Wireless LAN MAC Protocol: MAC to MAC Interface

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ABSTRACT

In this contribution we propose a complement to the Medium Access Control Protocol presented in previous submissions [1] [2]. The focus is placed on the MAC-to-MAC Interface which is described from several stand points: format of the pieces of data exchanged over the air through the PHY layer, segmentation / assembly process and procedures executed by the sending device and by the receiving device.

This contribution addresses the following issues (see [3]):

- Issue 20.3 - What is the MAC frame structure?
- Issue 17.5 - What meant by addressing?
- Issue 19.5 - What kind of error recovery mechanisms are to be incorporated into the MAC?

INTRODUCTION

Consider the operation of an autonomous network system (with either multiple Access Points interconnected by a Distribution System, or a single Access Point) complying to the protocol defined in previous contributions [1] and [2]. As introduced in another previous contribution [4], the *Association* process corresponds to the procedure by which a Mobile Station introduces itself and requests the services of an Access Point. During this procedure, the Mobile Station and the Access Point have to exchange some *Control* information where are carried the different pieces of data required by the procedure. This control information can flow either *Inbound* (from the Mobile Station to the Access Point) or *Outbound* (from the Access Point to the Mobile Station).

When this association procedure has successfully completed, the candidate Mobile station enters a steady data transfer state where it can send or receive inbound or outbound pieces of data. These pieces of data carry the information data which originate from layers higher than the Medium Access Control layer.

Later on, while the steady data transfer state is still on going, or when it is decided to terminate the connection between the Access Point and the Mobile Station, it is clear that some control information will have to be exchanged over the air interface (for instance the interval headers AH, BH and CH).

From all what precedes, it stands to reason that a format and a procedure need to be defined and specified for the exchange of **any** piece of information between stations at the MAC layer level. The present contribution answers to this need.

It is clear that the interface proposed in this contribution does not depend on the 802.11 PHY layer. Nevertheless it will be shown that the proposed framing facilitates some procedures performed at the PHY layer level.

OVERVIEW

What are the characteristics of the framing to be used between wireless MAC entities? The following list identifies some conditions that we consider to be important to be fulfilled by a framing format:

- The overhead associated to the framing (especially for small MPDU packets) should be kept to a minimum.
- A destination address should allow to distinguish at least 100 different stations.
- A source address should allow to distinguish at least 100 different stations.
- Frames should support variable length (for efficiency and flexibility reasons).
- Frames should contain an error-detecting field capable of detecting multiple-bit errors.
- Frames should contain some control information such as sequencing information, type information, etc...
- Frames should be delimited by unambiguous separators to ease the detection of frame start and end, and to avoid false frame detection.

Besides those requirements concerning the framing used between wireless MAC entities, it is desirable that the MAC layer appears from the upper layers as a "regular" IEEE 802 MAC layer. This is justified because it will allow a seamless migration of networking protocol stacks from 802.3 or 802.5 connectivity towards 802.11 connectivity. For instance, it is to be hoped that a wireless LAN 802.11 adapter could replace a Token Ring or Ethernet adapter without having to redefine or replace the networking stacks running on top of them. As a result the 802.11 MAC layer will be uniquely identified by a 48 bit long MAC address which follows the same encoding rules as other 802 MAC addresses.

As an answer to the previous list of requirements, the proposed frame format used between MAC instances is derived from the framing defined at the data link layer of the OSI model: this framing format will be referred to as the **Media Link Framing** (MLF).

In the next sections will be described how the MLF format addresses the former requirements. Before going to these technical details, there are three important reasons to justify this choice:

- The proposed framing induces a very small formatting overhead. In the following will be shown that it corresponds to 12 bytes (including the frame delimiters): it is quite small and allows to exchange small MPDU packets without prohibitive overheads.
- This framing is very well suited for pieces of data resulting from a fragmentation process. As the MAC protocol assumes a fixed length slot, it is necessary to fragment before transmission (and to re-assemble after reception) the pieces of data that does not fit within a single MAC time slot.
- This framing is very popular and is today available in many controllers, or even imbedded as macros in some microprocessors. Thus from an economical stand point, this approach allows low cost implementations of the proposed protocol.

Finally it can be added that there is no reason NOT to choose an OSI like standard representation for 802.11 MAC level framing.

VOCABULARY

Before describing the format, it is necessary to specify some vocabulary to avoid any misunderstanding. The following figure specifies this vocabulary.

- The **outbound** flow originates from the Access Point.
- The **inbound** flow originates from the Mobile Station.
- The pieces of information crossing the MAC to PHY interface are called **MPDU** packets
- The pieces of information crossing the MAC to Upper Layers interface are called **MSDU** Data Frames (such as LLC frame for instance).

  Note: The MSDU data frame must be distinguished from the MAC frame as introduced in [1] which corresponds to the cyclic scheme G-AH-A-BH-B-CH-C.
- The MPDU packets which originate in the Management Entity are called **MPDU** Control Packets.
- The MPDU packets which result from MSDU data frame segmentation are called **MPDU** Data Packets.

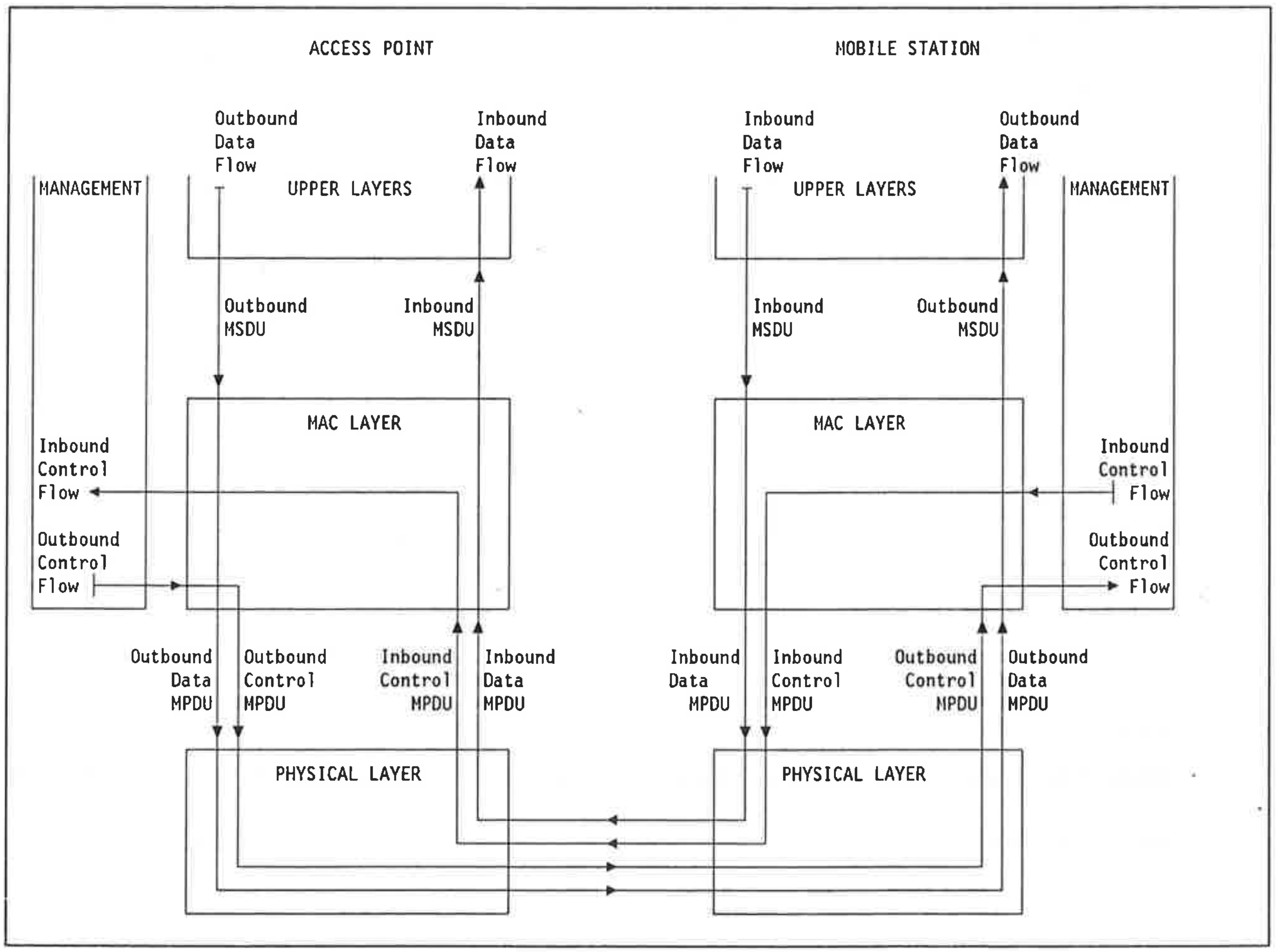

Figure 1. Vocabulary

FRAMING

All the pieces of data exchanged between a Access Point and a Mobile Station are carried within a MLF frame. The establishment of a MLF channel between a Mobile Station and its associated Access Point is done at connection establishment time. It simply corresponds to the allocation by the Access Point of a Mobile Station MLF address during the association procedure.

This MLF address is in fact a local identifier which corresponds to a local "alias" of the MAC address. This local identifier is returned by the Access Point to the Mobile Station at association completion (see association response MPDU packet as documented in [2]). As this MLF address is encoded on a single byte, the part of overhead due to addressing is significantly reduced, as opposed to other schemes relying only on 48 bit long addresses.

MLF FRAMING

This section describes the general framing structure which applies for all the MLF MPDU packets exchanged between a Access Point and a Mobile Station. This framing structure follows the scheme described in the following table:

Table 1. MLF MPDU packet frame structure

FIELD	BYTE LENGTH	VALUE	MEANING
Flag	1	X'7E'	Start frame delimiter (SFD)
DA	1	variable	Destination address
SA	1	variable	Source address
C	4	variable	Control field
L	1	variable	Data field length
Data	variable	variable	Information data
FCS	2	variable	Frame check sequence
Flag Abort	2	X'7E7F'	End frame delimiter (EFD)

Note: Error conditions may lead to receive an MLF MPDU packet that does not comply with the above framing.

Note: The Frame Check Sequence is evaluated thanks to the polynomial $X^{16} + X^{12} + X^{5} + 1$.

To ensure frame delimiter uniqueness, it is necessary to perform bit insertion on the frame part located between the delimiters. Each time five consecutive bits are equal to b'1', an extra bit b'0' is inserted after the fifth one before transmission. On the reception part, each time a b'0' is found after 5 consecutive bits b'1', it is removed from the bit stream. The overhead associated to this bit stuffing has been measured for typical traffics and is only around 1.63%.

The advantage of having unique MPDU packet framing delimiters is twofold. On one hand, the start frame and end frame delimiters can be used to automatically trigger in a RF / IR transceiver the start of transmission and the end of transmission. In other words, they can be used as "free" control information on the MAC-PHY interface.

On the other hand, the uniqueness of MPDU packet frame delimiters allows to avoid false MPDU packet detection. Any station which has missed the beginning of a MPDU packet cannot erroneously detect the beginning of a subsequent MPDU packet before completion of the current MPDU packet. This property is not found in alternate framing structures derived from the Ethernet one where nothing allows to avoid that the body of a MPDU packet "emulates" a MPDU packet start. As in such Ethernet-like schemes the end of MPDU packet is learned from a length field, there is a risk of misinterpreting several consecutive frames.

MLF ADDRESSES

With a one byte encoding, there exist 255 different MLF addresses. This set is divided into several subsets according to the following table. The justification of defining some address ranges for Access Point, for Mobile Station, and for Ad-hoc network is multiple:

- It speeds up the connection establishment time: indeed a Mobile Station willing to "get in touch" with an Access Point can take into account only the MPDU packets originating from an Access Point.
- In the same idea, if an Ad-hoc network is co-located with other wireless networks, it helps to discriminate between both: a Mobile Station pertaining to an Ad-hoc network can easily discard any information that does not originate from a station of the same Ad-hoc network.

Table 2. MLF individual addresses

RANGE (DECIMAL)	RANGE (HEXA)	DESCRIPTION
1-63	1-3F	Individual address of ad-hoc Access Point
64-127	40-7F	Individual address of regular Access Point
128-247	80-F7	Individual address of Mobile Station
248-253	F8-FD	Reserved addresses
254	FE	Default individual address of Mobile Station
255	FF	Broadcast address

The previous values of MLF addresses are the ones found in the DA and SA fields of the MLF frames.

The default individual address is used by all the Mobile Station before they know which individual MLF address has been allocated by the associated Access Point. The Mobile Station receives from its associated Access Point the allocated MLF address at the end of the association procedure (see [2]).

MLF CONTROL FIELD

The information found in the MLF control field depends on the nature of corresponding MLF MPDU packet. The following list gives the different types of MPDU packet:

- Outbound data MPDU packet
- Inbound data MPDU packet
- Outbound control MPDU packet
- Inbound control MPDU packet
- Data MPDU packet acknowledgment (inbound and outbound)
- Outbound control MPDU packet acknowledgment

- Inbound control MPDU packet acknowledgment

For each element of the previous list, the information found in the control field is described in the following tables:

Table 3. Control field for outbound data MPDU packet

FIELD	VALUES / MEANING
TYPE	Data MPDU packet
COMP	Compression flag
ENC	Encryption flag
LAST	Last MPDU packet in a MSDU data frame flag
SEQ	sequence count
SLOT	Number of slots requested.

Table 4. Control field for inbound data MPDU packet

FIELD	VALUES / MEANING
TYPE	Data MPDU packet
COMP	Compression flag
ENC	Encryption flag
LAST	Last MPDU packet in a MSDU data frame flag
SEQ	sequence count
SLOT	Number of slots requested (meaningful if ASRES or ISRES is true)
ASRES	Asynchronous reservation. flag
ISRES	Isochronous reservation flag
RESID	Reservation Identifier. Meaningful for isochronous reservation.

Table 5. Control field for outbound control MPDU packet

FIELD	VALUES / MEANING
TYPE	Outbound control MPDU packet
CODE	Control MPDU packet code: • AH Header • BH Header • CH Header • ASSOCIATION_RESPONSE • Others...
SEQ	sequence count

Table 6. Control field for inbound control MPDU packet

FIELD	VALUES / MEANING
TYPE	Inbound control MPDU packet
CODE	Control MPDU packet code: • ASSOCIATION_REQUEST • Others...
SEQ	sequence count

Table 7. Control field for data MPDU packet acknowledgment	
FIELD	**VALUES / MEANING**
TYPE	Data MPDU packet acknowledgment
COMP	Echo COMP field of data MPDU packet
ENC	Echo ENC field of data MPDU packet
LAST	Echo LAST field of data MPDU packet
SEQ	Echo SEQ field of data MPDU packet
SENSE	Acknowledge sense code: • Positive acknowledge • Negative ack: receive overrun • Negative ack: frame too long • Negative ack: frame too short • Negative ack: out of resource • Negative ack: wrong MPDU packet format • Negative ack: bad length field • Negative ack: out of sequence MPDU packet

Table 8. Control field for outbound control MPDU packet acknowledgment	
FIELD	**VALUES / MEANING**
TYPE	Outbound control MPDU packet
CODE	Control MPDU packet code: must echo the CODE field of inbound control MPDU packet: • ASSOCIATION_REQUEST • Others...
SENSE	Acknowledge sense code
SEQ	sequence count

Table 9. Control field for inbound control MPDU packet acknowledgment	
FIELD	**VALUES / MEANING**
TYPE	Inbound control MPDU packet
CODE	Control MPDU packet code: must echo the CODE field of outbound control MPDU packet (not broadcasted one) • ASSOCIATION_RESPONSE • Others
SENSE	Acknowledge sense code
SEQ	sequence count

SEGMENTATION

This section describes the packetisation/assembly process used for data transmission in the MAC Protocol. The purpose is to translate between data frames (exchanged on the MAC layer to upper layers interface) and the MLF MPDU packets (exchanged on the MAC layer to physical layer interface).

Packetisation is done to facilitate the sharing of the channel for both inbound and outbound transmissions. A MSDU data frame (such as an IEEE 802.2 frame) can be several kilobytes long and therefore can occupy a large amount (if not several) of a MAC frame (AH-A-BH-B-CH-C). Therefore, too large a MSDU data frame leaves no room for many users to share the channel. Another reason for packetisation is to increase the probability of successful data transmission. At channel bit error of 10^{-5}

, an IEEE 802.2 MSDU data frame of 2000 bytes will incur a MSDU data frame error rate of 0.15. However, if it is segmented into 10 MPDU packets each of length 200 bytes, the MPDU packet error rate will be 0.016, which is almost ten times smaller.

The functions of data packetisation for transmission by the PHY layer are the following:

- Segment MSDU data frames into MLF MPDU packets.
- Insert local MLF addresses in the MLF MPDU packet.
- Insert an appropriate control field in the MLF MPDU packet. The last MLF MPDU packet for a MAC frame is marked in the control byte. (see the LAST field in Table 4 on page 6 and in Table 3 on page 6).

When a Mobile Station chooses and associates to a Access Point, it gets a local MLF address for itself. When a Access Point is opened, it gets a local MLF address for itself. Both a Access Point and a Mobile Station will use these two addresses in the source and destination address field of every MLF MPDU packet. When the Access Point MAC layer receives a MSDU data frame from its upper layer for transmission to a Mobile Station, it will segment the frame into appropriately sized MLF MPDU packets and do the necessary address translation. On the other hand, when the Mobile Station MAC layer wants to transmit a MSDU data frame to the Access Point, it will segment the MSDU data frame into appropriately sized MLF MPDU packets and use the Access Point's MLF address. The length of MLF MPDU packets is given in "MPDU PACKET SIZE." A control field is added in the MLF MPDU packet (see Table 1 on page 4). The source of the data transmission indicates in the control byte whether the MPDU packet is the last one for a particular frame.

The functions of data assembly after RF reception are the following:

- Check the control byte to see whether the MPDU packet is the last one for a particular MSDU data frame.
- Assemble the data field of the MLF MPDU packet into a MSDU data frame.

MPDU PACKET SIZE

Table 10. MLF MPDU packet size

	A interval	B interval	C interval
MLF Header (SFD DA SA C L)	8 bytes	8 bytes	8 bytes
MLF data field	Variable	Variable	Variable
MLF Trailer (FCS EFD)	4 bytes	4 bytes	4 bytes

Note: The MLF data field length is variable but upper bounded just because they have to fit within a slot of either the A or B or C period of the MAC frame which have a fixed length.

TRANSMISSION

This section describes the mechanism followed either by a Access Point or by a Mobile Station for MPDU packet transmission on the air interface. A Access Point transmits the headers of the MAC Protocol frame and transmits either data or control MPDU packets during the A interval while a Mobile Station transmits MPDU packets during the B and the C intervals.

OUTBOUND MPDU PACKET TRANSMISSION

The transmission of outbound MPDU packets from an Access Point is triggered by timer events which specify when each interval of the MAC Protocol begins and when each slot of the A interval begins. Previously the scheduler has built the headers AH, BH and CH and has determined the A interval slot number and the Mobile Station destination of each MPDU packet. Let us call MS the destination Mobile Station of a MPDU packet to be transmitted outbound: MS is found in the list of receiving stations specified in the AH header. This MPDU packet can be either a first MPDU packet, a middle MPDU packet or a last MPDU packet. Even more it can be a single MPDU packet as are the MAC Protocol frame headers AH, BH and CH.

The Access Point MAC layer has to:

- build the MLF header of the MPDU packet to be transmitted, with the various fields reflecting the nature of the MPDU packet,
- ask the PHY layer to send the whole MLF MPDU packet,
- start a dedicated timer to wait for the reception of the acknowledgment MPDU packet (unless the MPDU packet was broadcasted),
- handle the reception of the acknowledgment according to the following cases:
  - Time-out: transmission of the MPDU packet is not successful, meaning that the MPDU packet is to be retried.
  - Reception of a negative acknowledgment: the timer is stopped and the same type of operations as above is to be performed.
  - Reception of a positive acknowledgment: the timer is stopped. If the transmitted MPDU packet is the last MPDU packet of a MSDU data frame, then the Access Point MAC layer understands that the whole MSDU data frame has been successfully sent to the destination Mobile Station. If the transmitted MPDU packet is not the last one, then the Access Point MAC layer understands that the next MPDU packet to be transmitted in a slot assigned to MS is the MPDU packet that immediately follows the transmitted MPDU packet in the segmentation output. In both cases, the sequence count associated to MS must be incremented.

INBOUND MPDU PACKET TRANSMISSION

The procedure followed by a Mobile Station MAC layer to transmit MPDU packets on the air interface is similar to the one used by a Access Point MAC layer, but with some differences which are listed hereafter.

- The transmissions occur only during B and C intervals. The C interval is used for the transmission of control MPDU packets and of the first (may be only) MPDU packet of a MSDU data frame.
- When a MPDU packet is transmitted on the C interval, the Mobile Station MAC layer adds in the MLF control field a slot allocation request if necessary (the data to be sent is larger than a C slot MLF data field).
- None MPDU packet is broadcasted from a Mobile Station.
- None MAC Protocol header MPDU packet is sent from a Mobile Station.
- Transmission on the B interval occurs only in the slots allocated by the Access Point.

RECEPTION

This section describes the mechanism followed either by a Access Point or by a Mobile Station for MPDU packet reception on the air interface. A Mobile Station receives the headers of the MAC Protocol frame and MPDU packets during the A and the B intervals while a Access Point receives MPDU packets during the B and the C intervals.

INBOUND MPDU PACKET RECEPTION

The reception of inbound MPDU packets in a Access Point is triggered by the FP FSM which knows when each slot of the B and C interval begins. Previously the scheduler has determined which Mobile Station transmits in each slot of the B interval.

- **Reception during the C interval**

  The Access Point MAC layer does not know a priori if the received MPDU packet will be a data MPDU packet or a control MPDU packet: this will be learned from the MLF header of the received MPDU packet. When the MPDU packet has been received the Access Point MAC layer has to:

  - check if the reception was successful,
  - build the appropriate acknowledgment MPDU packet,
  - ask the PHY layer to send the acknowledgment MPDU packet,
  - handle the received MPDU packet according to the following cases:
    - If the received MPDU packet was the first (not last) MPDU packet of a data frame, the Access Point MAC layer must build an entry in the queue of outstanding reservation requests based on the slot allocation request information found in the MLF control field.
    - If the received MPDU packet is a last data MPDU packet (meaning that the whole MSDU data frame fits in a C interval MPDU packet), then the Access Point MAC layer understands that a whole MSDU data frame can be passed to the upper layers.
    - If the received MPDU packet is a control MPDU packet, then the Access Point MAC layer passes the control information to the Management entity.

- **Reception during the B interval**

  The reception on the B interval is more simple than on the C interval because the Access Point knows who is the source Mobile Station. The different steps followed by the Access Point MAC layer are detailed hereafter.

  - check if the reception was successful,
  - build the appropriate acknowledgment MPDU packet,
  - ask the PHY layer to send the acknowledgment MPDU packet,
  - handle the received MPDU packet according to the following cases:
    - If the received MPDU packet is a last data MPDU packet then the Access Point MAC layer understands that a whole MSDU data frame has just been received and can be passed to the upper layers.
    - Otherwise the received MPDU packet is accumulated.

OUTBOUND MPDU PACKET RECEPTION

- **Reception during the A / B intervals**

  The procedure followed by a Mobile Station MAC layer to receive MPDU packets on the air interface is a mix of the one used by a Access Point MAC layer in the B and C intervals as explained below.

  When the reception of a new frame is starting, the reception procedure performed by a Mobile Station in the phase A / B is similar to the procedure performed by a Access Point in phase C. In a different manner, after the first-packet-in-the-frame is received, the reception procedure in a Mobile Station is similar to the base reception during the phase B.

  When the MPDU packet has been received, the Mobile Station MAC layer has to:

  - check if the reception was successful,
  - build the appropriate acknowledgment MPDU packet,
  - ask the PHY layer to send the acknowledgment MPDU packet,
  - handle the received MPDU packet according to the following cases:
    - If the received MPDU packet was a control MPDU packet, then the Mobile Station MAC layer passes it to the Management entity.
    - If the received MPDU packet was a last data MPDU packet, then the Mobile Station MAC layer understands that a whole MSDU data frame has been received and passes it to the upper layers.

- **Reception of MAC Protocol headers**

  When the Mobile Station knows that either AH, BH or CH are to be received, it must be ready to receive, validate and record them, but as these headers are broadcasted MPDU packets, no acknowledgment is returned after reception.

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