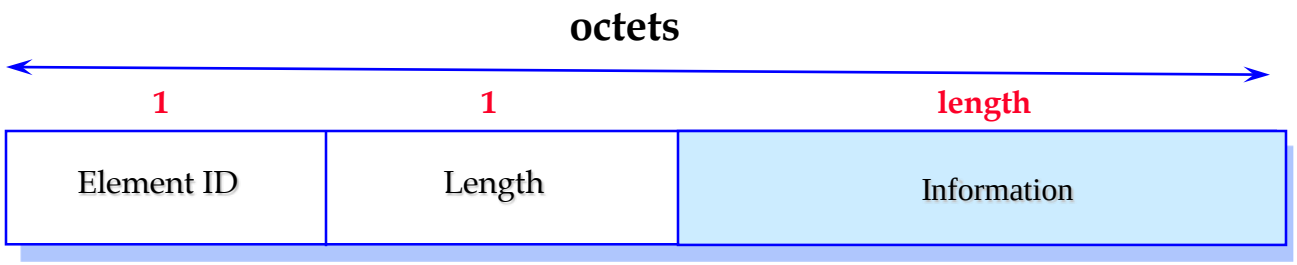
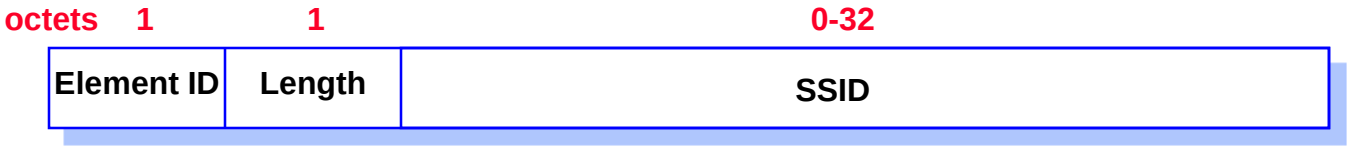
Information Element



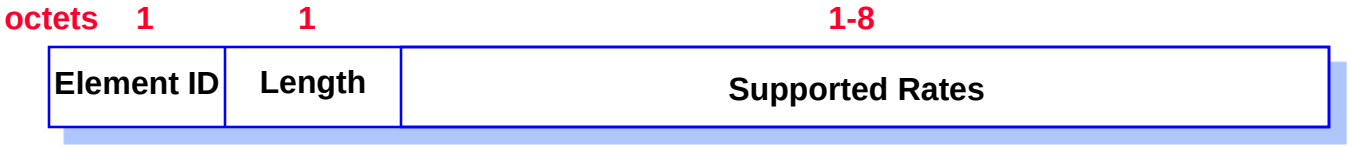
Information Element	Element ID
SSID	0
Supported rates	1
FH Parameter Set	2
DS Parameter Set	3
CF Parameter Set	4
TIM	5
IBSS Parameter Set	6
Country	7
Legacy Indication (11g)	8
Reserved	9-15
Challenge Text	16
Reserved for challenge text extension	17-31
Reserved	32-255

Elements

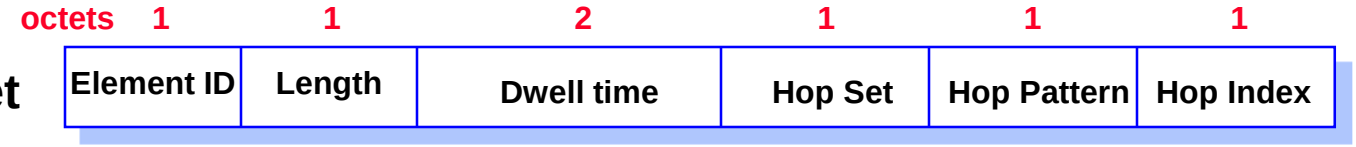
SSID



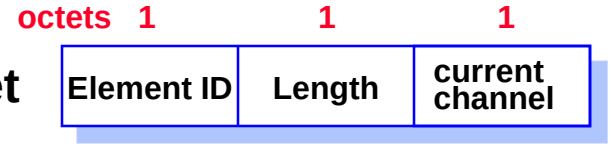
Supported Rate



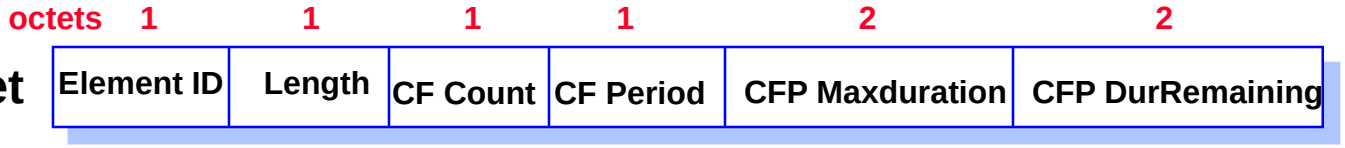
FH Parameter Set



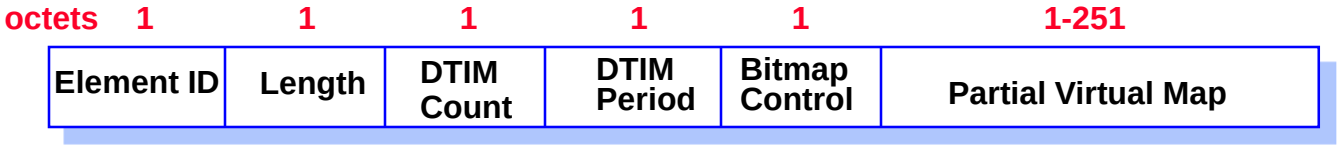
DS Parameter Set



CF Parameter Set

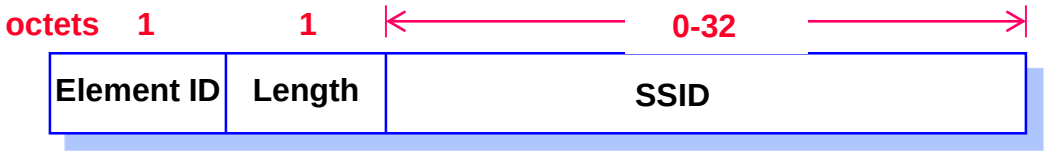


TIM



SSID Elements

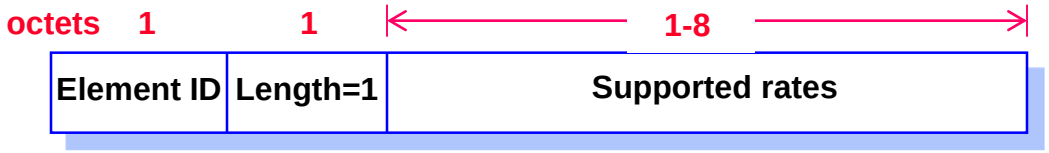
SSID Indication



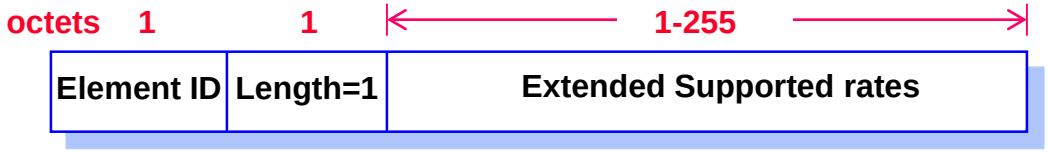
- indicates the identity of an ESS or IBSS
- a ‘0’ length information field indicates the broadcast SSID

Supported Rate Elements

802.11 (a, b only)



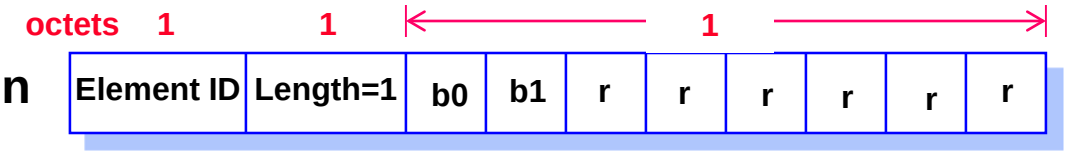
802.11g Extended supported rate



- The number of supported rates is **14** (a/b/g).
- Each supported rate belonging to the BSSBasicRateSet is encoded as an octet with the msb (bit 7) set to 1
  - e.g., a 1 Mbit/s rate is encoded as X'82‘
- Rates not belonging to the BSSBasicRateSet are encoded with the msb set to 0
  - e.g., a 2 Mbit/s rate is encoded as X'04'.

ERP Information Elements

NonERP Indication



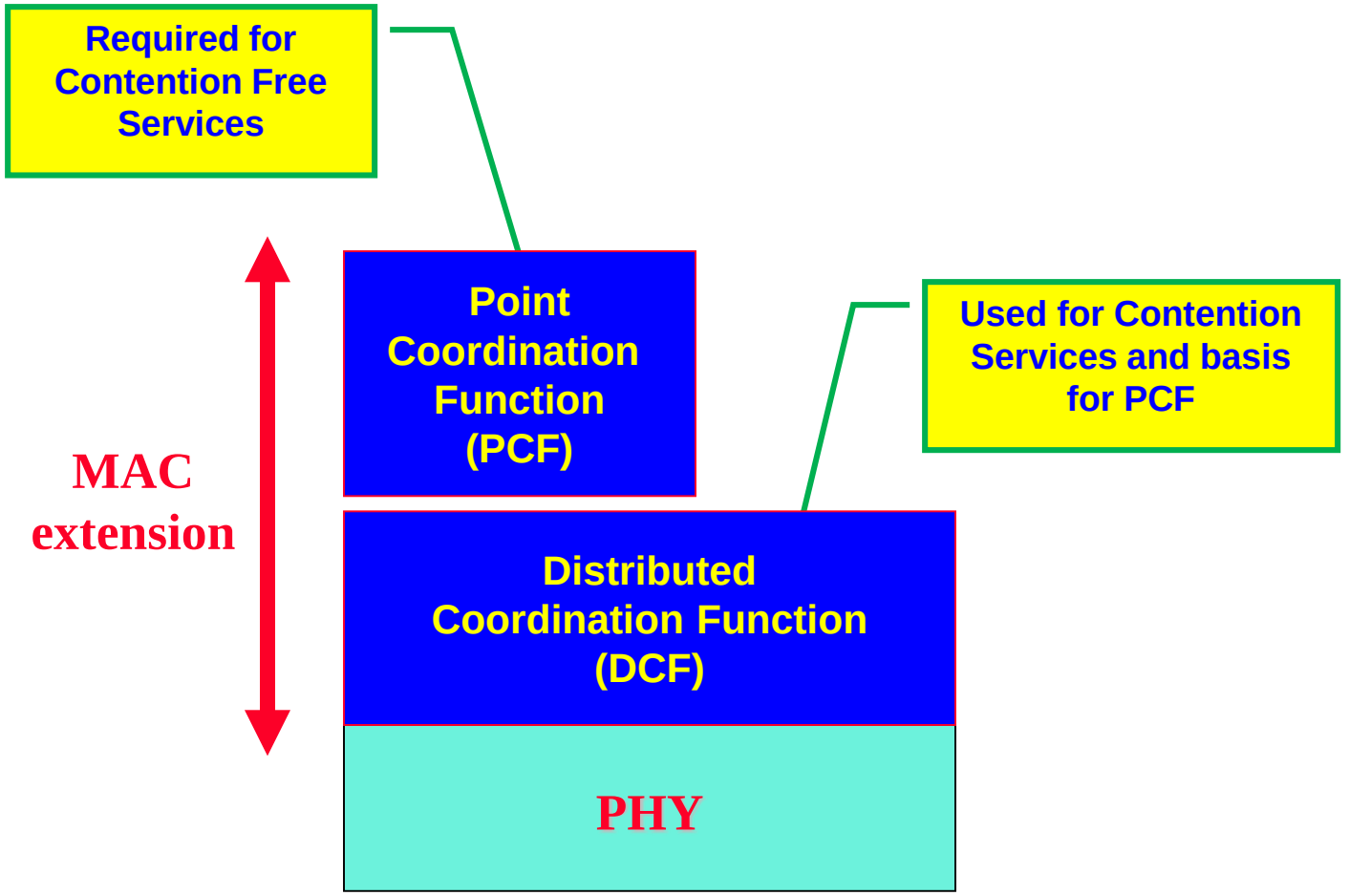
Bit b0	**NonERP_Present**
0	No NonERP stations are within the BSS
1	There are NonERP stations within the BSS

Bit b1	**Use_Protection**
0	STAs with an ERP should not use protection mechanisms for MPDUs transmitted at one of the ERP-OFDM rates.
1	STAs with an ERP shall use protection mechanisms for MPDUs transmitted at one of the ERP-OFDM rates.

- transmitted from AP in BSS or STA in IBSS
- defined in IEEE 802.11g
- **Protection mechanism**

  Use CTS frame to update the NAV of all receiving STAs prior to the transmission of a frame that may or may not be understood by receivers. The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

MAC Architecture



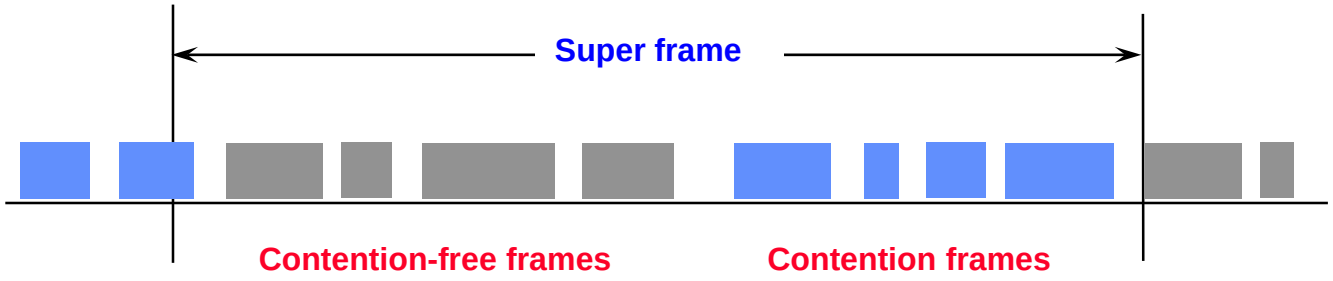
MAC Architecture

- **Distributed Coordination Function (DCF)**
  - The fundamental access method for the 802.11 MAC, known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
  - Shall be implemented in all stations and APs.
  - Used within both ad hoc and infrastructure configurations.
- **Point Coordination Function (PCF)**
  - An alternative access method
  - Shall be implemented on top of the DCF
  - A point coordinator (polling master) is used to determine which station currently has the right to transmit.
  - Shall be built up from the DCF through the use of an access priority mechanism.
  - Different accesses of traffic can be defined through the use of different values of IFS.
  - Shall use a Point IFS (PIFS) < Distributed IFS (DIFS)

MAC Architecture

- Point coordinated traffic shall have higher priority to access the medium, which may be used to provide a *contention-free* access method.
- The priority access of the PIFS allows the point coordinator to seize control of the medium away from the other stations.

- **Coexistence of DCF and PCF**
  - Both the DCF and PCF shall coexist without interference.
  - They are integrated in a superframe in which a contention-free burst occurs at the beginning, followed by a contention period.



Distributed Coordination Function

- Allows for automatic medium sharing between similar and dissimilar PHYs through the use of CSMA/CA and a random backoff time following a busy medium condition.
- All directed traffic uses immediate positive ack (ACK frame) where retransmission is scheduled by the sender if no ACK is received.
- The virtual Carrier Sense mechanism is achieved by distributing medium busy reservation information through an exchange of special small RTS and CTS frames (contain a duration field) prior to the actual data frame.
  - Unicast only, not used in multicast/broadcast.
- The use of RTS/CTS is under control of RTS_Threshold (payload length, under which without any RTS/CTS prefix).
- All stations are required to be able to receive any frame transmitted on a given set of rates, and must be able to transmit at (at least) one of these rates.
  - Virtual Carrier Sense mechanism still works on multiple rates environments.

Distributed Coordination Function

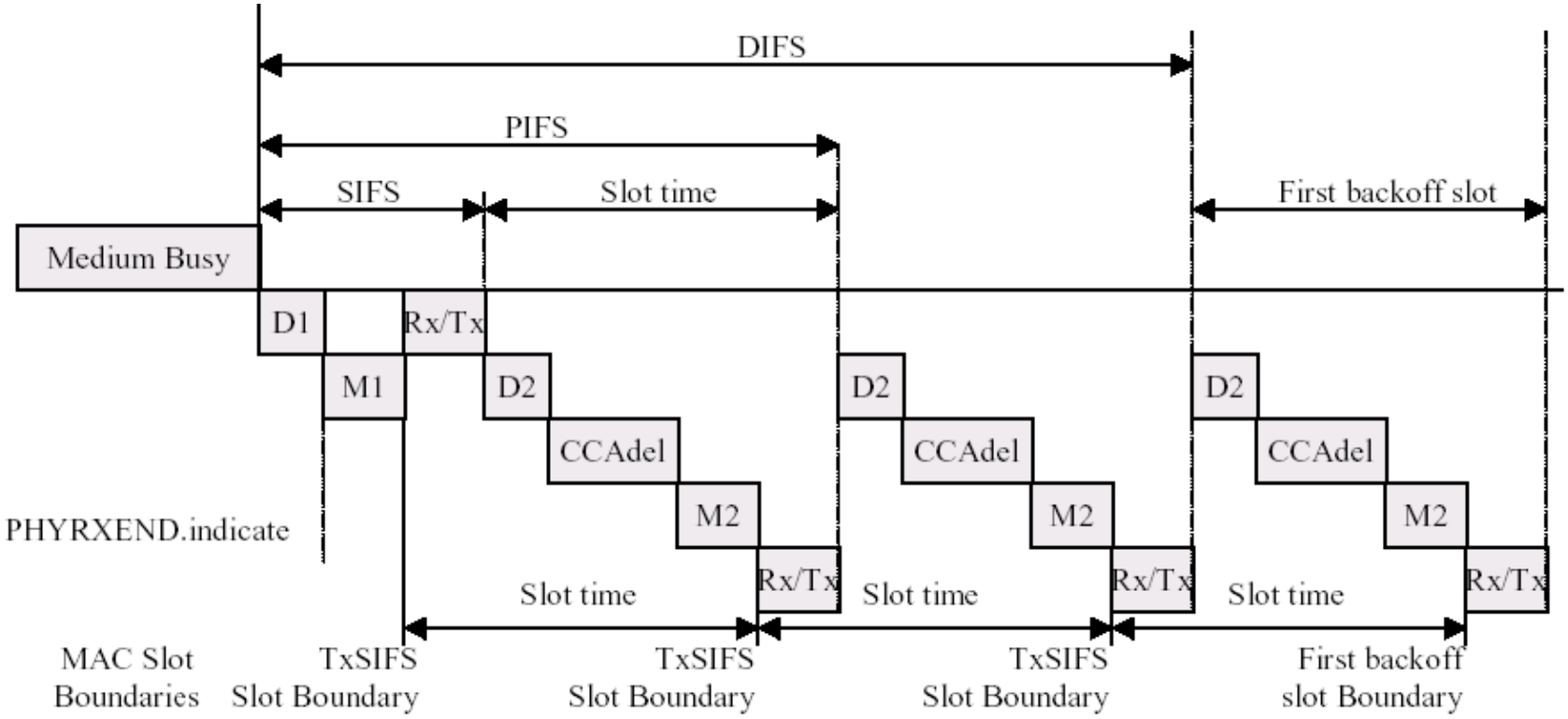
- Carrier Sense shall be performed both through *physical* (listen) and *virtual* mechanisms.
- Physical Carrier Sense Mechanism
  - A physical carrier sense mechanism shall be provided by the PHY.
- Virtual Carrier Sense Mechanism
  - Provided by the MAC, named Net Allocation Vector (NAV), which maintains a prediction of future traffic based on duration information announced in RTS/CTS frames.
- MAC-Level Acknowledgments (Positive Acknowledgment)
  - To allow detection of a lost or errored frame, an ACK frame shall be returned immediately following a successfully received frame.
  - The gap between the received frame and ACK frame shall be SIFS.
  - The frame types should be acknowledged with an ACK frame:
    - » Data
    - » Poll
    - » Request
    - » Response
  - The lack of an ACK frame means that an error has occurred.

Why does not Ethernet use ACK frame?

Distributed Coordination Function -- Inter-Frame Space (IFS)

- A station shall determine that the medium is free through the use of carrier sense function for the interval specified.
- Three different IFS's are defined to provide priority levels.
- Short-IFS (SIFS)
  - Shall be used for an ACK frame, a CTS frame, by a station responding to any polling.
  - It may also be used by a PC for any types of frames during the CFP.
  - Any STA intending to send only these frame types shall be allowed to transmit after the SIFS time has elapsed following a busy medium.
- PCF-IFS (PIFS)
  - Shall be used only by the PCF to send any of the Contention Free Period frames.
  - The PCF shall be allowed to transmit after it detects the medium free for the period PIFS, at the start of and during a CF-Burst.
- DCF-IFS (DIFS)
  - Shall be used by the DCF to transmit asynchronous MPDUs.
  - A STA using the DCF is allowed to transmit after it detects the medium free for the period DIFS, as long as it is not in a backoff period.
- Extended IFS (EIFS), (1ms)

Time Intervals SIFS/PIFS/DIFS



D1 = aRxRFDelay + aRxPLCPDelay (referenced from the end of the last symbol of a frame on the medium)
D2 = D1 + Air Propagation time
Rx/Tx = aRXTXTurnaroundTime (begins with a PHYTXSTART.request)
M1 = M2 = aMACPrcDelay
CCAdel = aCCATime – D1

EIFS

- **The EIFS shall begin following indication by the PHY that the medium is idle after detection of the erroneous frame, without regard to the virtual carrier-sense mechanism.**
- **The EIFS is defined to provide enough time for another STA to acknowledge what was, to this STA, an incorrect received frame before this STA commences transmission.**
- **EIFS = aSIFSTime + (8×ACKsize) + aPreambleLength + PLCPHeaderLength + DIFS,**

  where ACKsize is computed based on 1Mbps data rate.

Distributed Coordination Function -- Random Backoff Time

- **Before transmitting asynchronous MPDUs, a STA shall use the carrier sense function to determine the medium state.**
- **If busy, the STA shall defer until after a DIFS gap is detected, and then generate a random backoff period for an additional deferral time (resolve contention).**

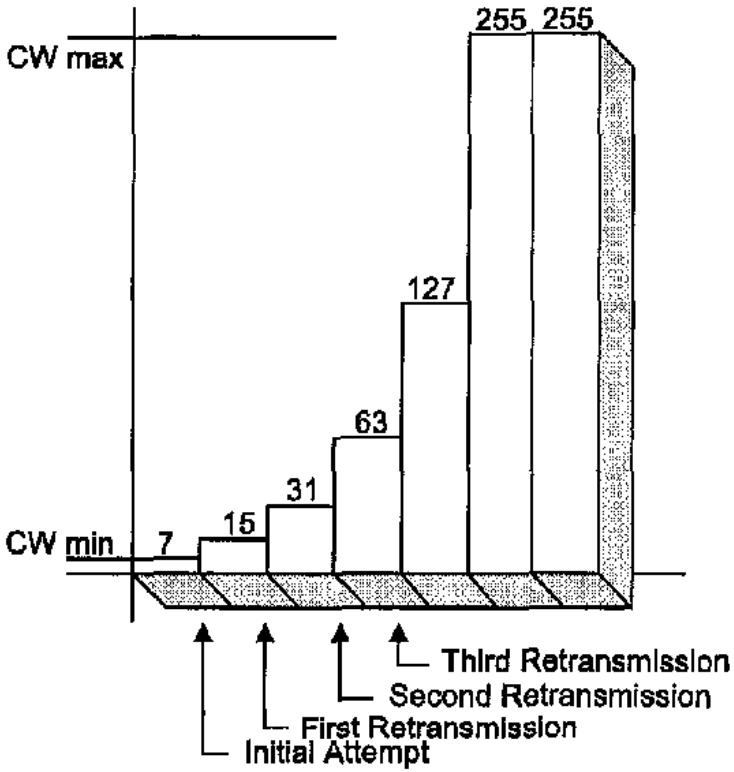
Backoff time = Random() * Slot time

Random() = Pseudorandom integer drawn from a uniform distribution over the interval [0, CW].

CW = An integer between CWmin and CWmax

Slot Time = Transmitter turn-on delay + medium propagation delay + medium busy detect response time

Binary Exponentional Backoff Window



15~1023 for FHSS PHY
Source: IEEE Std 802.11-1997
14.8.2 FH PHY attributes: Table 49

63~1023 for IR PHY
Source: IEEE Std 802.11-1997
16.4 PHY attributes: Table 74

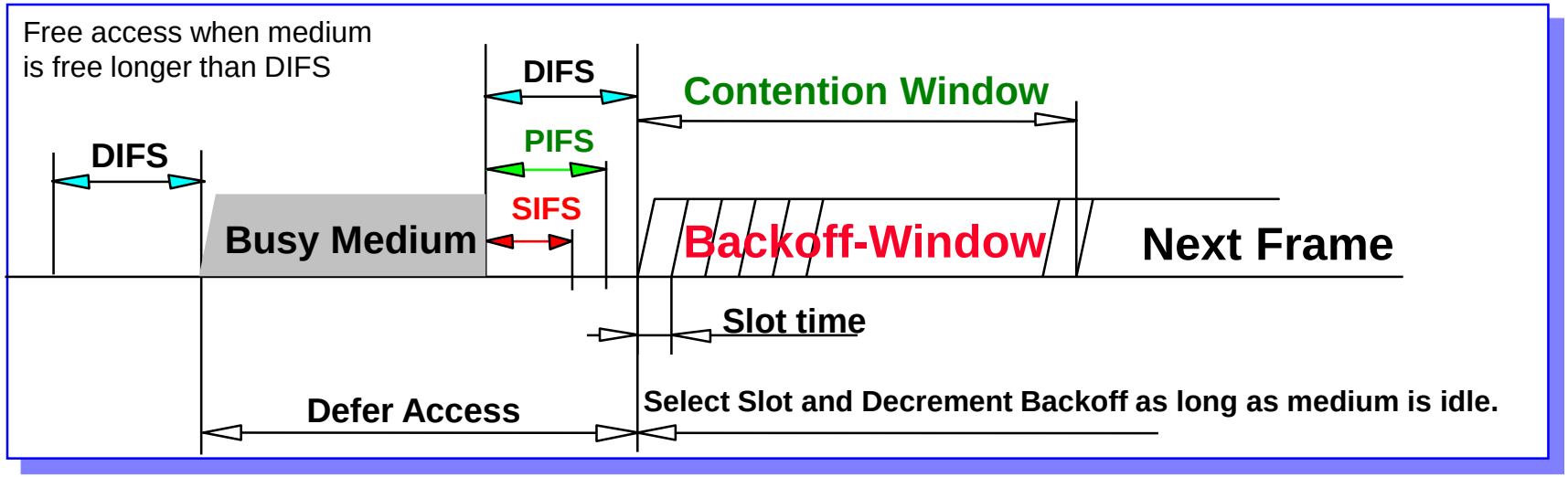
31~1023 for DSSS PHY
Source: IEEE Std 802.11-1997
15.3.2 DSSS PHY MIB: Table 58

15~1023 for DSSS ERP PHY (>20Mb/s)
31 ~1023 for DSSS ERP PHY (≤20Mb/s)
Source: IEEE Std 802.11g-2001
19.4.3.8.5 PHY Page 12

Basic Access Protocol Features

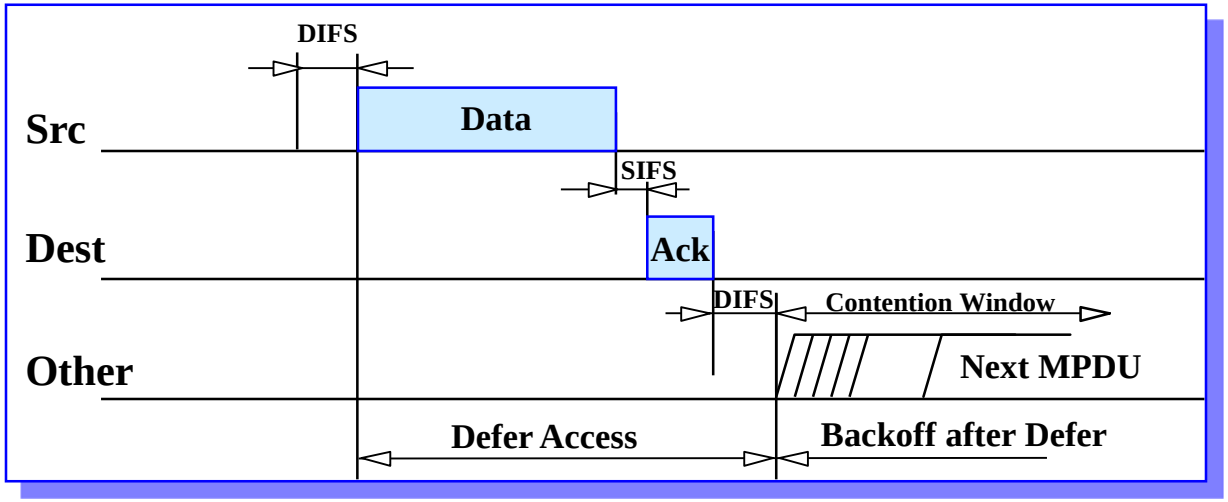
- **Use Distributed Coordination Function (DCF) for efficient medium sharing without overlap restrictions.**
  - **Use CSMA with Collision Avoidance derivative.**
  - **Based on *Carrier Sense* function in PHY called *Clear Channel Assessment* (CCA).**
- **Robust for interference (use positive acknowledge).**
  - ***CSMA/CA + ACK* for unicast frames, with MAC level recovery.**
  - **CSMA/CA for Broadcast frames.**
- **Parameterized use of RTS / CTS to provide a *Virtual Carrier Sense* function to protect against *Hidden Nodes*.**
  - ***Duration* information is distributed by both transmitter and receiver through separate RTS and CTS Control Frames.**
- **Includes fragmentation to cope with different PHY characteristics.**
- **Frame formats to support the access scheme**
  - **Infrastructure and Ad-Hoc Network support.**
  - ***Wireless Distribution System.***

CSMA/CA Explained



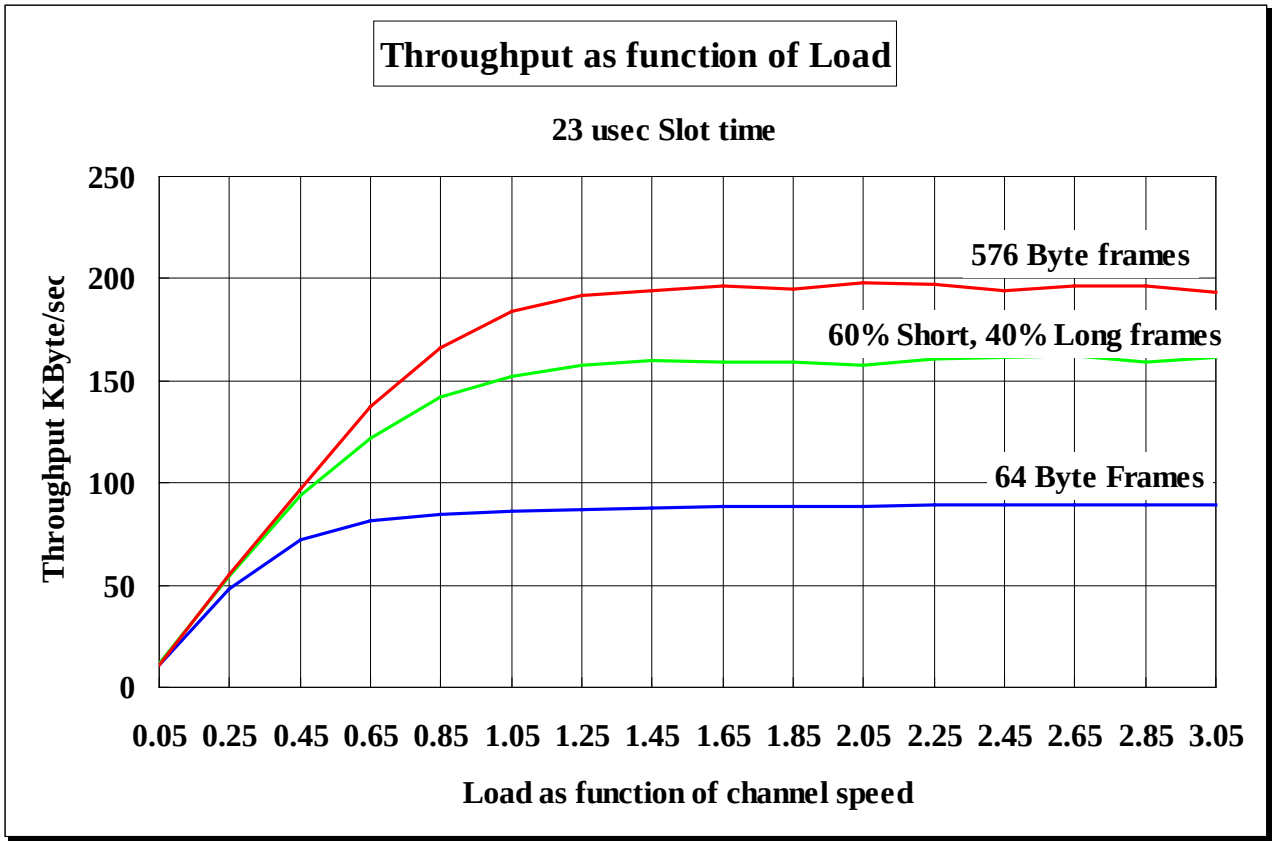
- **Reduce collision probability where mostly needed.**
  - **Stations are waiting for medium to become free.**
  - **Select Random Backoff after a Defer, resolving contention to avoid collisions.**
- **Efficient Backoff algorithm stable at high loads.**
  - **Exponential Backoff window increases for retransmissions.**
  - **Backoff timer elapses only when medium is idle.**
- **Implement different fixed priority levels.**
  - **To allow immediate responses and PCF coexistence.**

CSMA/CA + ACK protocol



- **Defer access based on *Carrier Sense*.**
  - **CCA from PHY and *Virtual Carrier Sense* state.**
- **Direct access when medium is sensed free longer than DIFS, otherwise defer and backoff.**
- **Receiver of directed frames to return an ACK immediately when CRC correct.**
  - **When no ACK received then retransmit frame after a random backoff (up to maximum limit).**

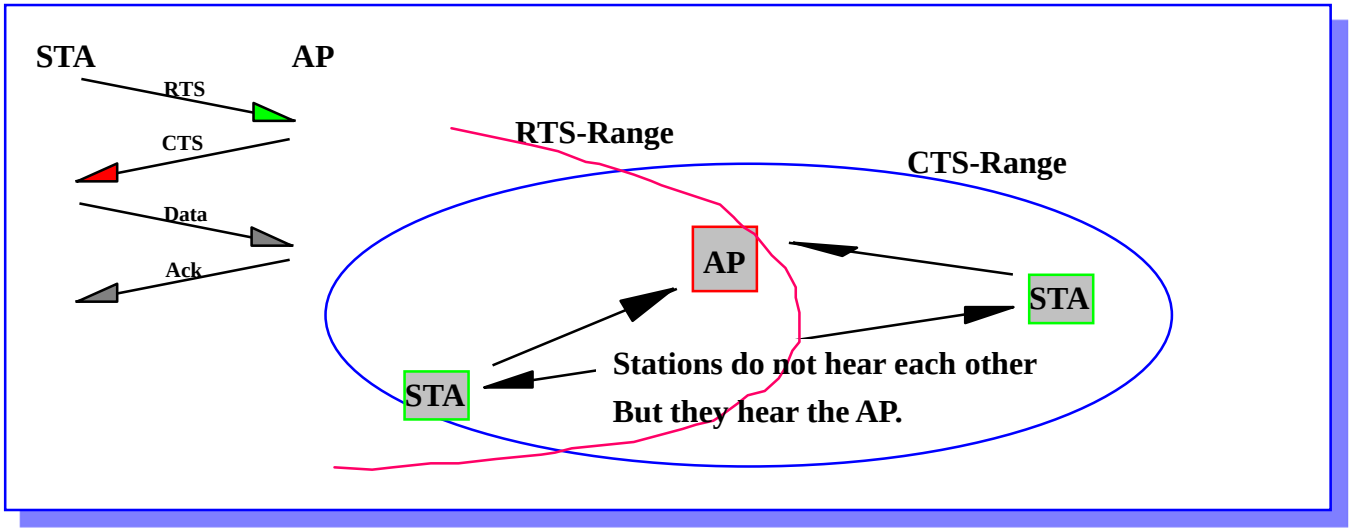
Throughput Efficiency



- **Efficient and stable throughput.**
  - **Stable throughput at overload conditions.**
  - **To support Bursty Traffic characteristics.**

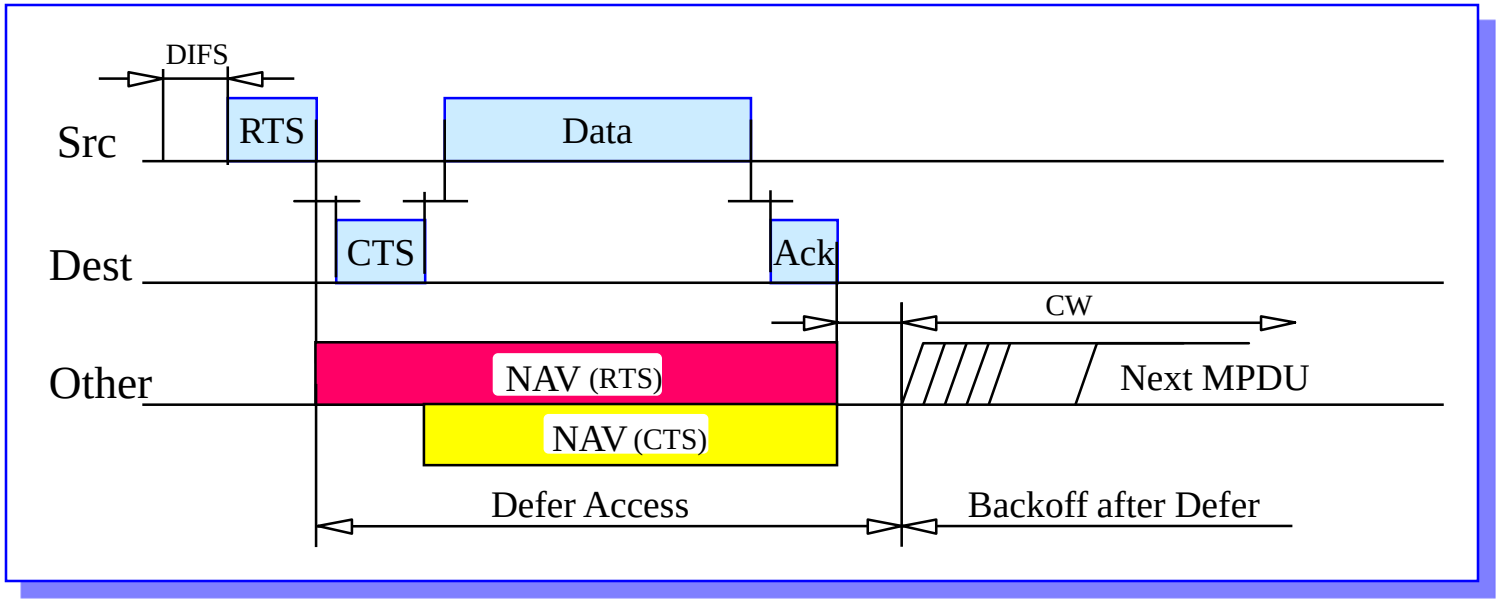
Hidden Node Problem

- **Transmitters contending for the medium may not *"Hear each other"* as shown below.**



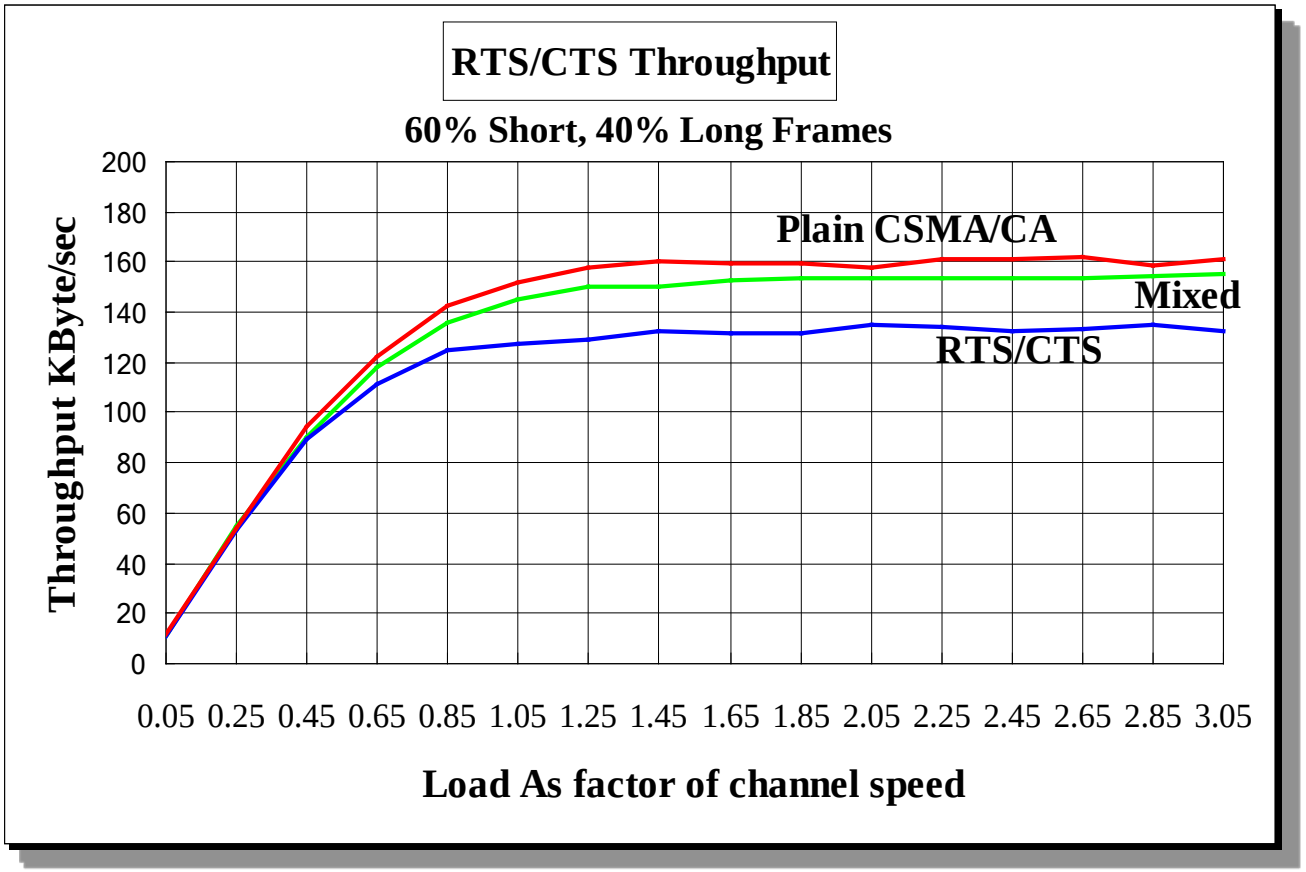
- **Separate Control frame exchange (RTS / CTS) between transmitter and receiver will *Reserve the Medium* for subsequent data access.**
  - ***Duration* is distributed around both Tx and Rx station.**

Hidden Node Provisions



- ***Duration*** **field in RTS and CTS frames distribute** ***Medium Reservation*** **information which is stored in a** ***Net Allocation Vector (NAV)*****.**
- **Defer on either NAV or "CCA" indicating** ***Medium Busy*****.**
- **Use of RTS / CTS is optional but must be implemented.**
- **Use is controlled by a** ***RTS_Threshold*** **parameter per station.**
  - **To limit overhead for short frames. (200 bytes)**

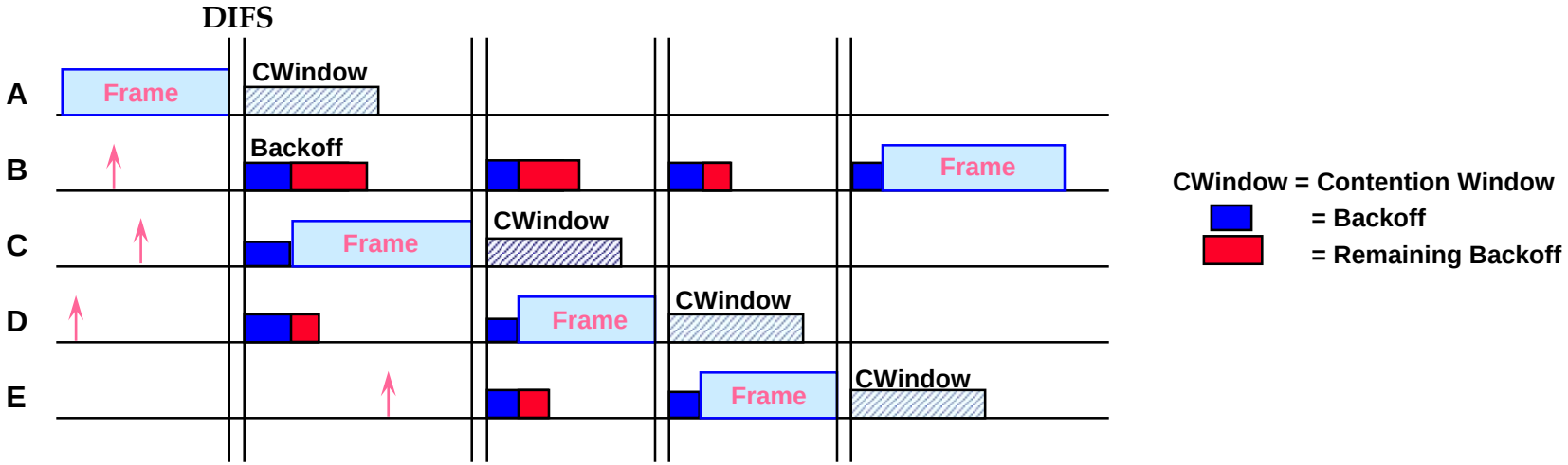
RTS/CTS Overhead Impact



Good mixed Throughput (long inbound frames) efficiency.

Distributed Coordination Function -- DCF Access Procedure

- **Backoff Procedure**
  - **A backoff time is selected first. The Backoff Timer shall be frozen while the medium is sensed busy and shall decrement only when the medium is free (resume whenever free period > DIFS).**
  - **Transmission whenever the Backoff Timer reaches zero.**
  - **A STA that has just transmitted a frame and has another frame ready to transmit (queued), shall perform the backoff procedure (fairness concern).**
  - **Tends toward fair access on a FCFS basis.**

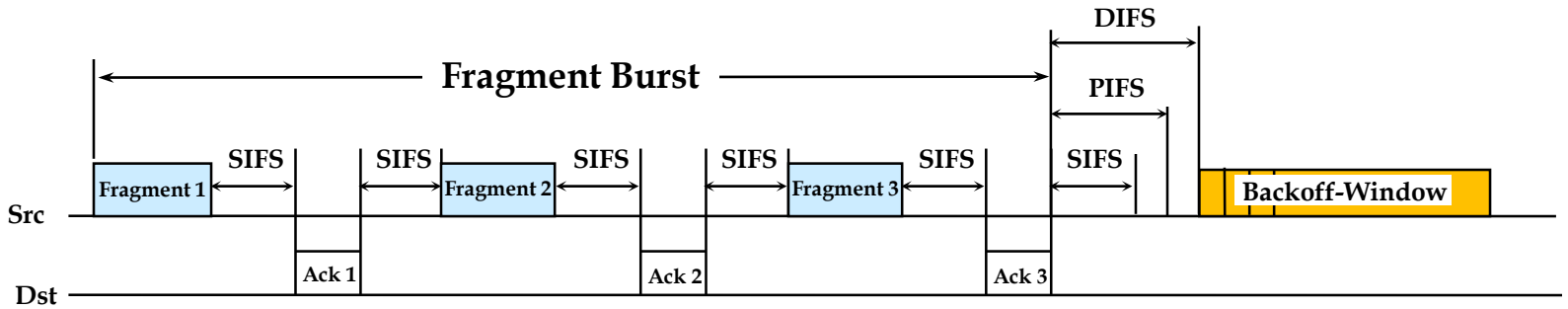


Distributed Coordination Function -- DCF Access Procedure

- **RTS/CTS Recovery Procedure and Retransmit Limits**
  - **After an RTS is transmitted, if the CTS fails in any manner within a predetermined CTS_Timeout (T1), then a new RTS shall be generated (the CW shall be doubled).**
  - **This procedure shall continue until the RTS_Re-Transmit_Counter reaches an RTS_Re-Transmit_Limit.**
  - **The same backoff mechanism shall be used when no ACK is received within a predetermined ACK_Window(T3) after a directed DATA frame has been transmitted.**
  - **This procedure shall be continue until the ACK_Re-Transmit_Counter reaches an ACK_Re-Transmit_Limit.**
  - **STAs shall maintain a short retry count (for MAC frame <= RTS_Threshold) and a long retry count (for MAC frame > RTS_Threshold) for each MSDU and MMPDU awaiting transmission.**
    - » **These counts are incremented and reset independently of each other.**

Distributed Coordination Function -- Fragment

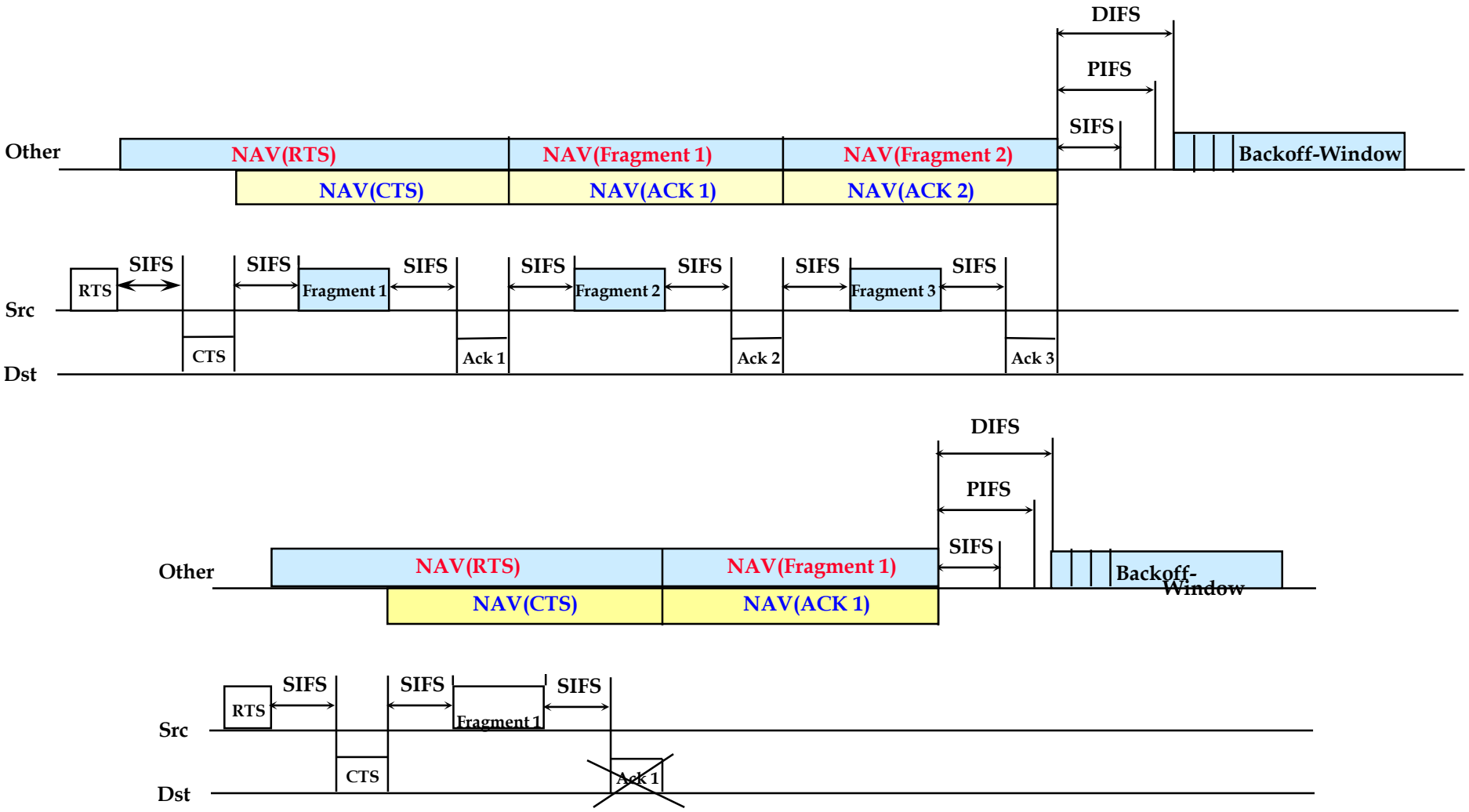
- Control of the Channel (Fragment)
  - The IFS is used to provide an efficient MSDU delivery mechanism.
  - Once a station has contended for the channel, it will continue to send fragments until either all fragments of a MSDU have been sent, an ack is not received, or the station can not send any additional fragments due to a dwell time boundary.
  - If the source station does not receive an ack frame, it will attempt to retransmit the fragment at a later time (according to the backoff algorithm).
  - When the time arrives to retransmit the fragment, the source station will contend for access in the contention window.



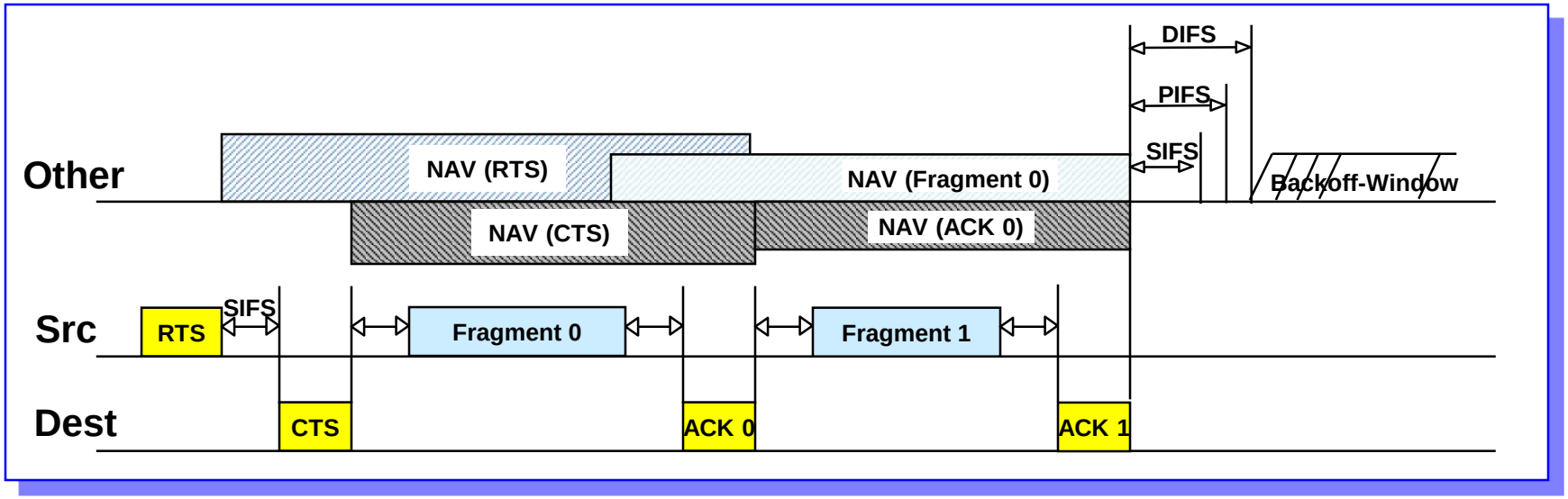
Distributed Coordination Function -- DCF Access Procedure

- **RTS/CTS Usage with Fragmentation**
  - **The RTS/CTS frames define the duration of the first frame and ack.**
  - **The duration field in the data and ack frames specifies the total duration of the next fragment and ack.**
  - **The last Fragment and ACK will have the duration set to zero.**
  - **Each Fragment and ACK acts as a virtual RTS and CTS.**
  - **In the case where an ack is not received by the source station, the NAV will be marked busy for next frame exchange.**
    - » **This is the worst case situation.**
  - **If the ack is not sent by the destination, stations that can only hear the destination will not update their NAV and be free to access the channel.**
  - **All stations that hear the source will be free to access the channel after the NAV from Fragment 1 has expired.**
  - **The source must wait until the NAV (Fragment 1) expires before attempting to contend for the channel after not receiving the ack.**

RTS/CTS Usage with Fragmentation



Fragmentation (1/2)



- **Burst of Fragments which are individually acknowledged.**
  - **For Unicast frames only.**
- **Random backoff and retransmission of failing fragment when no ACK is returned.**
- ***Duration* information in data fragments and ACK frames causes NAV to be set, for medium reservation mechanism.**

Fragmentation (2/2)

- The length of a fragment MPDU shall be an equal number of octets for all fragments except the last, which may be smaller.
- The length of a fragment shall never be larger than aFragmentationThreshold unless WEP is invoked for the MPDU.
  - Because the MPDU shall be expanded by IV and ICV.
- The sequence number shall remain the same for all fragments of a MSDU or MMPDU.
- The fragments shall be sent in order of lowest fragment number to highest fragment number (start at zero, and increased by one).
- More Fragments bit is used to indicate the last (or only) fragment of the MSDU or MMPDU.

Integrity Check Value(ICV)
Initialization Vector (IV)

Defragmentation

- The header of each fragment contains the following information that is used by the destination STA to reassemble the MSDU or MMPDU.
  - Frame type.
  - Address of the sender.
  - Destination address.
  - Sequence Control field.
- More Fragments indicator. If WEP has been applied, it shall be decrypted before the defragmentation.
- All STAs shall maintain a Receive Timer for each MSDU or MMPDU. If the timer is not maintained, all the fragments belong to the part of an MSDU or MMPDU are discarded.
- If the receive MSDU timer exceeds aMaxReceiveLifetime, then all received fragments of this MSDU or MMPDU are discarded.

DCF -- Broadcast and multicast

- **Broadcast and multicast MPDU transfer procedure**
  - **In the absence of a PCF, when broadcast or multicast MPDUs are transferred from a STA with the ToDS bit clear, only the basic access procedure shall be used. Regardless of the length of the frame, no RTS/CTS exchange shall be used. (will not receive ACK)**
  - **Any broadcast or multicast MPDUs transferred from a STA with a ToDS bit set shall obey the rules for RTS/CTS exchange, because the MPDU is directed to the AP (will receive ACK).**
  - **This no MAC-level recovery on broadcast or multicast frames, except for those frames sent with ToDS bit set.**
  - **The broadcast/multicast message shall be distributed into the BSS, so the STA originating the message will also receive the message. Therefore, all STAs must filter out broadcast/multicast messages that contain their address as the source address.**
  - **Broadcast/multicast MSDUs shall be propagated throughout the ESS.**