IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: **High-performance Access Control Method for Base Station-Controlled Systems**

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Abstract:
This paper focuses on an access method for wireless local area networks. The access method consists of a multiple access control, an error recovery control, and a retransmission control. Each control is discussed in terms of the means necessary for achieving efficient radio link utilization and high throughput using a single communication channel. This paper proposes a multiple access control called the Bandwidth-request Labeled-slot Multiple Access (BLMA). In the BLMA, a wireless terminal requests an access right from a base station during a request field in a frame, using a slotted ALOHA. The base station grants an access right to the wireless terminal at the top of the fragment to be assigned to the terminal. This access method is promising for achieving error recovery control in terminal to terminal direct communication.

1. Introduction
One of the key aims of wireless LANs is to provide personal computer portability. However, existing applications must be run in also wireless LAN environments and the number of radio communication channels is limited. These conditions in wireless LANs suggest that a wireless MAC should use an existing MAC-LLC interface and should provide transmission quality equal to existing LLCs. They also suggest that wireless communication control, including a wireless PHY and MAC, should achieve high efficiency and that its control board should ultimately be implemented in PCs.

Generally, in wireless LANs, the limitation on transmission speed depends on physical layer specifications such as modulation/coding scheme, transmission power and antenna gain. The transmission efficiency depends on an access method such as multiple access control, error recovery control and retransmission control. Therefore, the discussion of access method is essential for understanding well-balanced system design .

This paper focuses on a wireless LAN access control protocol for achieving efficient radio link utilization and an easy error recovery control using a single communication channel. In addition, an error recovery control strategy is discussed from the standpoint of easy retransmission buffer control and high performance. The main problem with wireless transmission characteristics is intermittent multipath signal fading. To solve this problem, counterplans such as for spread spectrum method, directional antennas and modulation for tolerating multipath fading, are considered.

This proposed access method works effectively in wireless communication systems in which a base station grants access rights to terminals for accessing single channels and both the base station and terminals have omnidirectional antennas. Base station-controlled systems can provide microcell structure defined by the coverage area of a base station. The microcell structure leads to large wireless communication areas and terminal portability.

2. Multiple Access Control

2.1 Requirements and Proposed Multiple Access Control

Multiple access control for wireless LANs must satisfy the following requirements
(1) Mitigation performance penalty due to hidden terminals
(2) Frequent registration/secession to/from a microcell and low power consumption for terminal portability
(3) Efficient utilization of transmission resources and low delay characteristics
(4) Multiple access control flexibility for simplifying error recovery control

These requirements suggest that it is promising for a base station to grant explicit access rights to terminals in accordance with requests for data transmission. From this viewpoint, a Split-channel Reservation Multiple Access (SRMA) and a proposed Bandwidth request Labeled-slot Multiple Access (BLMA) are suitable for accessing wireless LANs. The frame formats of both controls consist of a request region, a reply region and fragment region. A fragment region consists of several fragment slots. Each terminal requests a bandwidth assignment to transmit data using the request region. In the SRMA method, the base station collectively informs terminals of the assignment of fragment slots in the reply region. In the BLMA method, the base station allows the terminal to use the fragment slots at the top of the fragment slot one by one. Comparing both access methods, one-by-one assignment by a base station in the BLMA method is flexible and is suitable for simplifying retransmission control (see Section 3.2.).

2.2 Outline of BLMA

An outline of the BLMA procedure is given as follows; details are described in Section 4.
(1) A terminal needing to send fragments requests that a number for the fragments be assigned to the base station using the request region.
(2) When the base station acknowledges the request, it stores it in a queue.
(3) In that frame, or in the following frames, the base station assigns fragment slots to the terminal one by one by transmitting the terminal identifier at the top of the fragment.
(4) The base station replies as to whether or not the request is acknowledged in the reply region of the next frame.

2.3 Data Transmission Path

Figure 1 shows the data communication path in the target system. The request process occurs on path A. On the other hand, data can be transmitted on path C. Path C can double the transmission efficiency of path B. However, path C will have a higher ratio of hidden terminals than path B for shadowing and multipath signal fading. The problem can be solved if the base station retransmits the fragment for a source terminal. This procedure can be easily performed by the BLMA as the base station assigns the access rights one by one and can also apply the intermicrocell communication.

2.4 Multiple Access Control in Request Region

Considering that the request information length is fixed and performance penalty due to hidden terminals must be mitigated, a slotted ALOHA or a template access in which each terminal has a request slot in the request region seems promising for multiple access control in the request region. However, the larger the number of terminals in a system, the lower the frame utilization in the template access method. Therefore, the BLMA employs the slotted ALOHA in the request region.

The throughput in a slotted ALOHA depends on backoff schemes. Results of a computer simulation follow. The simulation model is shown in Fig. 2. In this simulation, messages to be transmitted are generated with random interarrival times, and are distributed to randomly selected terminals. Each terminal generates one request per message and transmits the request information to the base station using a request slot selected at random from the request region. The request information consists a terminal identifier and the number of fragments for concluding the message transmission.

Table 1 shows the simulation parameters. In each case, when collisions occur in the request slots, each request is retransmitted in the next frame. It is well known that a p-persistent ($0<p<1$) access method improves the throughput under heavy traffic conditions. However, in the access method, access delay characteristics increase under light traffic conditions and it is difficult to decide the most efficient value of parameter p. Therefore, the access method is not employed in our proposal. Retrying requests increases collision probability and reduces throughput. To prevent this phenomenon, a mechanism called the preferential retry mechanism which prohibits new requests until the retried requests are finished, is employed in cases 3 and 4.

Request access characteristics are shown in Fig. 3 and maximum collision probability characteristics are shown in Fig. 4. Both figures show that the maximum throughput on request slots is about 30% and that it is useful for the preferential retry mechanism to raise the maximum throughput.

3. Error Recovery Control

3.1 Strategy of Error Recovery Control

Error recovery control for wireless LANs must satisfy the following requirements
(1) Bit error rate (BER) at LLC-MAC interface < 1E-8
(2) Random error control capability
In radio communication systems, random noise and the multipath signal fading phenomenon can degrade transmission quality. Multipath signal fading causes bursty errors. However, errors in fragments should be dealt with as random errors because the Doppler frequency of the fading is 10 Hz at most and this is sufficiently lower than the fragment frequency.
(3) High coding efficiency
(=(Information Block Length - Correcting Code Length) / Information Block Length), (e.g. >80%))

This discussion assumes that the average BER at a MAC-PHY interface is 1E-4. Some terminals may have a BER of 1E-3 or so for multipath signal fading. The error recovery control provides 3 means to improve the BER from 1E-3 to 1E-8. They are; (1) Forward Error Correction (FEC), (2) Automatic Repeat Request (ARQ), and (3) Hybrid ARQ.

Considering random errors in fragments, the Bose-Chaudhuri-Hocquenghem code is suitable as an error correcting code. Figure 5 shows the relationship between the the original BER Pb and the corrected BER PB for different values of the number of correctable bits t and the information block length m. The PB is given by

$$PB \sim \frac{d}{m} \, {}_{m}C_{t+1} \, Pb^{t+1} (1-Pb)^{m-t-1} \qquad (t, d) = (1,3), (2,5), (3,7)$$

As shown in Fig. 5, to satisfy the requirement using only FEC, a triple error correcting code or an even more powerful correcting code must be adopted. This FEC strategy causes an increase in hardware and degrades coding efficiency.

The relationship between the transmission efficiency R and the fragment length L is shown in Fig. 6. The transmission efficiency R is given by

$$R = (L-H) \cdot \frac{(1-P)^{L}}{L}$$

where
H = the fragment header length
P = the BER

In this figure, the Selective Repeat ARQ is employed as the retransmission scheme and the window size for flow control is infinite. Figure 6 shows that if an ARQ scheme is employed under low BER conditions, transmission efficiency is drastically reduced because of the fragment header overhead.

Consequently, strategy 3, a hybrid ARQ is employed (e.g., using several hundred bits of the information length and a single or double error correcting code). If PB is 1E-5 and the length of fragments is several thousand bits, the fragment error rate is about 1E-2. This fragment error rate is equal to a throughput degradation of several %. In this system, the multipsth signal fading causing the BER of 1E-2 must be handled by appropriate modulation or equalization in the physical layer.

Figure 7 shows the structure of a fragment in the error recovery control for achieving the hybrid ARQ in the wireless MAC layer. Using this structure, both the optimal length of the information block m and the fragment can be employed independently.

3.2 Retransmission Control

The most important issue in retransmission control in wireless communication, including broadcast communication, is the retransmission algorithm. There are the following algorithms : (1) Stop and Wait; (2) Go back N; (3) Selective Repeat; (4) Block Repeat, in which fragments failing in transmission must be retransmitted collectively; and (5) Block repeat + Go back N. Generally, control becomes difficult in the order from (1) to (5), efficiency increases in the order from (5) to (1) under the condition that the transmission latency is longer than the fragment length.

In wireless LANs, propagation delay is from 10 nsec to several 100 nsec and the transmission times of fragments of several thousand bits are several 100 microsec. This relationship suggests that Stop and Wait is the most suitable algorithm for efficiency if the processing rate is high.

The first problem in the retransmission control for broadcast communication is a response mechanism and the second is a retransmission mechanism without redundancy reception. Considering quick retransmission control, negative acknowledgement (NAK) responses are essential. On the other hand, acknowledgement (ACK) responses are useless in broadcast communication collisions. To solve the first problem, only NAK responses are employed and a collision of NAK responses is regarded as a NAK response. In other words, in broadcast communication, a NAK response is detected whether there is a carrier in the response field or not (this is called the Carrier Detecting).

To solve the second problem, each terminal selects fragments to be received (this is called Selective Reception). As the BLMA has flexible multiple access control and the base station performs the retransmission, if the Stop and Wait algorithm is employed, the proposed retransmission control can be achieved using the simple fragment header structure and retransmission buffer control.

4. Details of Proposed Method

4.1 Protocol Stack

Figure 8 shows the protocol stack for wireless LAN terminals implementing the proposed access method. In Fig. 8(a), the wireless communication facility is achieved by other equipment. In this case, the proposed access method is regarded as the physical layer protocol and the upper layer message is a MAC frame. The fragmentation and reassembly are performed by an adaptation layer (ADP).

In Fig. 8(b), the wireless communication facility is achieved by the terminal communication board. In this case, the proposed access method is regarded as a MAC layer protocol and the upper layer message is an LLC frame. Therefore, the fragmentation and reassembly are performed by the MAC protocol.

4.2 Frame Format

Figure 9 shows a frame format of the proposed access method. The request response slot field (AS) indicates whether or not the request is acknowledged. The request is transmitted by a terminal using a request slot field (RS) in the preceding frame. In this system, both fields have 8 slots each. The terminal needing to transmit fragments requests an access right from the base station using a request slot in the RS. The request slot consists of a terminal MAC address and a number of fragments.

The request mode field (RM) shows the limitation on access described in Table 1. In addition, the frame includes 4 fragments (FFs) and 4 response slots (AFs). The shaded parts in Fig. 9 are transmitted by the base station. Therefore, just before and just after he shaded parts and just before the AF, a guard time, a preamble and unique word regions are provided.

Figure 10 shows the fragment structure. The fragment attribution field (FA) indicates whether the fragment is a new one or one retransmitted by the base station or one retransmitted by the source terminal. The source address field (SA) also shows the terminal given an access right.

In this frame, the fragment length is 2 k bits and the information block length for error correcting is 511 bits. The frame efficiency (= (SA+DA+I)/frame length) is about 75%.

4.3 Communication Procedure and State Diagram

The proposed communication procedure is shown in Fig. 11. A source terminal transmits a request per frame to be transmitted. The base station sets a terminal MAC address on the SA (see Fig. 10) to assign a slot. The transmitted fragment is received by both the base station and the destination terminal. If the destination terminal cannot receive the fragment, the base station retransmits the fragment for the source terminal. If the base station also fails to receive the fragment, the base station assigns a fragment slot for retransmission to the source terminal and the source terminal retransmits the fragment.

The state diagram for the terminal request process is shown in Fig. 12. A terminal transits from the request state to the waiting for assignment state after transmitting a request. When a fragment is assigned in the following frames or an ACK response is indicated in the next frame by the base station, the request process is complete. On the other hand, when a NAK response is indicated by the base station, the terminal retransmits a request in accordance with the indication in the request mode field (RM).

The state diagram for transmitting fragments by terminals is shown in Fig. 13. A terminal having no frame to be transmitted is in the idle (I) state. A terminal having concluded the request process is in the waiting for transmitting state. When a terminal in the waiting for transmitting state is assigned a fragment by the base station, it transits to the transmitting state. In the transmitting state, the terminal may be requested to retransmit the last fragment.

The flow diagram for fragment reception in terminals is shown in Fig. 14. In the case of receiving a retransmitted fragment, when the terminal has successfully received the last fragment, the retransmitted fragment is discarded by the terminal. This procedure allows the use of Selective Reception. On the other hand, when the terminal has failed to receive the last fragment, the retransmitted fragment is received as a new fragment. In broadcast communication, the terminals, to prevent collision, do not return any acknowledgement.

4.4 Access Delay Time Characteristics

The results of the simulation of access delay time characteristics under the conditions in Table 1 are shown in Fig. 15. The access delay time is normalized by the transmission time of a frame. In a request - grant type access method such as SRMA and BLMA, the maximum throughput characteristics depend on the access characteristics in the request field and the distribution of the message length. In the simulation, the average message length is 500 bytes. As shown in the figure, fragment utilization ((average transmitted message length) / (fragment length)) is about 90% under the case 4 conditions in Table 1.

The frame efficiency is about 75%, the fragment utilization is about 90%, and the retransmission loss is 2%. Therefore, the total throughput is about 65% under ideal conditions.

5. Conclusion

This paper focused on a wireless LAN access method using single communication channels for base station-controlled systems. Each of the following methods is useful in achieving efficient radio link utilization and easy error recovery control.

(1) BLMA: base station allows terminal to use fragment slot at top of fragment slot in accordance with request
(2) Terminal to Terminal Direct Communication and Retransmission by Base Station
(3) Selective Reception Method: terminal decides whether or not fragment received in accordance with results of last fragment reception
(4) Carrier Detecting Method: in broadcast communication, NAK response detected whether or not carrier is in response field. Combination of selective reception and carrier detecting methods achieves retransmission

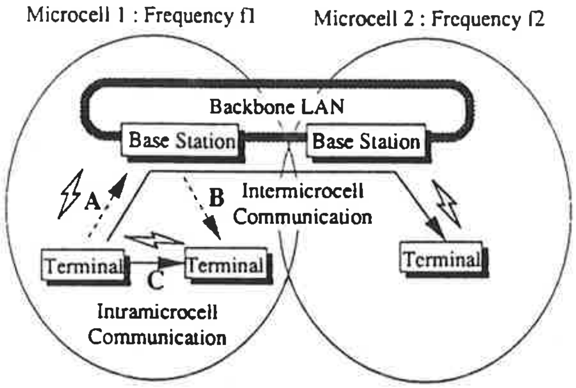


Fig. 1. Wireless LAN System Model and Communication Paths

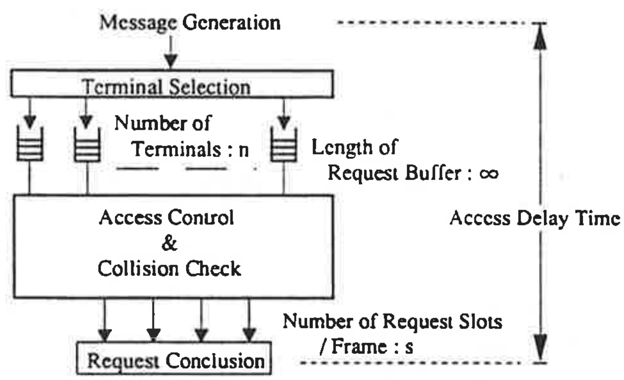


Fig. 2. Simulation Model

Table 1. Simulation Parameters

Items \ Cases & Symbols	1	2	3	4
	—□—	—■—	—○—	—△—
Number of Request Slots : s	4	4	4	8
Number of Terminals : n	10	100	100	100
Limitations onAccess	None	None	Wait for Next Request until Disappearance of Collisions	Wait for Next Request until Disappearance of Collisions

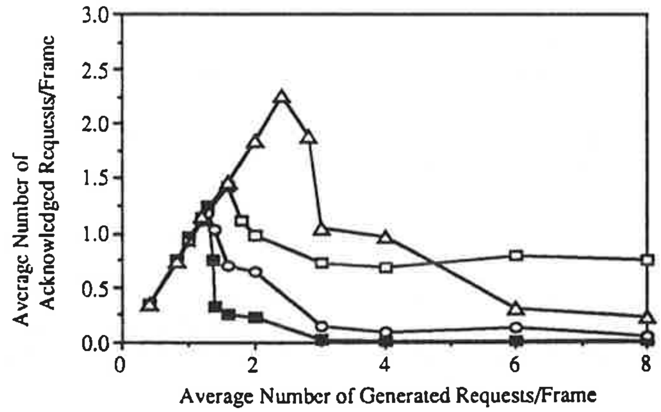


Fig. 3. Request Access Characteristics

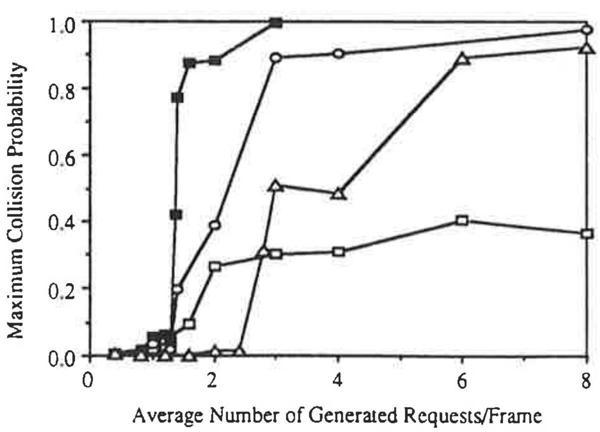


Fig. 4. Maximum Collision Probability Characteristics

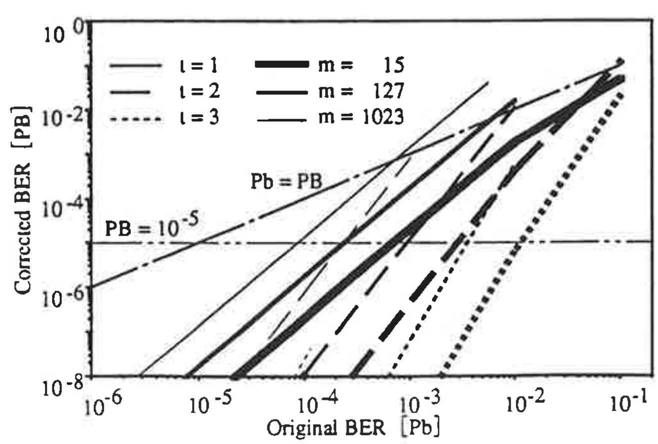


Fig. 5. Error Correcting Characteristics

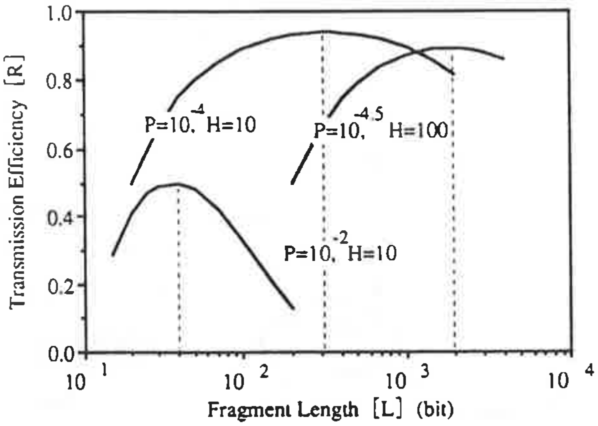


Fig. 6. Optimal Fragment Length Characteristics

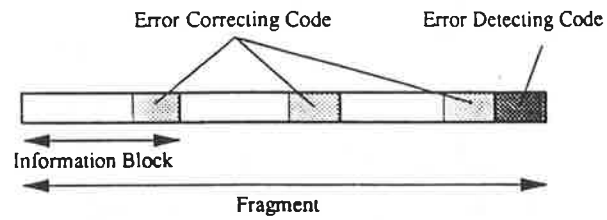
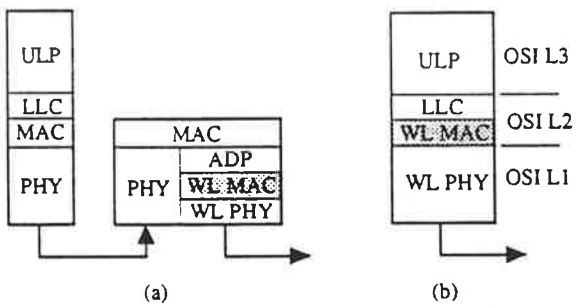
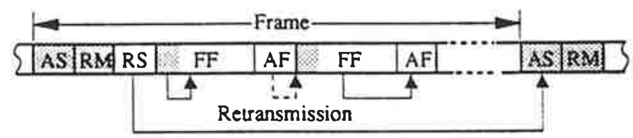


Fig. 7. Fragment Structure for Error Recovery Control



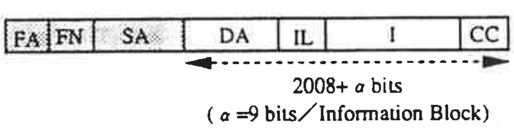
ULP: Upper Layer Protocol, ADP: Adaptation Layer Protocol
WL MAC: Access Control Protocol for Wireless LANs
WL PHY: Physical Layer Protocol for Wireless LANs

Fig. 8. Protocol Stack



AS : Request Response Slot Field
RS : Request Slot Field
AF : Fragment Response Field
RM : Request Mode Field
FF : Fragment

Fig. 9. Frame Format



FA : Fragment Attribution Field
FN : fragment Number
SA : Source Address Field
DA : Destination Address Field
IL : Information Length
I : Information
CC : Error Check Code

Fig. 10. Fragment Structure

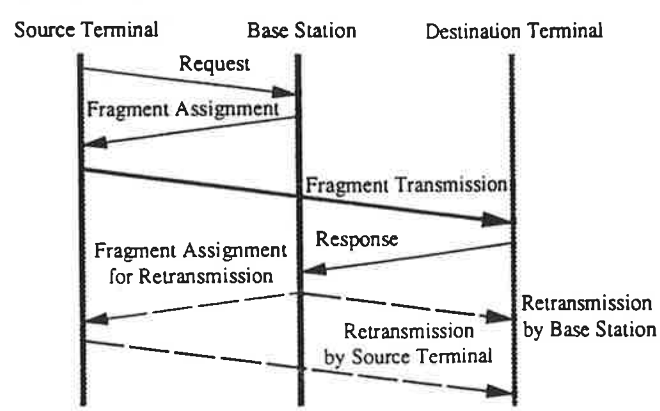


Fig. 11. Communication Procedures

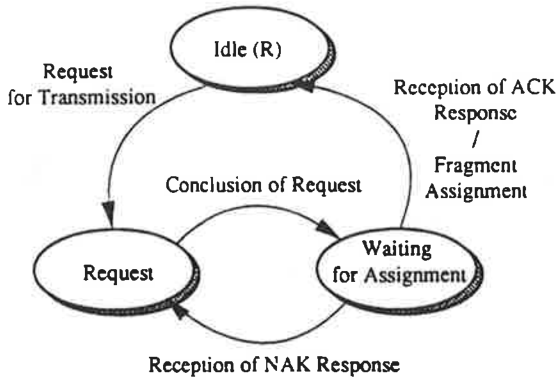


Fig. 12. State Diagram for Request Processing

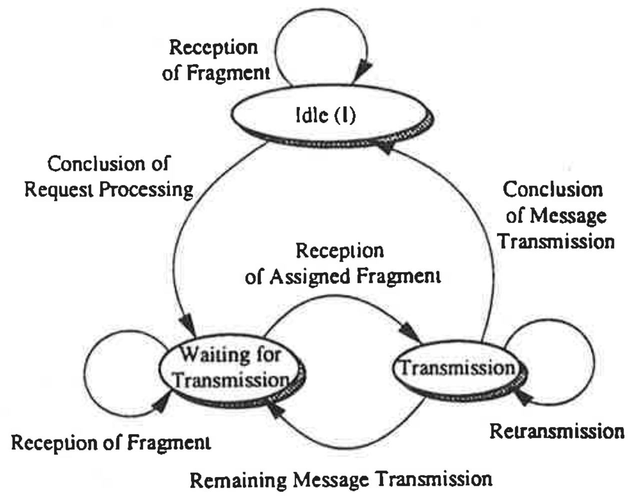


Fig. 13. State Diagram for Transmission

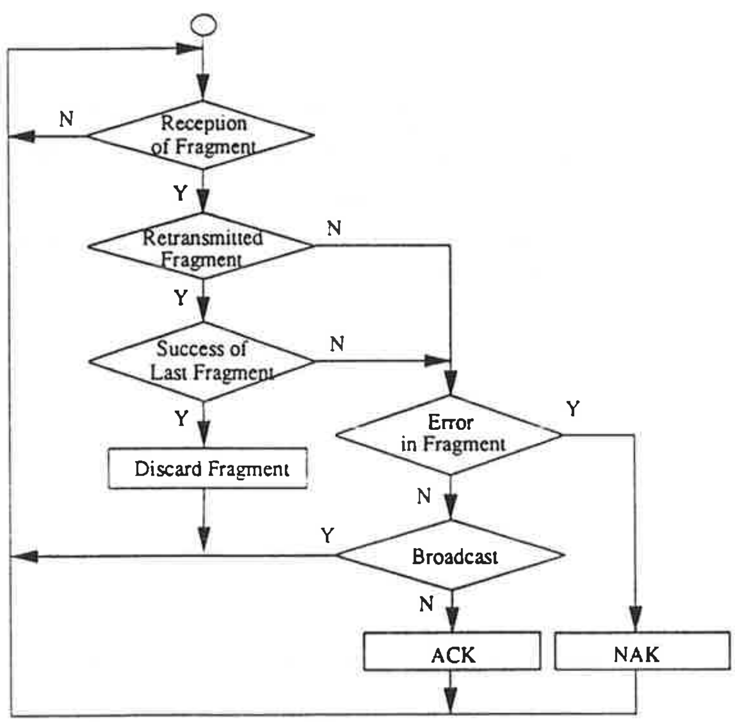


Fig. 14. Flow Diagram for Fragment Reception

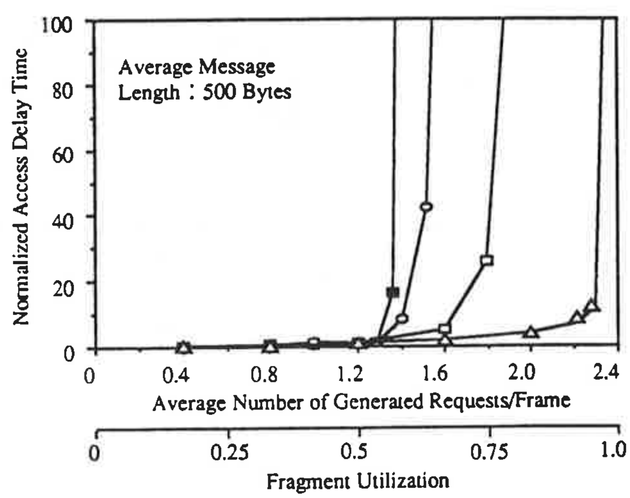


Fig. 15. Access Delay Time Characteristics

ANNEX

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High-performance Access Control Method for Base Station-Controlled Systems

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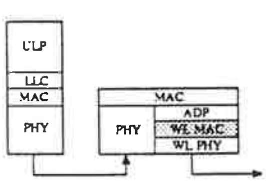
Outline

- System Image
- Multiple Access Control (BLMA)
- Error Recovery Control Strategy
- Retransmission Control (Selective Reception/Carrier Detecting Method)
- Communication Procedures
- Conclusion

System Image

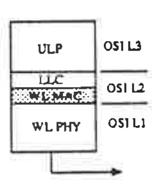
- Access Controlled by Base Station
  Microcell Structure Provides Large Wireless Communication Area and Terminal Portability
- Each Base Station Operates Using a Single Channel
- Access Control Facility Ultimately Implemented in Terminals
- Base Station and Terminals Have Omnidirectional Antennas
- Uses Existing LLCs

Protocol Stack



Wireless Communication Facility by Other Equipment

(a)



Wireless Communication Facility by Terminal Boards

(b)

ULP: Upper Layer Protocol, ADP: Adaptation Layer Protocol
WL MAC: Access Control Protocol for Wireless LANs
WL PHY: Physical Layer Protocol for Wireless LANs

BLMA Features

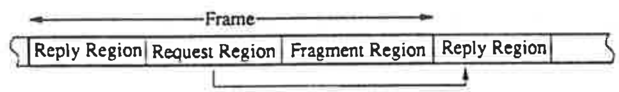
BLMA : Bandwidth-request Labeled-slot Multiple Access

(1) Mitigation Performance Penalty due to Hidden Terminals
  Request + Grant Type Multiple Access

(2) Provision for Efficient Utilization of Transmission Resources
  Terminal-to-Terminal Direct Communication
  Retransmission by Base Station

(3) Provision for Flexible Access Control to Simplify Error Recovery Control
  Stop & Wait ARQ
  Dynamic Fragment Assignment for Retransmission

Outline of BLMA



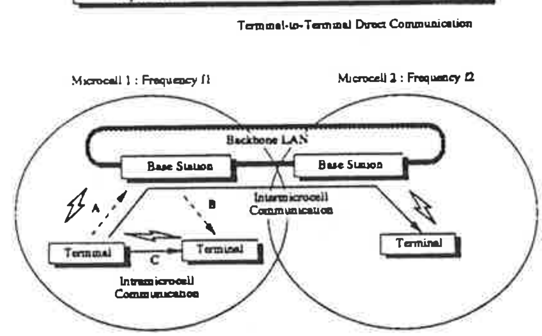
(1) Terminal Needing to Send Fragments Requests *the Number of Fragment Slots* to Be Assigned to the Base Station Using the Request Region.

(2) Upon Base Station Acknowledging Request, Base Station Stores Request in the Queue.

(3) In the Frame or the Following Frames, Base Station Assigns Fragment Slots to Terminal *One-by-One* by Transmitting Terminal Identifier (MAC Address) *at Top of Each Fragment Slot.*

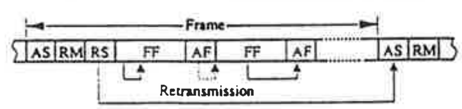
(4) Base Station Replies Whether or not Request Is Acknowledged in Reply Region of Next Frame.

System Model and Communication Paths

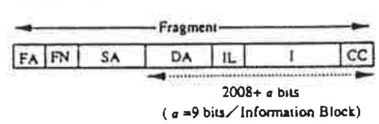


Frame and Fragment Format

Frame Efficiency ~ 75%



AS : Request Response Slot Field
RM : Request Mode Field
RS : Request Slot Field
FF : Fragment Slot
AF : Fragment Response Field



FA : Fragment Attribution Field
FN : Fragment Number
SA : Source Address Field
DA : Destination Address Field
IL : Information Length
I : Information
CC : Error Check Code

Error Recovery Control Strategy

Requirements for Error Recovery Control

(1) Bit Error Rate (BER) at LLC-MAC Interface < 10^{-8}
(2) Random Error Control Capability
(3) High Coding Efficiency

Strategy

(1) Forward Error Correction : FEC
→ Increase in Hardware and Degradation of Coding Efficiency

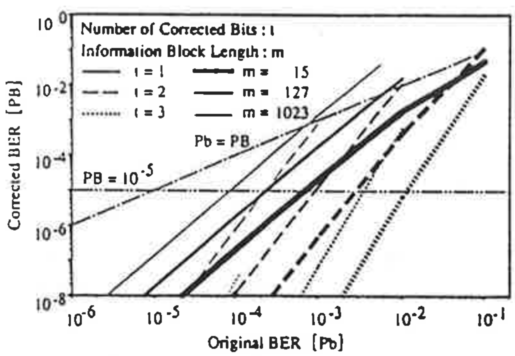
(2) Automatic Repeat Request : ARQ
→ Degradation of Transmission Efficiency under Low BER

(3) Hybrid ARQ

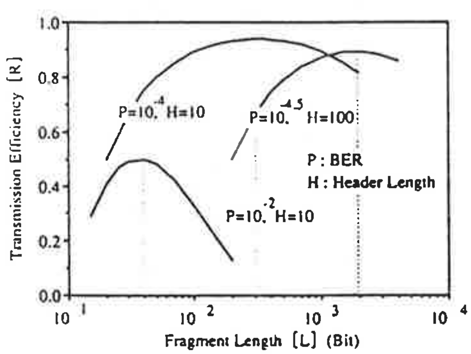
$10^{-3} \sim 10^{-4} \longrightarrow 10^{-5} \sim 10^{-6}$ (by FEC)

$10^{-5} \sim 10^{-6} \longrightarrow 10^{-8}$ (by ARQ)

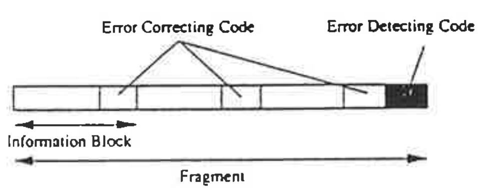
Error Correcting Characteristics



Optimal Fragment Length Characteristics



Hybrid ARQ Fragment Structure



Retransmission Algorithm

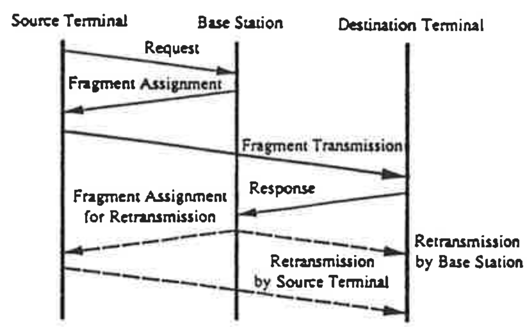
Stop & Wait is the Most Suitable Algorithm for Wireless LAN Environment

Retransmission Control for Broadcast Communication

- Carrier Detecting in Response Field
  - Using Only NAK Response
  - Collision of NAK Response Is Regarded as NAK
- Selective Reception by Terminal

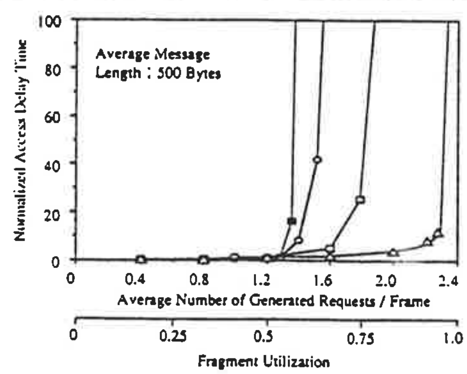
  The Terminal Decides Whether or Not the Fragment Should Be Received in Accordance with the Results of the Last Fragment Reception.

Communication Procedures



Access Delay Time Characteristics

Items \ Cases & Symbols	1	2	3	4
Items	–□–	–■–	–○–	–△–
Number of Request Slots : s	4	4	4	8
Number of Terminals : n	10	100	100	100
Limitations on Access	None	None	Preferential Retry	Preferential Retry



Conclusion

- This Presentation Focused on A Wireless LAN Access Method for A Base Station-Controlled System Using A Single Communication Channel.
- Each of the Following Methods Is Useful for Achieving Efficient Radio Link Utilization and Easy Error Recovery Control.

  (1) BLMA : Bandwidth-request Labeled-slot Multiple Access
  The Flexibility of BLMA Is Useful in the Following Methods
  (2) Terminal-to-Terminal Direct Communication and Retransmission by Base Station
  (3) Carrier Detecting in Response Field
  (4) Selective Reception by Terminal

- Using the Proposed Access Method, Total Throughput Is About 65% under Ideal Conditions.