Distributed Resource Allocation in Multimedia Ad Hoc Local Area Networks Based on OFDM-CDMA

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OFDM-CDMA 기반 멀티미디어 무선 Ad Hoc LAN에서의 분산적 자원 할당 방식

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ABSTRACT

A resource management scheme for ad hoc wireless local area networks (AWLAN's) is presented. This scheme combines distributed resource management scheme and orthogonal frequency division multiplexing-code division multiple access(OFDM-CDMA) technique to support multimedia services with QoS guarantees. The performance evaluation has done in terms of blocking rates and QoS loss probability.

요 약

본 논문에서는 Ad Hoc 무선 LAN에서의 자원 관리방식을 제안하였다. 이 방식은 분산적인 자원 관리방식과 직교주파수분할 다중화-부호분할 다중화(Orthogonal Frequency Division Multiplexing-Code Division Multiple Access, OFDM-CDMA) 기술을 결합하여 QoS를 보장하는 멀티미디어 서비스를 지원한다. 이 방식에 대하여 호 거절률(Blocking Rate)과 QoS 손실확률(QoS Loss Probability)의 관점에서 성능을 분석하였다.

키워드

QoS, OFDM-CDMA, distributed resource management, Ad Hoc, Wireless LAN

Ⅰ. Introduction

Multimedia traffic requires much larger bandwidth, at data rates greater than tens of megabits per second, hence higher frequency radio. High operating frequencies, along with a rather challenging radio channel in indoor environments, call for very robust multiple access techniques to avoid multipath fading and delay spread that can impair signal reception significantly. In addition, channel characteristics are strongly time-varying because of changes in the environment surrounding the node. Interference from other systems or relevant electrical

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접수일자: 2001. 12. 13

fields is another important sources of channel impairment.

It is the role of the resource management scheme to allocate network resources to the various application services so that the QoS requirements are met. Different from the majority of current wireless networks where the basestation is responsible for the management of network resources, AWLAN's are generally configured as distributed peer-to-peer networks with no centralized hub or controller. Distributed systems must offer a carefully designed decentralized MAC protocol to accommodate QoS requirements with flexibility and limited complexity.

OFDM-CDMA is a robust modulation / multiple access technique to encompass all channel impairment stated above. OFDM-CDMA technique proposed in [1]-[3] provides reduced fading and peak-average power ratio. In addition, by virtue of the channel granularity, it has high flexibility in bandwidth assignment for multimedia traffic.

In [4] and [5] there proposed MAC protocol using OFDM-CDMA technique for wireless local area network(WLAN) and wireless local loop(WLL) respectively. Both of them introduced and evaluated the applicability of OFDM-CDMA as a centralized, not distributed, MAC protocol for multimedia wireless networks. They also provide QoS guarantees by fair scheduling algorithm on IP layer rather than MAC layer.

In [6], they proposed a distributed resource management scheme for DS-CDMA based WLAN so called distributed resource negotiation protocol (DRNP). They also evaluated this scheme by three resource allocation criteria; minimum power, maximum rate and maximum signal to interference ratio(SIR). Despite of well defined procedure, it is rather complicated job to calculate and manage the minimum transmission power, the maximum allowed data rate and maximum SIR of each nodes in time varying radio environments.

We propose a new resource management scheme, distributed channel allocation protocol (DCAP), which combines OFDM-CDMA technique and DRNP. With this scheme, by introducing OFDM-CDMA channel architecture, we can avoid laborious channel management work in the time varying radio link. More over, we can implement distributed resource management mechanism which guarantees QoS support for the multimedia AWLAN's.

II. Channel Structure

Multicarrier modulation has drawn a lot of attention in the field of radio communications as an effective way to combat frequency selectivity in hostile radio channels. In OFDM, the entire channel is divided into many narrow subchannels transmitted in parallel. The number of OFDM subcarriers comes from a compromise of several factors: increasing the number of subcarriers improves multipath robustness, reduces the guard interval overhead, and increases the flexibility in bandwidth assignment; on the other hand, it increases phase noise sensitivity and makes baseband processing(i.e FFT) more complex[5].

By increasing the symbol rate after serial-to-parallel conversion, equalizers of OFDM require less computational effort than those of single carrier systems. But conventional OFDM has a drawback that the envelope power of the transmitted signal fluctuates widely. For example, a K-carrier OFDM system has peak-average power ratio (PAPR) of K.

Since OFDM-CDMA systems spread the data symbols across the frequency domain and employ OFDM modulation for conveying each spread data symbol, their transmitted signal exhibits a high PAPR. However, this impairment can be mitigated by appropriate selection of the spreading codes and moderate amplifier backoff[7].

The suitability of a given multiple access scheme for AWLAN applications also depends on its flexibility to assign variable bit rates to users. In OFDM-CDMA, one symbol interval can be used for the transmission of data symbols belong up to K different users.

Table 1 *summarizes the physical channel parameters*. As shown in the table, we assume a channel bandwidth of 110MHz, the intercarrier spacing is 212 kHz. Thus, the Fourier period of the OFDM-CDMA symbol is equal to 4.71μs and ISI is prevented in typical AWLAN channels at millimeter-wave frequencies. Hence symbol duration results equal to 5.15μs, where an overhead of 8.5% is used to provide protection against multipath.

Table. 1 Physical Channel Parameters

Parameter	Value
Carrier Frequency	28 GHz
Channel Bandwidth	110 MHz
Intercarrier Spacing	212 KHz
Total Subcarriers	512
Guard Band	11.8 MHz
Modulation Scheme	QPSK
Overall Bit Rate	155 Mbps

Typical OFDM implementations sacrifice some of the carriers to create a guard band between adjacent channels. Accordingly, we decided to use 400 out of 512 subcarriers, corresponding to a guard band of 11.8 MHz at each side. Therefore, if one adopts robust QPSK modulation, an aggregated bit rate of 155 Mbps is obtained. For a system designed with the above described parameters and adopting an MMSE equalization criterion, BER of less than 10-3 can be obtained for an Eb/No of 8 dB, and a special efficiency of about 1.4 b/s/Hz.

Fig. 1 depicts the logical structure of the proposed multiple access. In our OFDM-CDMA scheme we assume the radio capacity is structured as K orthogonal codes that can be used simultaneously. Each code is regarded as a channel used in a time-division multiple-access fashion; time is structured into frames lasting N time slots($T_{\_FRAME}$). A time slot of a code channel, referred as time slot-code(TC) pair, carries a MAC protocol data unit(MAC_PDU) ($T_{\_SLOT} = T_{\_MAC\_PDU}$). Moreover a *code channel, say common control channel(CCCH)*, is shared by all nodes to exchange the resource allocation requests and answers. Consequently a frame can be filled by (K-1)*N MAC_PDU's.

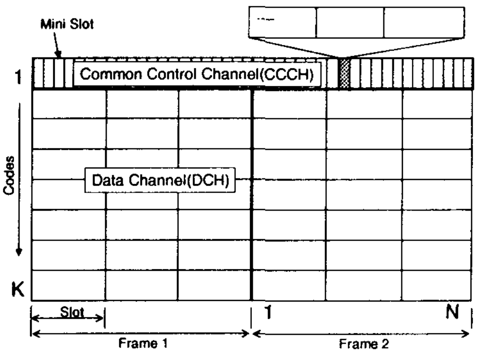


Fig.1 Logical Channel Structure of Proposed Scheme

The CCCH is structured in minislots: each minislot carries control message packets. All nodes are assumed to be synchronized previously by some mechanism and the capacity assignment is performed frame by frame. Each node can transmit on several time slots in a frame, distributing the MAC_PDU's on a given number of codes.

Ⅲ. Distributed Channel Allocation Protocol (DCAP)

All the nodes, as mentioned in[6], have the resource allocation list(RAL), which is an extension of the network allocation vector (NAV) used in 802.11 WLAN's. Each node maintains a database encoding its knowledge about other ongoing sessions in the network. Let {i,j} be a currently active session and l be a third party node with respect to {i,j} that can track the CCCH. A third party node l encodes information about the session in its database as a record containing the following information: the source (i) and destination (j) addresses for {i,j}; the allocated TC(Time slot-Code) pairs for the session {i,j}; the estimated duration for the {i,j} session, τ ij. RAL of node l contains a similar record for every active session in the network.

Whenever a session is to be established, a session negotiation procedure is performed. At first the request to send(RTS) message is issued by a transmitter i to another node j. Its format is

RTSij={i, j, RTS, Nijr, {(t,c)1,...,(t,c)n}, τ ij}

where Nijr is the requested number of TC pairs, (t,c)n are the TC pair candidates for the session {i,j} and τ ij is the estimated duration of the session.

The clear to send(CTS) message is issued by j, the recipient of the RTS message, if it can support the QoS requested by i. The format of CTS is

CTSij={j, i, CTS, Nija, {(t,c)1,...,(t,c)n}}

where Nija is the number of allocated TC pairs.

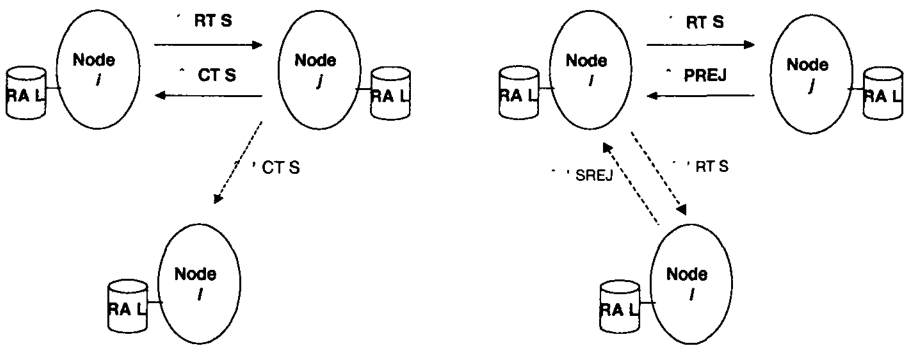
The primary reject (PREJ) is issued by the receiver j, if it is unable to support the QoS requested by the transmitter i. The format of PREJ is

PREJji={j, i, PREJ, Nijr, {(t,c)1,...,(t,c)n}}.

As a node is essentially deaf while transmitting, even if no other form of message loss occurs, a node's RAL will not be updated. Out-of-date RAL's on both sides can cause an invalid TC pair allocation, which would degrade the QoS of the currently active sessions in the network. The secondary reject (SREJ) mechanism allows third-party receivers to interrupt the setup of sessions that violate their QoS guarantees. The receiver of each third party nodes(l) tracks the CCCH while it is receiving data. If the allocation of TC pairs for the session {i,j} causes QoS violation for existing session, l issues a SREJ message

SREJli={l, i, SREJ, {(t,c)1,...,(t,c)n}}

to the transmitter. The transmitter i waits for SREJ for certain amount of time, i. e., several minislots of CCCH. If no SREJ message is received in the given time interval, it starts transmission or regards the session as blocked. Fig. 2 shows the



Request Successful

Request Fail

Fig. 2 Schematic Diagram of Session Negotiation Procedure schematic diagram of the session negotiation for two cases, i. e., request successful and request fail.

The end of session request(ESR) message

ESRij={i, j, ESR}

is used by the transmitter i to signify the end of a session. The end of session acknowledgement (ESA) message is sent by the receiver node j, in response to the ESR. Its format is

ESAji={j, i, ESA}.

Ⅳ. Performance Evaluation

The behavior of our proposed MAC protocol, with reference to key targets such as availability(the blocking rate) and QoS guarantees(QoS loss probability), has been investigated.

We consider single hop network with frequency-division duplex(FDD); hence, non overlapping bandwidth portions are assigned to the links. Concerning bandwidth granularity, to obtain a rate of h data symbols per symbol time (with h<K), h codes (h subcarriers) in the same symbol interval are used.

The traffic sources are measured MPEG coded traces, used to model real time multimedia traffic. The experimental MPEG traces used in simulations are 12 sequences measured at the University of Würzburg, Institute of Computer Science[8]. In each frame, the number of coded bytes produced depends on the type of frame picture: intraframe (I), predictive (P), and interpolative (B) pictures. Each MPEG trace is made of a repeated structure IBBPBBPBBPBB. We assume all the MPEG traces are synchronized to each other with respect to this structure, which is a worst case for the traffic burstiness.

Using the above models, simulation had been done to analyze the performance of DCAP under a variety of conditions, for an idealized network where no message loss occurs. Table 2 summarizes the simulation parameters.

Table 2 Parameters Used in the Performance Evaluation

Parameter	Value
Network Topology	single hop ad hoc
Used Orthogonal Codes(K)	400
Number of Time Slots(N)	3
Max. Number of Nodes	varying(5~200)
Mean Arrival Rate	varying(.1~2.0)
Time Duration/Time slot	2.064 ms
MAC_PDU Size	800 bits

Our simulation results show merely overall trends from which we can get conceptual insight for performance behavior of proposed scheme

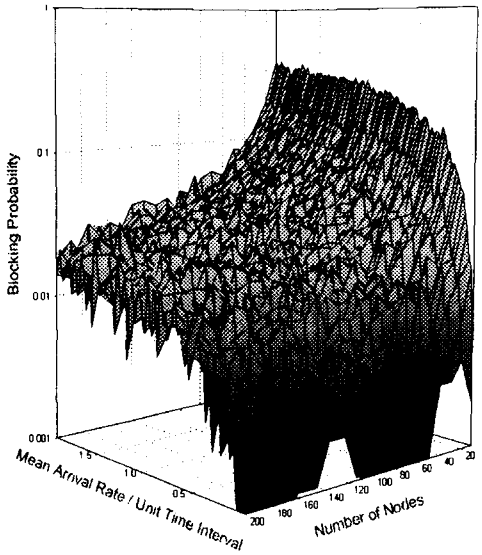


Fig. 3 Blocking Rate Distribution

The blocking rate is essentially a throughput measure and represents sessions deemed lost due to the receiver unavailable. Fig. 3 shows the distribution of blocking probability.

When the number of nodes is small, the destination is more probable to be engaged in a session. Thus the availability of destination node is low. As the number of nodes increases, blocking probability decreases. Intuitively, blocking rate is also influenced by network load, e. g., arrival rate. In the figure, when the number of nodes is 200 or above, blocking rate increases up to about 2%, as mean arrival rate per unit time(say, 1 sec) increases.

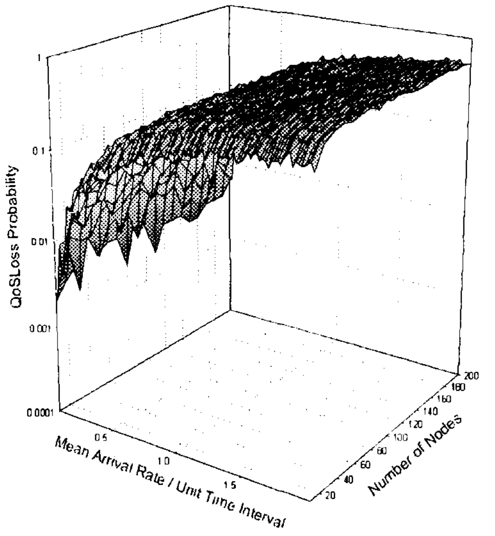


Fig. 4 QoS Loss Probability Distribution

Fig. 4 shows the QoS loss probability distribution. The loss of QoS (QoSLoss) parameter denotes the percentage of sessions that are successfully set up but lose their QoS guarantees because some other node already use same TC.

As mentioned above, when the number of nodes is small, QoS loss probability is relatively low even though total blocking rate is high. In this case, the probability of being busy for the destination node is relatively high, a third party terminal has no chance to interfere the session negotiation. QoS loss probability is more sensitive to the network load, e. g., mean arrival rate, than the number of nodes. As mean arrival rate increases, so does the number of concurrently allocated TC pairs. Consequently, for a given set of TC pairs being selected by the transmitter, the probability that a TC from the set being already used by some other node increases rapidly. In case the number of nodes is 200 and arrival rate 2.0, the QoS loss probability value approaches about 50%.

It is intuitively evident that our proposed scheme can implement distributed channel resource management with simplified procedure. In addition, from the results of the simulations e. g. blocking rate, QoS loss, it seems to be possible to find out some reasonable practical conditions to guarantee specific QoS requirement.

V. Conclusions

DCAP was designed especially for the allocation and management of resources in a multimedia AWLAN environment. In this work we proposed a MAC protocol on the top of an OFDM-CDMA radio channel. Further, we combined this with distributed resource allocation scheme to implement and support QoS guaranteeing channel resource management especially for multimedia AWLAN.

We investigated the performance of DCAP, in terms of network wide metrics such as blocking and QoS loss rates. OFDM-CDMA channel architecture can provides high bandwidth assignment flexibility without the burden of laborious power control procedure, hence the complexity of node functions. Further, blocking those users that violate the QoS constrains of the currently active sessions, the protocol fulfills the role of a call admission control (CAC) mechanism for AWLAN. It is completely distributed and adaptive to changing network conditions.

It is evident that, with some performance tuning, e.g., fair scheduling, this new scheme can be a good choice of multiple access and resource management protocol for AWLAN.

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