SUBJECT

WIRELESS NETWORKS

SESSION 7 Radio resource management (RRM) Medium Access Control (MAC)

Radio Resource Management"

Radio resource management (RRM) is the system level control of co-channel interference and other radio transmission characteristics in wireless communication systems, for example cellular networks, wireless networks and broadcasting systems.[1][2] RRM involves strategies and algorithms for controlling parameters such as transmit power, user allocation, beamforming, data rates, handover criteria, modulation scheme, error coding scheme, etc. The objective is to utilize the limited radio-frequency spectrum resources and radio network infrastructure as efficiently as possible.

RRM concerns multi-user and multi-cell network capacity issues, rather than the point-to-point channel capacity. Traditional telecommunications research and education often dwell upon channel coding and source coding with a single user in mind, although it may not be possible to achieve the maximum channel capacity when several users and adjacent base stations share the same frequency channel. Efficient dynamic RRM schemes may increase the system spectral efficiency by an order of magnitude, which often is considerably more than what is possible by introducing advanced channel coding and source coding schemes. RRM is especially important in systems limited by co-channel interference rather than by noise, for example cellular systems and broadcast networks homogeneously covering large areas, and wireless networks consisting of many adjacentaccess points that may reuse the same channel frequencies.

The cost for deploying a wireless network is normally dominated by base station sites (real estate costs, planning, maintenance, distribution network, energy, etc.) and sometimes also by frequency license fees. The objective of radio resource management is therefore typically to maximize the system spectral efficiency in *bit/s/Hz/area unit* or*Erlang/MHz/site*, under some kind of user fairness constraint, for example, that the grade of service should be above a certain level. The latter involves covering a certain area and avoiding outage due to co-channel interference, noise, attenuation caused by path losses, fading caused by shadowing and multipath, Doppler shift and other forms ofdistortion. The grade of service is also affected by blocking due to admission control, scheduling starvation or inability to guarantee quality of service that is requested by the users.

While classical radio resource managements primarily considered the allocation of time and frequency resources (with fixed spatial reuse patterns), recent multi-user MIMOtechniques enables adaptive resource management also in the spatial domain.[3] In cellular networks, this means that the fractional frequency reuse in the GSM standard has been replaced by a universal frequency reuse in LTE standard.

Some chief information officers and information technology managers are reluctant to deploy wireless LANs. Among their concerns are reliability, availability, performance, and deployment. Each of these concerns can be directly addressed through the radio resource management techniques used in a new generation of wireless LAN equipment. The new capabilities include dynamic channel assignment, dynamic power control, and load sharing. Changing from the relatively static radio resource management techniques generally in use today to dynamic methods like those highlighted in this article helps to increase the capacity and improve the performance of large-scale wireless LANs.

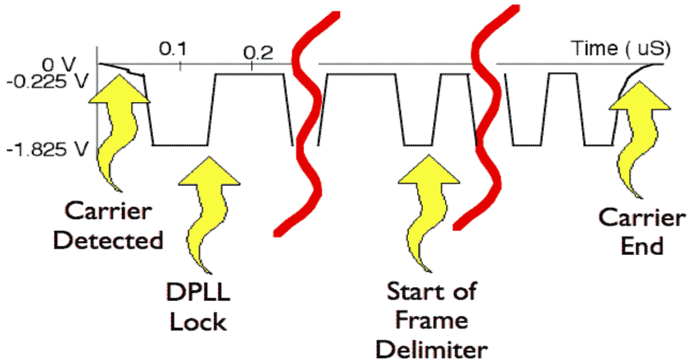
MAC address

Medium Access Control (MAC)

The Medium Access Control (MAC) protocol is used to provide the data link layer of the Ethernet LAN system. The MAC protocol encapsulates a SDU (payload data) by adding a 14 byte header (Protocol Control Information (PCI)) before the data and appending an integrity checksum, The checksum is a 4-byte (32-bit) Cyclic Redundancy Check (CRC) after the data. The entire frame is preceded by a small idle period (the minimum inter-frame gap, 9.6 microsecond (µS)) and a 8 byte preamble (including the start of frame delimiter).

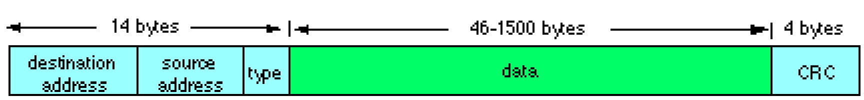
Preamble

The purpose of the idle time before transmission starts is to allow a small time interval for the receiver electronics in each of the nodes to settle after completion of the previous frame. A node starts transmission by sending an 8 byte (64 bit) preamble sequence. This consists of 62 alternating 1's and 0's followed by the pattern 11. Strictly speaking the last byte which finished with the '11' is known as the "Start of Frame Delimiter". When encoded using Manchester encoding, at 10 Mbps, the 62 alternating bits produce a 10 MHz square wave (one complete cycle each bit period).



The purpose of the preamble is to allow time for the receiver in each node to achieve lock of the receiver Digital Phase Lock Loop which is used to synchronise the receive data clock to the transmit data clock. At the point when the first bit of the preamble is received, each receiver may be in an arbitrary state (i.e. have an arbitrary phase for its local clock). During the course of the preamble it learns the correct phase, but in so doing it may miss (or gain) a number of bits. A special pattern (11), is therefore used to mark the last two bits of the preamble. When this is received, the Ethernet receive interface starts collecting the bits into bytes for processing by the MAC layer. It also confirms the polarity of the transition representing a '1' bit to the receiver (as a check in case this has been inverted).

Header



MAC encapsulation of a packet of data

The header consists of three parts:

- A 6-byte destination address, which specifies either a single recipient node (unicast mode), a group of recipient nodes (multicast mode), or the set of all recipient nodes (broadcast mode).
- A 6-byte source address, which is set to the sender's globally unique node address. This may be used by the network layer protocol to identify the sender, but usually other mechanisms are used (e.g.arp). Its main function is to allow address learning which may be used to configure the filter tables in a bridge.
- A 2-byte type field, which provides a Service Access Point (SAP) to identify the type of protocol being carried (e.g. the values 0x0800 is used to

identify the IP network protocol, other values are used to indicate other network layer protocols). In the case of IEEE 802.3 LLC, this may also be used to indicate the length of the data part. Th type field is also be used to indicate when a Tag field is added to a frame.

CRC

The final field in an Ethernet MAC frame is called a Cyclic Redundancy Check (sometimes also known as a Frame Check Sequence). A 32-bit CRC provides error detection in the case where line errors (or transmission collisions in Ethernet) result in corruption of the MAC frame. Any frame with an invalid CRC is discarded by the MAC receiver without further processing. The MAC protocol does not provide any indication that a frame has been discarded due to an invalid CRC.

The link layer CRC therefore protects the frame from corruption while being transmitted over the physical mediuym (cable). A new CRC is added if the packet is forwarded by the router on another Ethernet link. While the packet is being processed by the router the packet data is not protected by the CRC. Router processing errors must be detected by network or transport-layer checksums.

Inter Frame Gap

After transmission of each frame, a transmitter must wait for a period of 9.6 microseconds (at 10 Mbps) to allow the signal to propagate through the receiver electronics at the destination. This period of time is known as the Inter-Frame Gap (IFG). While every transmitter must wait for this time between sending frames, receivers do not necessarily see a "silent" period of 9.6 microseconds. The way in which repeaters operate is such that they may reduce the IFG between the frames which they regenerate.

Byte Order

It is important to realise that nearly all serial communications systems transmit the least significant bit of each byte first at the physical layer. Ethernet supports broadcast, unicast, and multicast addresses. The appearance of a multicast address on the cable (in this case an IP multicast address, with group set to the bit pattern 0xxx xxxx xxxx xxxx xxxx xxxx) is therefore as shown below (bits transmitted from left to right):

```
0                          23 IP Multicast Address Group  47
|                          | <------------------------->|
1000 0000 0000 0000 0111 1010 xxxx xxx0 xxxx xxxx xxxx xxxx
```

```
  |                              |
  Multicast Bit                      0 = Internet Multicast
                                1 = Assigned for other uses
```

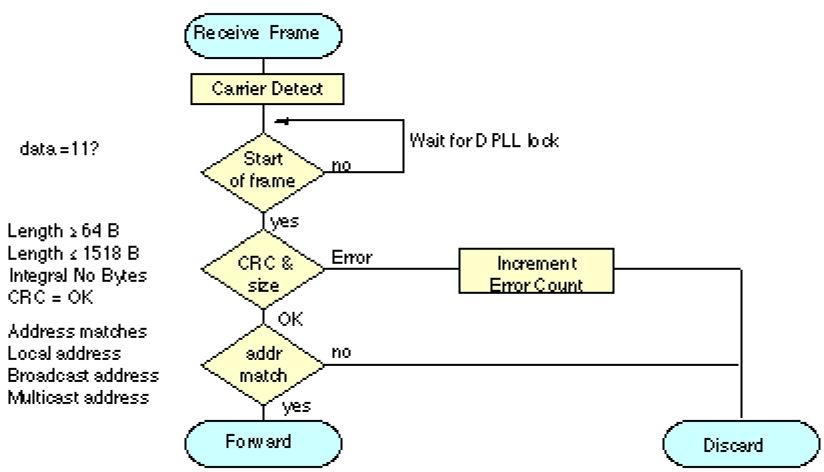
However, when the same frame is stored in the memory of a computer, the bits are ordered such that the least significant bit of each byte is stored in the right most position (the bits are transmitted right-to-left within bytes, bytes transmitted left-to-right):

```
  0                      23                        47
  |                      |                         |
  0000 0001 0000 0000 0101 1110 0xxx xxxx xxxx xxxx xxxx xxxx
        |                <-------------------------->
        Multicast Bit        IP Multicast Address Group
```

CSMA /CD

The Carrier Sense Multiple Access (CSMA) with Collision Detection (CD) protocol is used to control access to the shared Ethernet medium. A switched network (e.g. Fast Ethernet) may use a full duplex mode giving access to the full link speed when used between directly connected NICs, Switch to NIC cables, or Switch to Switch cables.

Receiver Processing Algorithm



Runt Frame

Any frame which is received and which is less than 64 bytes is illegal, and is called a "runt". In most cases, such frames arise from a collision, and while they indicate an illegal reception, they may be observed on correctly functioning networks. A receiver must discard all runt frames.

Giant Frame

Any frame which is received and which is greater than the maximum frame size, is called a "giant". In theory, the jabber control circuit in the transceiver should prevent any node from generating such a frame, but certain failures in the physical layer may also give rise to over-sized Ethernet frames. Like runts, giants are discarded by an Ethernet receiver.

Jumbo Frame

Some modern Gigabit Ethernet NICs support frames that are larger than the traditional 1500 bytes specified by the IEEE. This new mode requires support by both ends of the link to support Jumbo Frames.Path MTU Discovery is required for a router to utilise this feature, since there is no other way for a router to determine that all systems on the end-to-end path will support these larger sized frames.

A Misaligned Frame

Any frame which does not contain an integral number of received bytes (bytes) is also illegal. A receiver has no way of knowing which bits are legal, and how to compute the CRC-32 of the frame. Such frames are therefore also discarded by the Ethernet receiver.

Other Issues

The Ethernet standard dictates a minimum size of frame, which requires at least 46 bytes of data to be present in every MAC frame. If the network layer wishes to send less than 46 bytes of data the MAC protocol adds sufficient number of zero bytes (0x00, is also known as null padding characters) to satisfy this requirement. The maximum size of data which may be carried in a MAC frame using Ethernet is 1500 bytes (this is known as the MTU in IP).

A protocol known as the "Address Resolution Protocol" (arp) is used to identify the MAC source address of remote computers when IP is used over an Ethernet LAN.

Exception to the Rule

An extension to Ethernet, known as IEEE 802.1p allows for frames to carry a tag. The tag value adds an extra level of PCI to the Ethernet frame header. This increases the size of the total MAC frame when the tag is used. A side effect of this is that NICs and network devices designed to support this extension require a modification to the jabber detection circuit.

A **media access control address** (**MAC address**) is a unique identifier assigned to network interfaces for communications on the physical network segment. MAC addresses are used as a network address for most IEEE 802 network technologies, including Ethernet and WiFi. Logically, MAC addresses are used in the media access control protocol sublayer of the OSI reference model.

MAC addresses are most often assigned by the manufacturer of a network interface controller (NIC) and are stored in its hardware, such as the card's read-only memory or some other firmware mechanism. If assigned by the manufacturer, a MAC address usually encodes the manufacturer's registered identification number and may be referred to as the **burned-in address** (**BIA**). It may also be known as an **Ethernet hardware address** (**EHA**), **hardware address** or **physical address**. This can be contrasted to a programmed address, where the host device issues commands to the NIC to use an arbitrary address.

A network node may have multiple NICs and each NIC must have a unique MAC address.

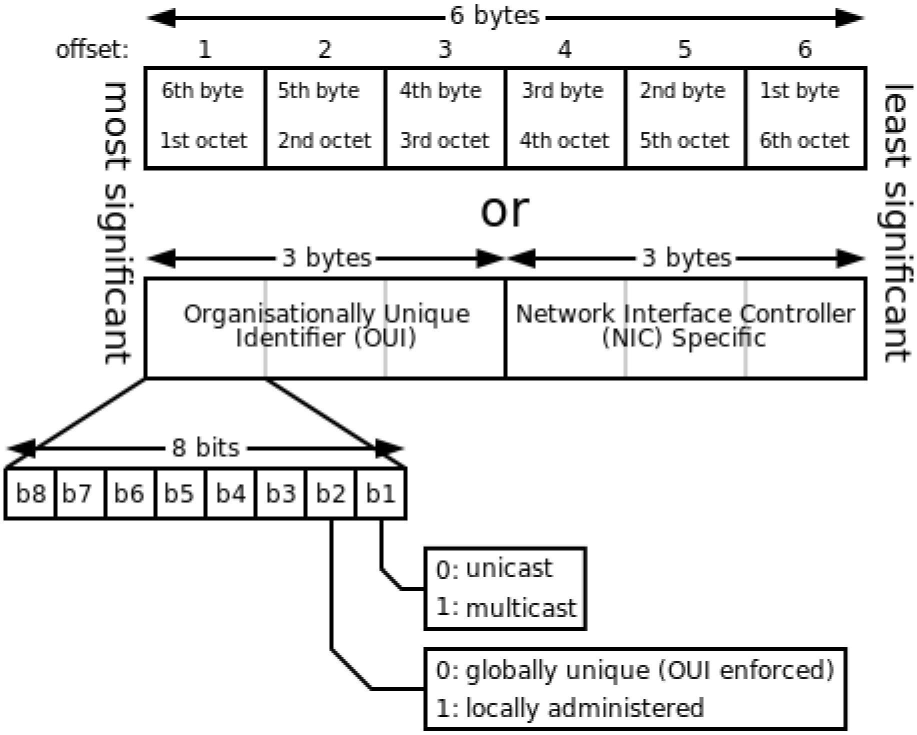
MAC addresses are formed according to the rules of one of three numbering name spaces managed by the Institute of Electrical and Electronics Engineers (IEEE): MAC-48, EUI-48, and EUI-64. The IEEE claims trademarks on the names EUI-48 and EUI-64, in which EUI is an abbreviation for *Extended Unique Identifier*.

Contents

Notational conventions[

The standard (IEEE 802) format for printing MAC-48 addresses in human-friendly form is six groups of two hexadecimal digits, separated by hyphens (-) or colons (:), in transmission order (e.g. 01-23-45-67-89-ab or 01:23:45:67:89:ab). This form is also commonly used for EUI-64. Another convention used by networking equipment uses three groups of four hexadecimal digits separated by dots (.) (e.g. 0123.4567.89ab), again in transmission order.[1]

Address details[



The original IEEE 802 MAC address comes from the original Xerox Ethernet addressing scheme.[2]This 48-bit address space contains potentially 2^{48} or 281,474,976,710,656 possible MAC addresses.

All three numbering systems use the same format and differ only in the length of the identifier. Addresses can either be *universally administered addresses* or *locally administered addresses*. A universally administered address is uniquely assigned to a device by its manufacturer. The first threeoctets (in transmission order) identify the organization that issued the identifier and are known as theOrganizationally Unique Identifier (OUI).[3] The following three (MAC-48 and EUI-48) or five (EUI-64) octets are assigned by that organization in nearly any manner they please, subject to the constraint of uniqueness. The IEEE has a target lifetime of 100 years for applications using MAC-48 space, but encourages adoption of EUI-64s instead.[3] A locally administered address is assigned to a device by a network administrator, overriding the burned-in address. Locally administered addresses do not contain OUIs.

Universally administered and locally administered addresses are distinguished by setting the second-least-significant bit of the most significant byte of the address. This bit is also referred to as the U/L bit, short for Universal/Local, which identifies how the address is administered. If the bit is 0, the address is universally administered. If it is 1, the address is locally administered. In the example address 06-00-00-00-00-00 the most significant byte is 06 (hex), the binary form of which is

00000110, where the second-least-significant bit is 1. Therefore, it is a locally administered address.[4] Consequently, this bit is 0 in all OUIs.

If the least significant bit of the most significant octet of an address is set to 0 (zero), the frame is meant to reach only one receiving NIC.[5] This type of transmission is calledunicast. A unicast frame is transmitted to all nodes within the collision domain, which typically ends at the nearest network switch or router. A switch will forward a unicast frame through all of its ports (except for the port that originated the frame) if the switch has no knowledge of which port leads to that MAC address, or just to the proper port if it does have knowledge.[6][Only the node with the matching hardware MAC address will accept the frame; network frames with non-matching MAC-addresses are ignored, unless the device is in promiscuous mode.

If the least significant bit of the most significant address octet is set to 1, the frame will still be sent only once; however, NICs will choose to accept it based on criteria other than the matching of a MAC address: for example, based on a configurable list of accepted multicast MAC addresses. This is called multicast addressing.

The following technologies use the MAC-48 identifier format:

- Ethernet
- 802.11 wireless networks
- Bluetooth
- IEEE 802.5 token ring
- most other IEEE 802 networks
- Fiber Distributed Data Interface (FDDI)
- Asynchronous Transfer Mode (ATM), switched virtual connections only, as part of an NSAP address
- Fibre Channel and Serial Attached SCSI (as part of a World Wide Name)
- The ITU-T G.hn standard, which provides a way to create a high-speed (up to 1 gigabit/s) local area network using existing home wiring (power lines, phone lines and coaxial cables). The G.hn Application Protocol Convergence (APC) layer accepts Ethernet frames that use the MAC-48 format and encapsulates them into G.hn Medium Access Control Service Data Units (MSDUs).

Every device that connects to an IEEE 802 network (such as Ethernet and WiFi) has a MAC-48 address.[7] Common consumer devices to use MAC-48 include every PC, smartphone or tablet computer.

The distinction between EUI-48 and MAC-48 identifiers is purely nominal: MAC-48 is used for network hardware; EUI-48 is used to identify other devices and software. (Thus, by definition, an EUI-48 is not in fact a "MAC address", although it is syntactically indistinguishable from one and assigned from the same numbering space.)

The IEEE now considers the label MAC-48 to be an obsolete term, previously used to refer to a specific type of EUI-48 identifier used to address hardware interfaces within existing 802-based networking applications, and thus not to be used in the future. Instead, the proprietary term EUI-48 should be used for this purpose.

The EUI-48 is expected to have its address space exhausted by the year 2100.[3]

EUI-64 identifiers are used in:

- FireWire
- IPv6 (Modified EUI-64 as the least-significant 64 bits of a unicast network address or link-local address when stateless autoconfiguration is used)
- ZigBee / 802.15.4 / 6LoWPAN wireless personal-area networks

The IEEE has built in several special address types to allow more than one network interface card to be addressed at one time:

- Packets sent to the *broadcast address*, all one bits, are received by all stations on a local area network. In hexadecimal the broadcast address would be FF:FF:FF:FF:FF:FF. A broadcast frame is flooded and is forwarded to and accepted by all other nodes.
- Packets sent to a *multicast address* are received by all stations on a LAN that have been configured to receive packets sent to that address.
- **Functional addresses** identify one or more Token Ring NICs that provide a particular service, defined in IEEE 802.5.

These are all examples of *group addresses*, as opposed to *individual addresses*; the least significant bit of the first octet of a MAC address distinguishes individual addresses from group addresses. That bit is set to 0 in individual addresses and set to 1 in group addresses. Group addresses, like individual addresses, can be universally administered or locally administered.

In addition, the EUI-64 numbering system encompasses both MAC-48 and EUI-48 identifiers by a simple translation mechanism.[8] To convert a MAC-48 into an EUI-64, copy the OUI, append the two octets FF-FF and then copy the organization-specified extension identifier. To convert an EUI-48 into an EUI-64, the same process is used, but the sequence inserted is FF-FE. In both cases, the process can be trivially reversed when necessary. Organizations issuing EUI-64s are cautioned against issuing identifiers that could be confused with these forms. The IEEE policy is to discourage new uses of 48-bit identifiers in favor of the EUI-64 system.
IPv6 — one of the most prominent standards that uses a Modified EUI-64 — treats MAC-48 as EUI-48 instead (as it is chosen from the same address pool) and

toggles the U/L bit (as this makes it easier to type locally assigned IPv6 addresses based on the Modified EUI-64). This results in extending MAC addresses (such as IEEE 802 MAC address) to Modified EUI-64 using only FF-FE (and never FF-FF) and with the U/L bit inverted.

Individual address block

An Individual Address Block is a 24-bit OUI managed by the IEEE Registration Authority, followed by 12 IEEE-provided bits (identifying the organization), and 12 bits for the owner to assign to individual devices. An IAB is ideal for organizations requiring fewer than 4097 unique 48-bit numbers (EUI-48).[10]

Usage in hosts[

Although intended to be a permanent and globally unique identification, it is possible to change the MAC address on most modern hardware. Changing MAC addresses is necessary in network virtualization. It can also be used in the process of exploiting security vulnerabilities. This is called MAC spoofing.

A host cannot determine from the MAC address of another host whether that host is on the same link (network segment) as the sending host, or on a network segment bridged to that network segment.

In IP networks, the MAC address of an interface can be queried given the IP address using the Address Resolution Protocol (ARP) for Internet Protocol Version 4 (IPv4) or theNeighbor Discovery Protocol (NDP) for IPv6. In this way, ARP or NDP is used to translate IP addresses (OSI layer 3) into Ethernet MAC addresses (OSI layer 2). On broadcast networks, such as Ethernet, the MAC address uniquely identifies each node on that segment and allows frames to be marked for specific hosts. It thus forms the basis of most of the link layer (OSI Layer 2) networking upon which upper layer protocols rely to produce complex, functioning networks.

Spying[edit]

According to Edward Snowden, the National Security Agency has a system that tracks the movements of everyone in a city by monitoring the MAC addresses of their electronic devices.[11]