, the AP must make a determination about whether the destination station is awake or asleep. The source station does not yet know whether relay is required and hence will transmit the first fragment window with the relay bit set to zero. In this case, if the destination was awake and in range, the destination will accept and acknowledge the fragment window after the SIFS interval. However, if the AP believes the destination station is alseep, the AP is also supposed to accept and acknowledge the first fragment window.

We propose that when the AP hears a data frame with the relay bit set to zero and the destination station is assumed to be asleep, the AP should send its acknowledgment following the PIFS time spacing (instead of the shorter SIFS spacing). If the destination station happened to be awake, the destination station will acknowledge the data frame following the SIFS interval. This modification will prevent the AP and the destination of a data frame from simultaneously attempting to acknowledge a frame in the case where the AP mistakenly assumed the destination was asleep.

If the destination station was actually asleep, the AP accepts the first fragment window and sends an acknowledgment with the relay bit set to one to indicate to the source station that relay is being performed. If more fragments of the same packet require delivery, the source station must set the relay bit in the header of those remaining fragments so that the remaining fragments will also be directed towards the access point. In this case, if the destination station heard the remaining fragments with the relay bit set, the packet acceptance rules will prohibit that destination station from accepting (and therefore acknowledging) the remaining fragments.

When the relay and access point bits direct a data frame soley to the access point, the AP can send its acknowledgment in the SIFS interval, since there will be no contention for the channel during that interval. We propose that the AP delay its acknowledgment to the PIFS interval only when there is a chance that the destination may be acknowledging the frame in the SIFS interval. This case occurs only when relay is not requested and when the AP thinks the destination is asleep.

Frame formats

This submission has proposed two new frame formats: a ETE packet and an ETE acknowledgment. The ETE packet is transmitted by the AP to a source station to indicate the success or failure of the packet being relayed. The ETE Packet Ack is an acknowledgment of the ETE packet and is sent by a source station receiving the ETE packet. These formats are shown below in Figures 8 and 9.

Fixed Header	NID	DEST	SRC	CRC

Figure 8: Format of ETE Packet

Fixed Header	NID	DEST	SRC	CRC

Figure 9: Format of ETE Packet Acknowledgment

Conclusion

This submission has proposed a strategy for delivering packets within a BSS. This strategy supports peer-to-peer communication as well as power management. By providing a mechanism for delivery between out-of-range stations, the proposed strategy would significantly improve the reliability of RF coverage within a BSS.

The authors would like to see packet relay added to the current MAC (Issue 11.5 - YES).

The authors would also like to see the proposed packet delivery strategy incorporated into the current MAC.

References

[1] IEEE P802.11-93/190 Distributed Foundation Wireless Medium Access Control, Wim Diepstraten, NCR, Greg Ennis, Symbol Technologies, and Phil Belanger, Xircom.

[2] IEEE P802.11-93/208 A Complete Description of Frame Prioritization in a CSMA/CA MAC Protocol, Rick White, Fred Vook, Kevin Doss, Mark Demange, Motorola.