The Multi-rate Support Scheme with Virtual Carrier Sensing in a Heterogeneous IEEE 802.11 Wireless LAN*

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ABSTRACT

A multi-rate support scheme with Virtual Carrier Sense mechanism for IEEE 802.11 mobile stations is proposed. The scheme is designed under the premise that the new *advanced mobile stations* (AMS) which support high-speed data rate, such as 1/2/5.5/11 Mbps, can fully inter-operate with the existing *standard mobile stations* (SMS), which only transmit data at 1/2 Mbps; and still, the AMSs can use high-speed transmission when communicating with each other. In our scheme, the usage of *RTS*/*CTS* mechanism that is originally designed for hidden node problems is extended to exchange capability for transmission speed. To solve the problem that the SMSs could unintentionally destroy the transmission between two AMSs due to falsely sense the channel idle in an AMS/SMS coexisting heterogeneous environment, the Virtual Carrier Sense mechanism is enforced to guarantee a disturbance-free high-speed communication.

I. Introduction and background

The wireless access to networks has obtained great interest in the last several years. It can provide mobile users with communication capability and information access regardless of locations. A good example of this trend is marked by the standardization and the rapidly growing market spread of IEEE 802.11 products. The scope of the IEEE 802.11 standard [1] is the physical layer (PHY) and medium access control (MAC) layer implementation in a limited geographical area. The MAC scheme is designed to support three different physical layer implementations: one baseband infrared transmission, one ratio transmission employing Frequency Hopping Spread Spectrum, and one radio transmission employing Direct Sequence Spread Spectrum. In this paper, we will describe our multi-rate support MAC scheme by assuming Direct Sequence Spread Spectrum transmission for ease of explanation. Nevertheless, our scheme can be applied to the other two PHY implementations, since none of the physical layer implementation (such as preamble or PLCP header) is modified in our scheme.

In the current design of IEEE 802.11 standard, the preamble and PLCP header should always be transmitted at 1 Mbps data rate. The MAC frame can be optionally transmitted at either 1 Mbps or 2 Mbps (cf. Figure 1). The contention-based medium access of IEEE 802.11 is based on a distributed random access scheme, known as Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA), with rotating back-off windows and an optional *RTS*/*CTS* message exchange to increase the system robustness towards hidden terminal scenarios. To prioritize access for urgent control messages, such as the return of *CTS* in response to *RTS* or the return of *ACK* in response to a data (or unicast management) frame, different inter-frame spaces are specified (cf. Figure 2).

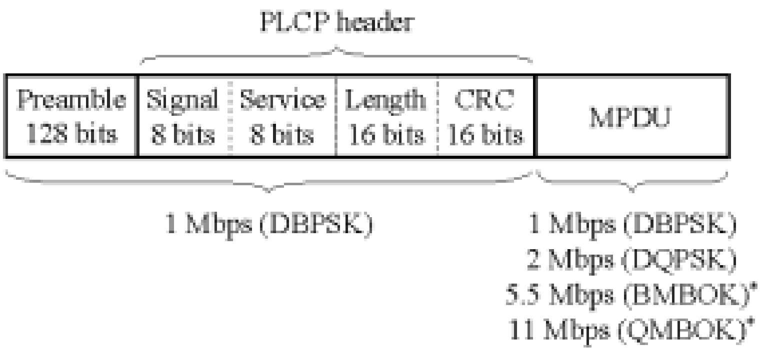

Figure 1: The data rate shall be equal to the Signal Field value multiplied by 500 Kbps. * BMBOK and QMBOK are the proposed modulation techniques by Harris.

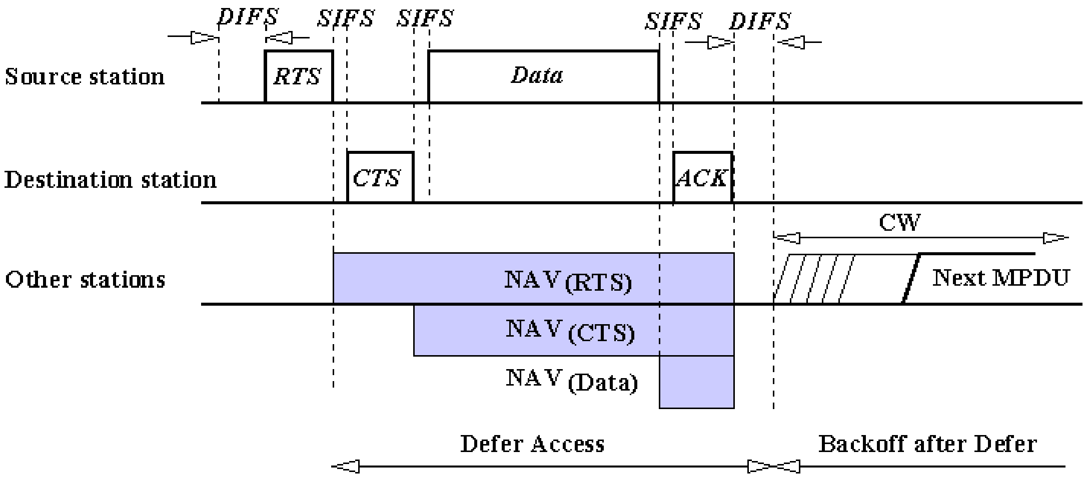

Figure 2: *RTS*/*CTS*/*Data*/*ACK* and NAV setting. DIFS = Distributed (Coordination Function) Inter-frame Space, and SIFS = Short Inter-frame Space.

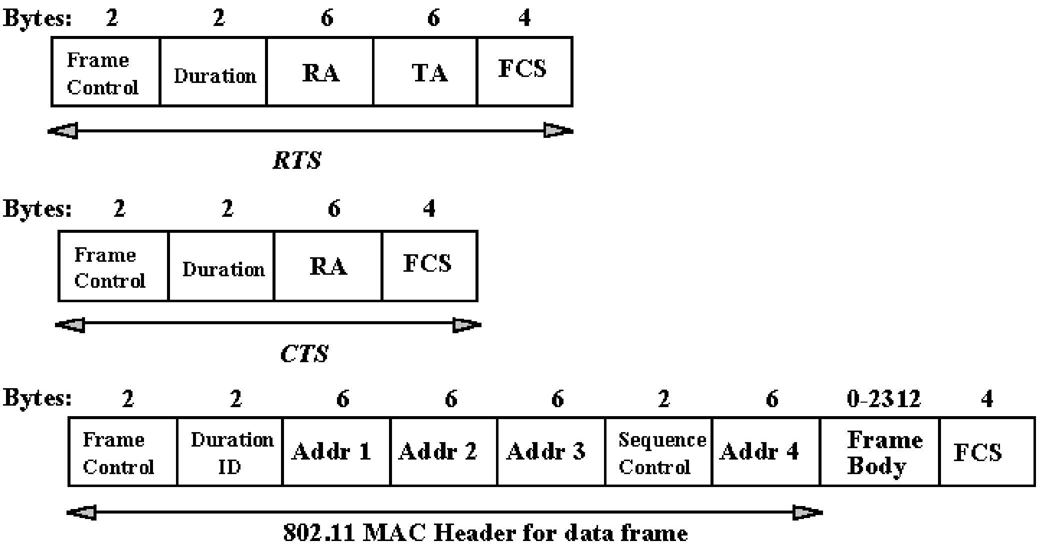

Figure 3: Frame formats of *RTS*, *CTS* and data frame.

More specifically, a station that intends to transmit and sense the channel busy will wait for the end of the ongoing transmission. After the channel clear, the station will wait for an additional time period of DIFS (Distributed Coordination Inter-Frame Space); and then randomly selects a number within the back-off window. The number, which is exactly the back-off counter, will decrease one after each time slot period. If no other station starts transmitting before the number reduces to zero, it starts to transmit; otherwise, it will freeze its back-off counter, wait for the end of this transmission, and now only wait for the remaining number to decrease to zero under channel-clear count-down.

The above access mechanism can optionally be extended by the *RTS*/*CTS* message exchange. Before the transmission of a data frame, a short control frame named *RTS* (Request To Send) is sent to the receiving station. This frame is answered by a *CTS* (Clear to Send) control frame to indicate that the receiving station is ready to take the data frame. Both the *RTS* and *CTS* control frames contain the Duration information (in microseconds) of how long the channel will be used, including the inter-frame spaces and the time to obtain the returned *ACK* message for the MPDU (cf. Figure 2 and Figure 3). Other stations as informed by the *RTS*/*CTS* frames will set their NAV (Network Allocation Vector) using the Duration information. Before the expiration of the NAV, the Carrier Sense Status of other stations will be automatically set to “Busy” without performing physical channel assessment; and hence, such mechanism is named *Virtual Carrier Sense*. The *RTS*/*CTS* message exchange has been designed to solve the hidden terminal problem. The successful exchange of the *RTS*/*CTS* message can reserve the medium from those stations within the radio range of the transmitter and the receiver for the intended transmitting period.

The Virtual Carrier Sense mechanism is also enforced to reserve the medium for a sequence of data frames that belong to the same MSDU (MAC Service Data Unit). If the *More-Fragment* bit is set to one in the Frame Control Field of a data frame, the Duration field will include not only the time to transmit one *ACK* frame plus one *SIFS* interval, but also the time to send the next data fragment of the same MSDU plus another *ACK* frame and two additional *SIFS* intervals (cf. Figure 4). Accordingly, with high probability, a station should be able to finish the transmission of a sequence of fragmented MSDU without the disturbance of other stations.

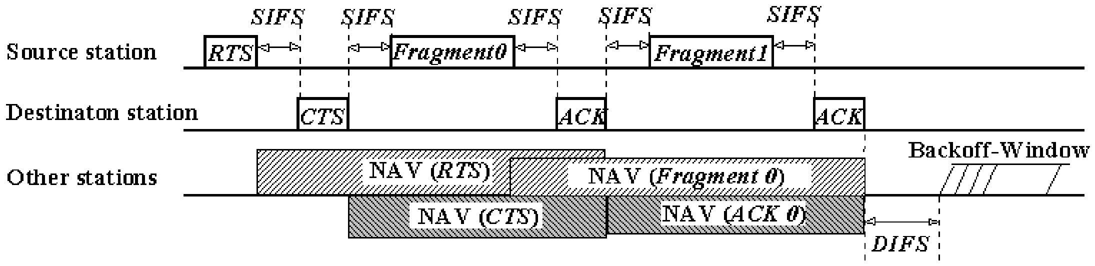

Figure 4: *RTS*/*CTS* with fragmented MSDU.

After the first standardization of IEEE 802.11 wireless LAN protocol, a new effort is followed to push the data rate up to 10 Mbps. Several proposals are in the process of evaluating. The standard body plans to call for publication of the combined document in October 1998, if some proposals are approved at that time. Currently, the working group has selected the modulation technology of Harris/Lucent as the basis for higher data rate in the 2.4GHz band. In the Harris submission for DSSS radio transmission, a new modulation technique, BMBOK/QMBOK, is added to the current BPSK/QPSK scheme, which yields data rates as high as 5.5/11 Mbps. In order to be inter-operable with the existing wireless stations that are fully compliant to the current standard, the preamble and PLCP header are still transmitted as DBPSK waveforms at 1 Mbps while the MAC body now can be optionally configured to be either DBPSK (1 Mbps), DQPSK (2 Mbps), BMBOK (5.5 Mbps), or QMBOK (11 Mbps). As a consequence, the receiver can easily gain initial PN synchronization from preamble, and make the DBPSK to DQPSK or B/QMBOK switchover according to the Signal Field of PLCP header [2] (cf. Figure 1). Most of the system parameters remain the same, such as the Slot time.

With the above advance of new modulation technique, the transmission speed of the wireless LAN is now raised up to 11 Mbps. As expected, the new Advanced Mobile Stations (AMS) supporting 1/2/5.5/11 Mbps data rates should have the ability to inter-operate with the existing Standard Mobile Stations (SMS) that only support 1/2 Mbps. In such a heterogeneous environment under which AMSs and SMSs coexist, a multi-rate support communication scheme becomes necessary. The current IEEE 802.11 standard, however, only specify some basic rules for multi-rate support and does not nail down the algorithm for performing rate switching [clause 9.6, 1]. These rules include:

(1) all control frames (such as *RTS*/*CTS* and *ACK*) and multicast/broadcast frames shall be transmitted at one of the rates in the BSSBasicRateSet, which is defined as the set of data rates (in units of 500 Kbps) that must be supported by all the stations that desire to join this BSS (Basic Service Set);
(2) both *CTS* and *ACK* shall be responded with the same rate as the immediately previous *RTS* or MPDU.

One of the problem that could arise for a heterogeneous wireless environment is that there is no mechanism for the transmitter to know the support rates of the receiver prior to the beginning of message exchange, although there are Supported Rates Elements specified in some Management frames. Even if two AMSs get the knowledge of both supporting 11 Mbps data rate before transmission, another problem that could happen is that other SMSs may not be able to carrier-sense the exchanged messages of these two AMSs. As indicated by the IEEE 802.11 standard, the carrier sensing mechanism should report a busy channel only upon the detection of a DSSS signal. Also according to [2], the carrier sense becomes active only when a spread signal with the proper PN code has been detected. Since the high-speed rate transmission (5.5/11 Mbps) assume different pseudo-random (PN) code from those used for standard rate transmission (1/2 Mbps), the carrier sense may not be adequate in itself to detect the channel status. Of course, one can employ CCA mode 3 as suggested in the standard, which combines both carrier sense and energy detection for channel clear assessment. Yet, in the situation described above, the CCA mode 3 could reduce to a pure energy-detection channel assessment because of the malfunction of carrier sensing; and hence, the possibility of erroneously reporting the channel status unavoidably increases.

Thus, the SMSs may transmit their own packets due to falsely claim the channel idle during the transmission period of two AMSs. The ongoing communication is therefore disturbed, since the data transmission period of two AMSs at 11 Mbps is longer than the duration of contention windows[1]. Also in such situation, the Virtual Carrier Sense mechanism does not properly function as well, since the SMSs cannot get the Duration information from these high-speed exchanged messages.

In this paper, we propose a multi-rate support MAC scheme with virtual carrier sense consideration. Those AMSs implementing our proposed MAC scheme can not only inter-operate with the existing SMSs, but also can communication with other AMSs. Simulation results show that such enhancement does secure the advantage of high-speed transmission capability of the AMSs without losing the interoperability to SMSs. It is worth mentioning that one may also propose to modify the physical sub-layer implementation (such as the modification of PLCP header) to solve the multi-rate supporting problem in a heterogeneous environment; but this is beyond the scope of our viewpoint in this paper. In our proposed scheme, the PHY is assumed to be intact in itself.

II. Description of Multi-rate Support Scheme

As aforementioned, our goal is to enhance the current IEEE 802.11 MAC scheme for mobile stations supporting multiple transmission rates (such as, 1/2/5.5/11Mbps) under DSSS PHY. This scheme should be completely inter-operable with existing IEEE 802.11 mobile stations supporting 1/2 Mbps DSSS PHY, and can still, to some extent, retain the advantage of high-speed data transmission rates. Both Ad Hoc and Infrastructure environment are considered. Besides, we assume that the PHY implementation such as Preamble and PLCP header should remain the same.

For clarity, we only describe our proposed scheme under the simplest multi-rate scenario, where SMSs only transmit at 2 Mbps and AMSs only support 11 Mbps transmission rate. Such scenario is actually the real wireless LAN that we considered in our conducted project.

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[1] A full-length MPDU transmitting at 11 Mbps will require 192μs for preamble and PLCP header (at 1 Mbps), and $2346 \times 8 / 11M = 1706\mu s$ for MAC body. The initial Contention Windows for DSSS PHY is 32 which is at most $32 \times 20\mu s = 640\mu s$. Hence, the back-off counter will expire prior to the expiration of a full-length MPDU transmitting time, if the channel is falsely sensed idle.

Multi-rate support MAC scheme with Virtual Carrier Sense mechanism:

1. SMSs employ the current IEEE 802.11 MAC standard.
2. AMSs use the modified IEEE 802.11 MAC as follows (also see Figure 5).
    - 2.1 *RTS*/*CTS* mechanism always turns on. (I.e., *RTSThreshold* = 0.)
    - 2.2 *RTS* should first transmitted at 11 Mbps. If no response, re-try in *N100* times using 11 Mbps. (Still, the *Preamble* and *PLCP* header are both transmitted at 1 Mbps to comply with the IEEE 802.11 Standard.) The *Duration Field* of *RTS* is the time required to transmit[2]:

$$\begin{array}{l} SIFS\ \boxed{CTS2}\ SIFS\ \boxed{emptyDataFrame2}\ SIFS\ \boxed{ACK11} \\ SIFS\ \boxed{DataFrame11}\ SIFS\ \boxed{ACK11}, \end{array} \qquad (1)$$

if *More-Fragment* bit of the *DataFrame* is 0; or

$$\begin{array}{l} SIFS\ \boxed{CTS2}\ SIFS\ \boxed{emptyDataFrame2}\ SIFS\ \boxed{ACK11} \\ SIFS\ \boxed{1^{st}DataFrame11}\ SIFS\ \boxed{ACK11} \\ SIFS\ \boxed{2^{nd}DataFrame11}\ SIFS\ \boxed{ACK11} \\ SIFS\ \boxed{a^{th}DataFrame11}\ SIFS\ \boxed{ACK11}, \end{array} \qquad (2)$$

if *More-Fragment* bit of the 1^{st}*DataFrame* is 1, and there are *a* fragments to be transmitted. Note that *a* shall be equal to 2 in the current IEEE 802.11 standard [clause 7.2.3, 1]. In our scheme, we propose to use dynamic *a* value for different speed as[3]:

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[2] For convenience, we use the number attached to the name of each frame to indicate its true transmission speed. For example, *RTS*2 and *RTS*11 means that the *RTS* control frame is transmitted at 2 Mbps and 11 Mbps respectively.

[3] The transmission period of the sequence in (2) is $(838+2120\times a)$ μs. For $a = 11$, this quantity is still less than 32768, which is the maximum number of *Duration field*. Note that under the restriction of *Duration* < 32768, the maximum *a* is 15. It needs to be pointed out that according to clause 9.7 of the standard, the number of fragments should be limited to 10 if *RTS/CTS* mechanism is involved (cf. [Frames in Sequence for *RTS/CTS* is 2-22 in Table 21, 1]). This objective of this restriction is basically for manufacturers being able to measure the "*required receiving buffer size*" for their wireless LAN products. The MAC frame (cf. [7.1.3.4, 1]), however, contains 4-bit-wide Fragment number, and the

$$a=\begin{cases}2, & \text{when data frames are transmitted at 2 Mbps;}\\ 11, & \text{if 11 Mbps is selected as the current data rate.}\end{cases}$$

The calculation basis of *Duration Field* for (1) and (2) is explained as follows. If the receiver only supports 2 Mbps, there is no way for it to recognize *RTS11.* Thus, no *CTS* will be replied by the receiver. If, however, the receiving station supports 11 Mbps, it will surely respond with a *CTS*, excepts "Hidden Node Situation" happens. Upon receipt of *CTS*, the transmitter can straightforwardly presume that the receiver supports 11 Mbps, and the transmission can be proceeded at this data rate.

The objective of introducing the *emptyDataFrame*, which is exactly a *Data Frame* with empty *Frame Body*, will be explained in step 2.4.

2.3 If no *CTS* is received after *N100* retry of *RTS11*, *RTS* will be re-transmitted using 2 Mbps. In such case, the transmitter will assume that the receiver only supports 2 Mbps. Hence, the calculation basis of the *Duration Field* of this *RTS2* will be fully compliant to the current standard, i.e., it is the time required to transmit:

$$SIFS\ \boxed{CTS2}\ SIFS\ \boxed{DataFrame2}\ SIFS\ \boxed{ACK2},$$

if *More-Fragment* bit of the *DataFrame* is 0; or

$$\begin{array}{l}SIFS\ \boxed{CTS2}\ SIFS\ \boxed{1^{st}DataFrame2}\ SIFS\ \boxed{ACK2}\\ SIFS\ \boxed{2^{nd}DataFrame2}\ SIFS\ \boxed{ACK2}\\ \dots\\ SIFS\ \boxed{a^{th}DataFrame2}\ SIFS\ \boxed{ACK2},\end{array}$$

if *More-Fragment* bit of the 1^{st}*DataFrame* is 1.

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maximum number of fragments can actually be extended up to 16.

2.4 As shown in step 2.2, *CTS* is always replied using 2 Mbps.

The objective of this design is to let all other stations (including SMSs and AMSs) within the radio range of the receiver to update their *NAV*. Likewise, the *emptyDataFrame2* allows those stations within the radio range of the transmitter to block their carrier sense action for a proper duration. Hence, their Duration field should respectively be:

SIFS *emptyDataFrame2* *SIFS* *ACK11*
SIFS 1^{st}*DataFrame11* *SIFS* *ACK11*
SIFS 2^{nd}*DataFrame11* *SIFS* *ACK11*
…
SIFS a^{th}*DataFrame11* *SIFS* *ACK11*,

and

SIFS *ACK11* *SIFS* 1^{st}*DataFrame11* *SIFS* *ACK11*
SIFS 2^{nd}*DataFrame11* *SIFS* *ACK11*
…
SIFS a^{th}*DataFrame11* *SIFS* *ACK11*,

where $a = 1$ if *More-Fragment* bit of the 1^{st}*DataFrame* is 0, and $a = 11$, otherwise.

After the successful exchange of *CTS*2/*emptyDataFrame*2, the medium is reserved for high-speed transmission between two AMSs, even if the SMSs cannot sense their signals.

One may question that when *more fragment* = 0 which indicates only one data frame needs to be transmitted, can we benefit from introducing an additional *emptyDataFrame* to reserve the medium for the follow-up 11 Mbps data transmission, if comparing with transmitting the data frame directly using 2 Mbps? In other words, one could choose to transmit

Procedure 1: *RTS11* *SIFS* *CTS*2 *SIFS* *DataFrame*2
SIFS *ACK*2,

instead of

Procedure 2: *RTS11* *SIFS* *CTS*2 *SIFS*
emptyDataFrame2 *SIFS* *ACK11* *SIFS*
DataFrame11 *SIFS* *ACK11*.

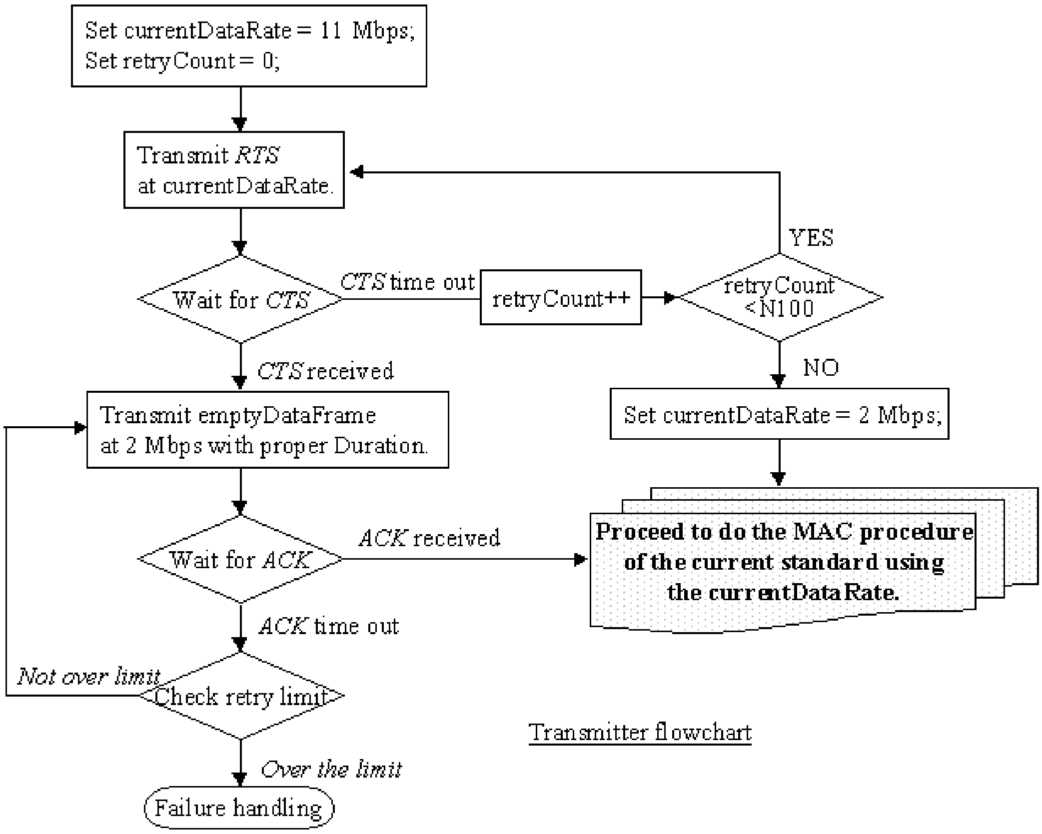
The next computation, however, shows that the latter procedure is still faster than the former one.

Procedure 1: 207+20+248+20+9576+20+248 = 10339μs
Procedure 2: 207+20+248+20+328+20+202+20+1898+20+202
= 3185μs

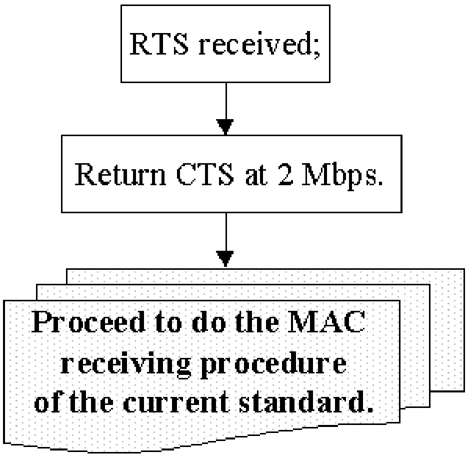
where

SIFS = 20μs,
emptyDataFrame2 = 192μs(PHY) +136μs(MAC) = 328μs,
*RTS*11 = 192μs(PHY) + 15μs (MAC) = 207μs,
CTS2 = 192μs(PHY) + 56μs(MAC) = 248μs,
*ACK*2 = 192μs(PHY) + 56μs(MAC) = 248μs,
*ACK*11 = 192μs(PHY) + 10μs(MAC) = 202μs,
DataFrame2 = 192μs(PHY) + 9384μs(MAC) = 9576μs,
and *DataFrame11* = 192μs(PHY) + 1706μs(*MAC*) = 1898μs.

Another advantage of using Procedure 2 is that we can make the procedure corresponding to *More-Fragment* = 0 consistent with that corresponding to *More-Fragment* = 1.



Transmitter flowchart



Receiver flowchart

Figure 5: Flow chart of proposed algorithm.

Remarks.

In the above scheme, *RTS* control frame is actually borrowed as a transmission-speed negotiator. If the PHY implementation gives more options at transmission rates, the transmission of *RTS* control frame shall try each rate from the highest one to the lowest one until a *CTS* is received. Under such design, the transmitter and the receiver, with high probability, should be able to communicate at the highest mutual-understandable rate.

One may suggest to create a new control frame, which composes of more useful information for speed negotiation, such as a list of supported rates. We remark that the new speed-negotiation control frame should transmit at the basic rate (e.g., 2 Mbps) which is supported by all the mobile stations; otherwise, some stations may not be able to recognize it. An alternative suggestion may be to use the existing management frames containing Supported Rates Elements to exchange speed capability. Both suggestions, however, require the modification of the MAC algorithm of existing SMSs; and hence, violate our design premise.

Another improvement on our scheme seems to be the shortening of *emptyDataFrame*, which is currently 328μs in length. We remark that since the preamble and PLCP header already contributes 192μs, and the length of MAC body cannot be shorter than an *ACK* frame, the improvement in performance due to shorting of *emptyDataFrame* is prohibitively limited. More importantly, the idea of shorting *emptyDataFrame* also fails the backward-compatibility premise.

We close this session by mentioning that our scheme is in fact applied to both Infrastructure and Ad Hoc wireless LANs.

III. Performance Analysis

The model that we used for performance analysis, as well as in simulations, is described as follows.

- ☐Each MPDU is assumed to contain 2312-byte information (which is the maximum size of an MPDU in the current standard).
- ☐There are infinitely many mobile stations, of which 1/(1+α) portion are

SMSs and $\alpha/(1+\alpha)$ portion are AMSs. The transmitter and the receiver of each MPDU are randomly drawn from these mobile stations.

☐For simplicity, the SMSs are assumed to support only 2 Mbps data rate, and the AMSs are assumed to transmit at either 2 Mbps or 11 Mbps, depending on the ability of the receiving station.

☐The *More-Fragment* bit in the Frame Control Field of each MPDU is 0.

☐For simplicity, the performance degradation due to CSMA/CA contention is ignored. Thus, only nominal performance is considered here.

The original nominal speed for 2 Mbps PHY with *RTS*/*CTS* message exchange is 2312byes / 10404μs = 1.78 Mbps (cf. Figure 2 and Figure 3). According to the above system model, there are

- $1/(1+\alpha)^2$ of the traffic from SMS to SMS, which takes 10404μs to transmit 2312-byte information (including *RTS*/*CTS*/*ACK* and *SIFS*);
- $\alpha/(1+\alpha)^2$ of the traffic transmitting from SMS to AMS, which takes 10404μs to transmit 2312-byte information;
- $\alpha/(1+\alpha)^2$ of the traffic transmitting from AMS to SMS, which takes 10631μs to transmit 2312-byte information (assuming N100 = 1);
- $\alpha^2/(1+\alpha)^2$ of the traffic transmitting from AMS to AMS, which takes 3185μs to transmit 2312-byte information.

Hence, the overall nominal transmission rate in our proposed scheme is

$$f(\alpha) = \frac{2312\times 8}{10404\times\frac{1}{1+\alpha}+10631\times\frac{\alpha}{(1+\alpha)^2}+3185\times\frac{\alpha^2}{(1+\alpha)^2}} \text{ Mbps.}$$

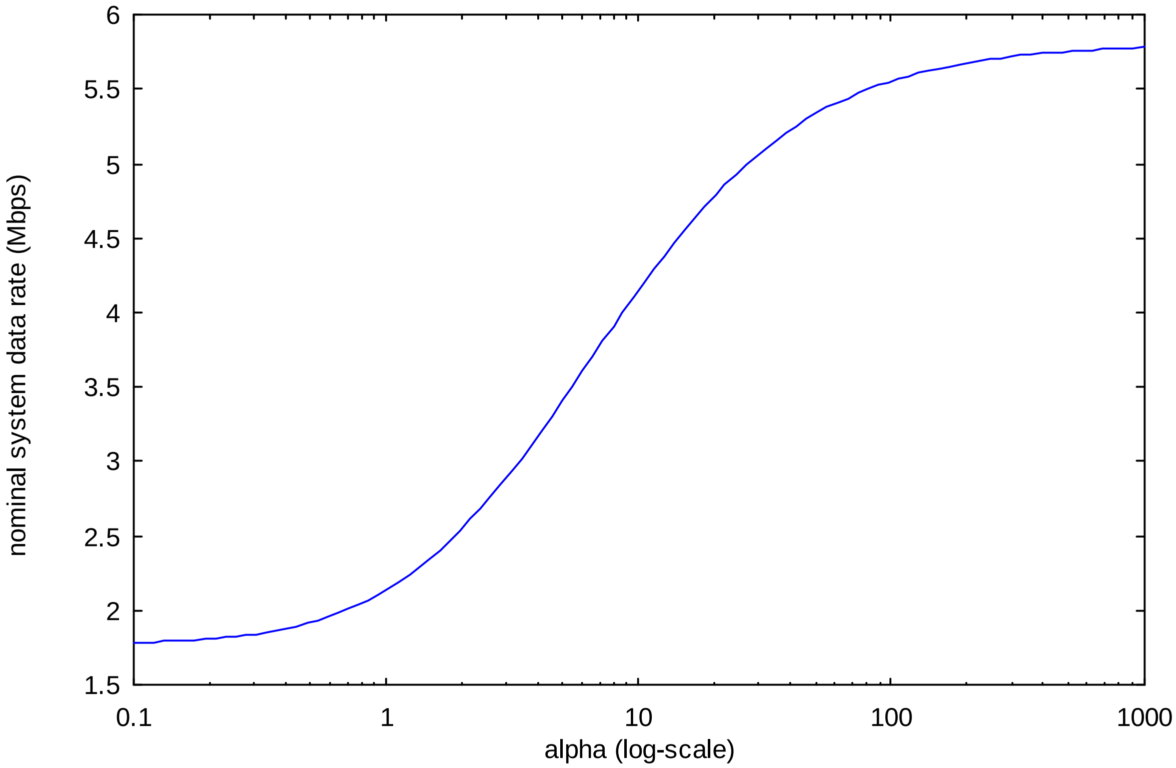


Figure 6: Function of *f*(α).

As anticipated, Figure 6 shows that the nominal system performance reduces to the original nominal speed for 2 Mbps PHY with *RTS*/*CTS* message exchange as α approaches zero. When α tends to infinity, the nominal system performance will only increase to 5.81 Mbps, even if the data rate of PHY implementation is 11 Mbps. This is due to the introduction of *RTS*/*CTS*/*emptyDataFrame* overhead. Note that according to the current MAC standard, the achievable nominal speed with *RTS*/*CTS* mechanism for 11 Mbps PHY is only 2312 × 8 / 2569μs = 7.20 Mbps. For moderate α, our multi-rate support MAC scheme only improve a little on the system performance. Observe that the nominal speed under our multi-rate scheme is only 2.14 Mbps at α = 1. We conclude this paragraph by a side observation that with the current design in IEEE 802.11 standard, the nominal speed with *RTS*/*CTS* message exchange (even if the PHY data rate approaches infinity) is bounded above by 2312 × 8 / 828μs = 22.34 Mbps, where 828μs comes from preambles and PLCP headers of *RTS*/*CTS*/*DATA*/*ACK* exchange sequence, and three *SIFS*s.

On the other hand, the individual nominal transmitting speeds for SMSs and

AMSs are respectively

$$f_{SMS}(\alpha) = \frac{2312 \times 8}{10404} = 1.78 \text{ Mbps}$$

and

$$f_{AMS}(\alpha) = \frac{2312 \times 8}{\frac{1}{1+\alpha} \times 10631 + \frac{\alpha}{1+\alpha} \times 3185} \text{ Mbps.}$$

These formulas show that the individual performance is unchanged for SMSs, and a more significant improvement than nominal system performance is observed for AMSs (cf. Figure 7).

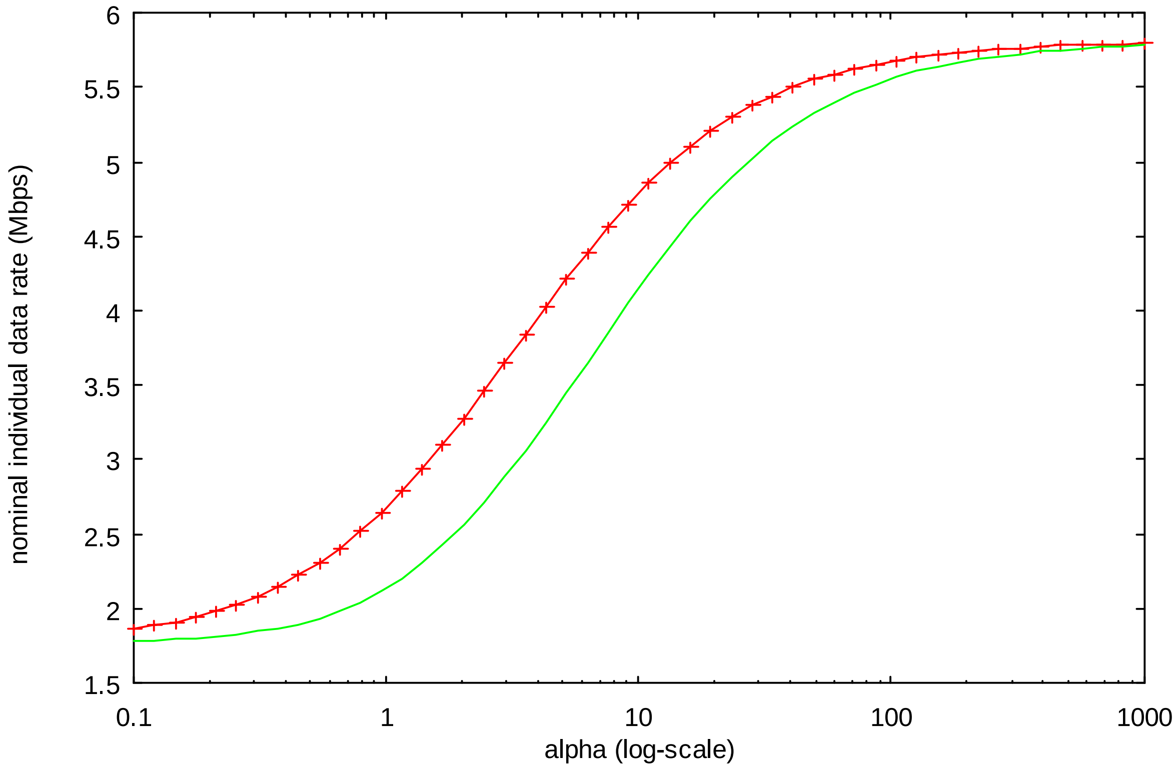


Figure 7: $f_{\text{AMS}}(\alpha)$ and $f(\alpha)$ are respectively the solid line with "+" signs and solid line only.

In the next session, we will simulate the influence on performance, regarding to overall traffic intensity λ MPDUs/slot and CSMA/CA, as well as BER (Bit Error Rate), followed by the discussion on these results.

IV. Simulation Results

The simulation model is basically the same as the previous session. To ease the simulations, some simplifications in system parameters are done as follows.

- ☐The overall traffic intensity is λ full-length data packets per slot.
- ☐Model 1: The full-length data frames (2346-byte MAC body) transmitted at 2 Mbps and 11 Mbps respectively require 9576μs and 1898μs. For simplicity, they are respectively rounded up to 500 slot-times and 100 slot-times, where slot time is 20μs in length. All other control frames, such as *ACK, RTS, CTS,* and *emptyDataFrame*, are approximated by 10 slot-times. Furthermore, we assume *SIFS* = 0μs.
- ☐Model 2: The full-length data frames (2346-byte MAC body) transmitted at 2 Mbps and 11 Mbps respectively require 9576μs and 1898μs. For simplicity, they are respectively rounded up to 500 slot-times and 100 slot-times, where slot time is 20μs in length. The length of the control frames, such as *ACK, RTS, CTS* and *emptyDataFrame* are ignored. Furthermore, we assume *SIFS* = 0μs.

Upon the time of writing this report, the simulation results have not completed. Hence, we do not put the simulation results in the current report. At the current stage, no conclusions will be drawn. It is our hope that our proposed scheme could provide some insight to this problem, and any one who is interested can take the idea for further study.

References

[1] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Standard IEEE 802.11; The editors of IEEE 802.11.

[2] *HFA 3860 Data Sheet--11 Mbps Direct Sequence Spread Spectrum Baseband Processor*, Harris Semiconductor, February 1998.

List of Figures