WI-FI TECHNOLOGY
FUNDAMENTALS COURSE

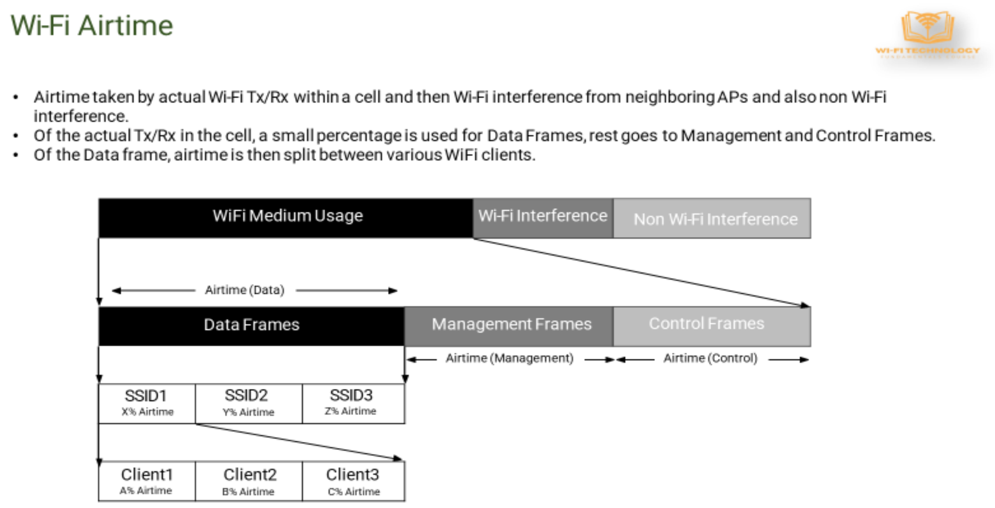
Module 3: WLAN MAC Layer

Session 3d:

DATA TRANSFER AND AGGREGATION

Thanushya Mothikivalasa
Rohini kaparapu
Nishtala Kiranmai
Jami Harika
Shiny Sayyad

Wi-Fi Airtime:



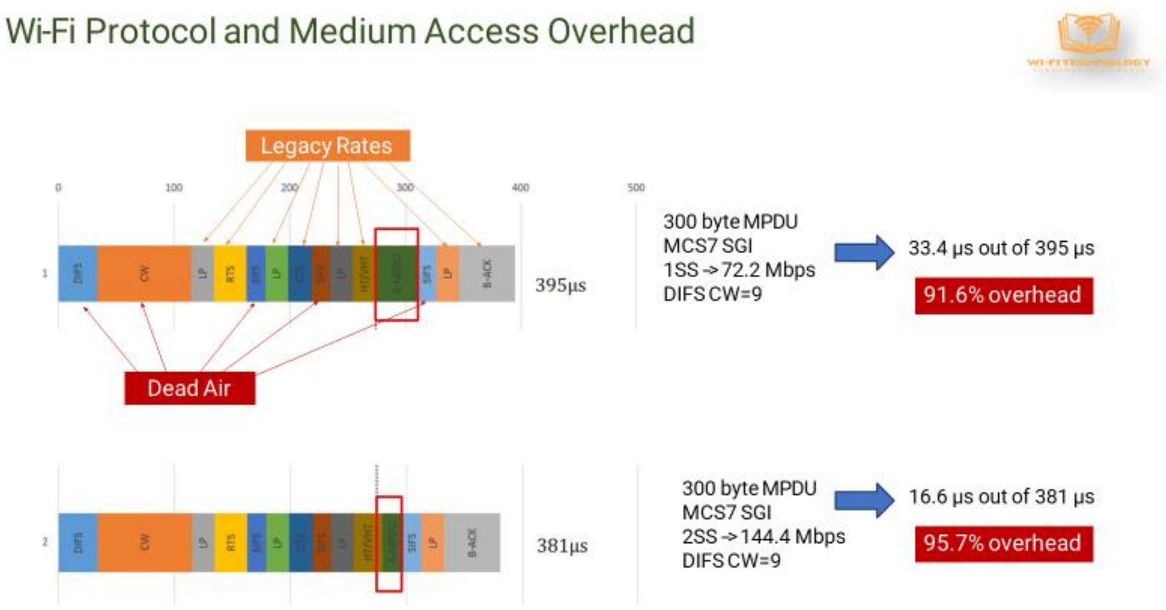
Optimizing Wi-Fi Medium Usage:

- The primary focus is on efficiently using Wi-Fi airtime to transmit useful data. This involves addressing interference and minimizing overhead to enhance overall wireless communication efficiency.

Non-Wi-Fi Interference:

- Allocating a portion of airtime to handle non-Wi-Fi interference, including signals from Bluetooth, Zigbee, cordless phones, Wi-Fi monitors, and radar signals. Clear Channel Assessment (CCA) is employed for signal and energy detection to adjust medium access accordingly.

Wi-Fi Protocol and Medium Access Overhead:



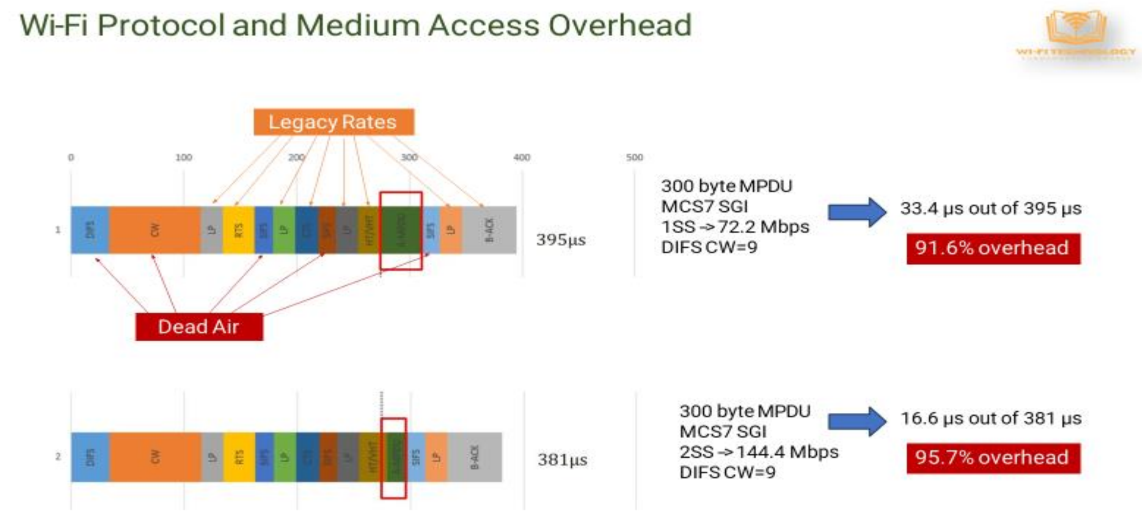
Overhead Components:

- A detailed breakdown reveals significant overhead introduced by protocol-related mechanisms. Components such as the Distributed Coordination Function (DCF), contention window, Short Inter-Frame Spacing (SIFS), and other protocol elements contribute to dead air or non-transmission periods.

Header Overhead Impact:

- The transmission of actual data frames is hindered by substantial overhead from headers, including Physical Layer Convergence Protocol (PLCP), High-Efficiency (HE), and Very High Throughput (VHT) headers. Despite minimal airtime required for data frames, header overhead results in a high percentage of non-transmission time.

Data Frame Transmission Overhead:



Impact of Frame Size and MCS:

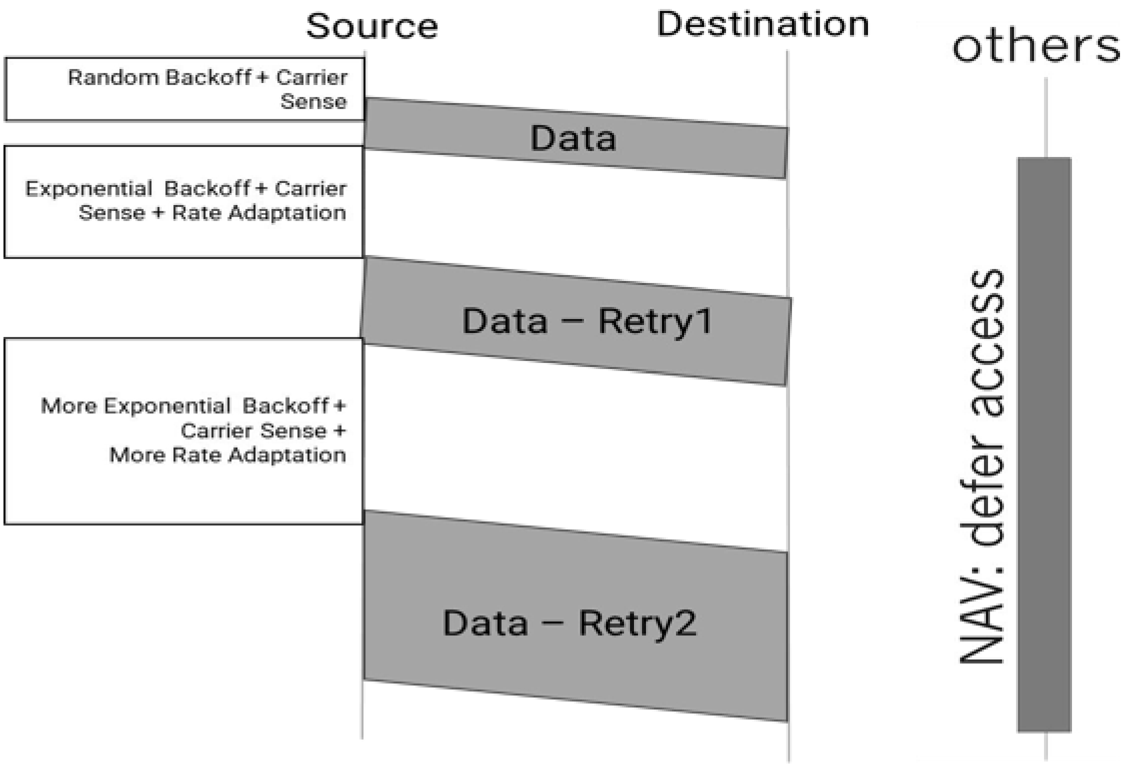
- Analyzing data transmission scenarios at varying frame sizes and Modulation and Coding Schemes (MCS). For instance, a 300-byte frame at MCS 7 with one spatial stream has a lower physical data rate but also incurs lower transmission overhead. Doubling spatial streams might increase the physical data rate but could lead to a higher percentage of overhead.

Challenges in Overcoming Overhead:

- Increasing data rates through methods like multiple spatial streams may enhance data transmission speed but can also elevate the percentage of time allocated to overhead. The challenge lies in balancing data rate improvements with associated overhead complexities to optimize Wi-Fi airtime.

Data Re-Transmission

Data retransmission is a crucial aspect of reliable data communication, helping to overcome errors and ensure the successful delivery of information in networked systems. It is a key element in achieving data integrity and maintaining the overall performance of communication protocols.



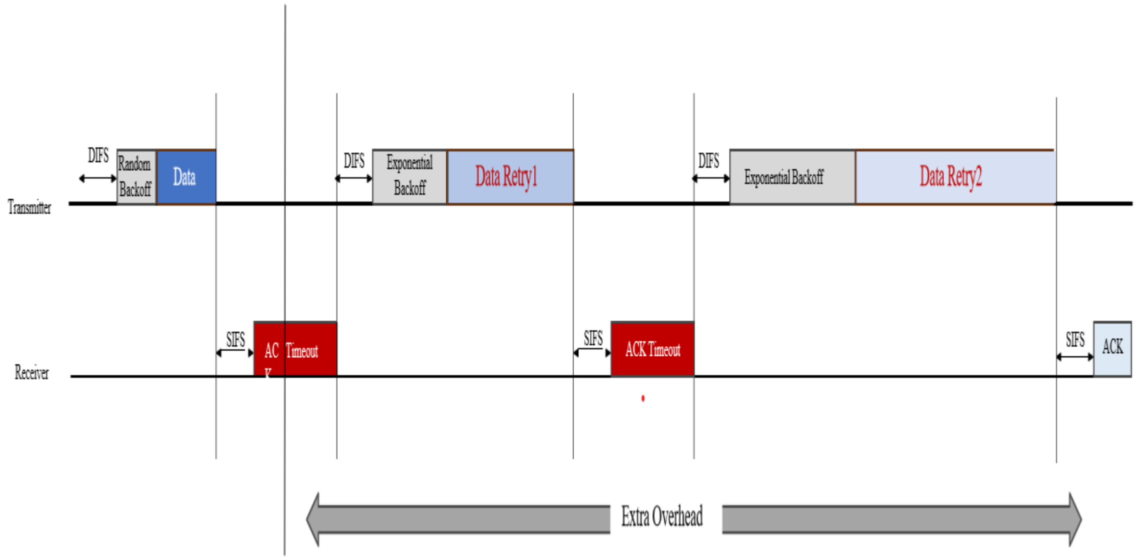
Data retransmission is a process in data communication where the sender needs to resend a data unit (such as a frame or packet) that was not successfully received or acknowledged by the recipient. This mechanism is an integral part of many communication protocols to ensure the reliability of data transmission over networks. Here's a more detailed explanation:

1.Transmission Errors:
During data transmission, errors can occur due to various factors such as noise, interference, or network congestion.These errors can lead to the loss or corruption of data as it travels from the sender to the receiver.
2.Acknowledgment and Timeouts:
In reliable communication protocols, the receiver sends acknowledgment signals to the sender upon successfully receiving and verifying a data unit.
If the sender does not receive an acknowledgment within a specified time (timeout period), it assumes that the data unit was not successfully delivered.
3.Retransmission Trigger:
When the sender detects a missing acknowledgment or receives a negative acknowledgment (NACK) indicating an unsuccessful transmission, it initiates the retransmission process.
4. Random Back-Off and Exponential Back-Off:
To avoid collisions and further improve reliability, many protocols employ random back-off and exponential back-off mechanisms.
Random back-off introduces a random delay before attempting retransmission.
Exponential back-off increases the waiting time exponentially with each unsuccessful attempt, reducing the chances of collisions.

5.Costs of Retransmission:
Retransmission incurs costs in terms of time, network resources, and bandwidth.
The larger the data unit being retransmitted, the higher the impact on the overall transmission efficiency.
6.Error Recovery:
The goal of retransmission is to recover from transmission errors and ensure the successful delivery of data.
Protocols may have built-in error detection and correction mechanisms to enhance reliability.
7.Flow Control:
Retransmission is closely related to flow control, where the sender adjusts the rate of transmission based on the acknowledgment received and the network conditions.
Effective flow control prevents congestion and minimizes the need for retransmission.
8.Automatic Repeat reQuest (ARQ):
Many communication protocols, especially in the context of point-to-point links, use Automatic Repeat reQuest (ARQ) mechanisms for managing retransmissions automatically.

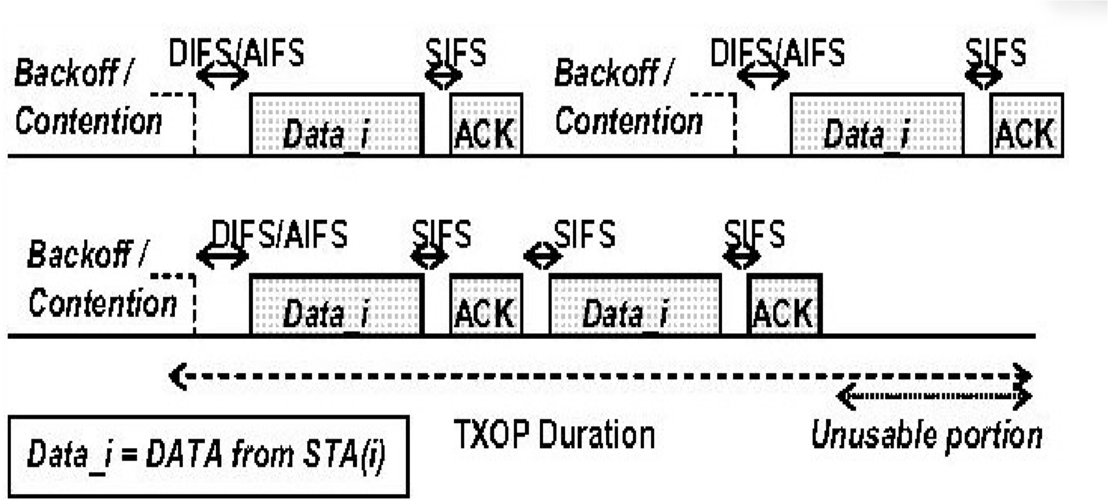
Why not send larger frames for increased throughput?

Frame Size Consideration:
Larger frames could enhance throughput, but there are limitations.
Explains the trade-off: Larger frames increase error susceptibility.
Example: A lost 100-byte frame is less costly than a 10,000-byte frame.
Retransmission Challenges:
Acknowledges the need for limiting data transmission size.
Highlights the high cost of retransmissions in terms of time and resources.
Describes the process: Random back-off, carrier sense, and retransmission.
Exponential Back-Off and Rate Adaptation:
Illustrates the exponential back-off concept after a failed transmission.
Emphasizes the increase in wait time for medium access.
Discusses the need for rate adaptation to counter potential errors.
Impact on Transmission Time:
Demonstrates the domino effect of retransmissions on transmission time.
Explains how retries lead to increased overhead and time consumption.
Visualizes the extended time for transmission due to retries.
Avoiding Retries:
Stresses the importance of minimizing retransmissions.
Acknowledges the need for protection mechanisms to avoid failures.
Balancing act: Sending information quickly while ensuring reliability.
Optimizing Transmission Opportunities:
Explores methods to send more information in each transmission opportunity.
Acknowledges the energy invested in gaining medium access.
Focus: Sending a substantial amount of information reliably.



Reducing overhead using TXOP

Transmission Burst, commonly abbreviated as TXOP, is a method employed in data communication protocols to optimize the efficiency of data transmission. In contrast to the traditional model of contention, acknowledgment, and back-off, TXOP introduces a streamlined approach for transmitting data frames.



Traditional Model vs. TXOP:

Traditional Model:
In the traditional model, the sender contends for the medium, waits for a designated interframe space, sends a data frame, awaits acknowledgment, and then repeats the process. This method involves repeated contention for medium access, resulting in potential delays and increased contention overhead.

TXOP Method:

TXOP, on the other hand, simplifies the process by allowing the sender to contend for the medium only once. Once medium access is granted, the sender can transmit bursts of data frames consecutively without constant contention. After sending each data frame, a short interframe space is observed, during which the receiver sends an acknowledgment. Notably, there is no additional back-off, leading to more efficient use of transmission opportunities.

Key Characteristics:

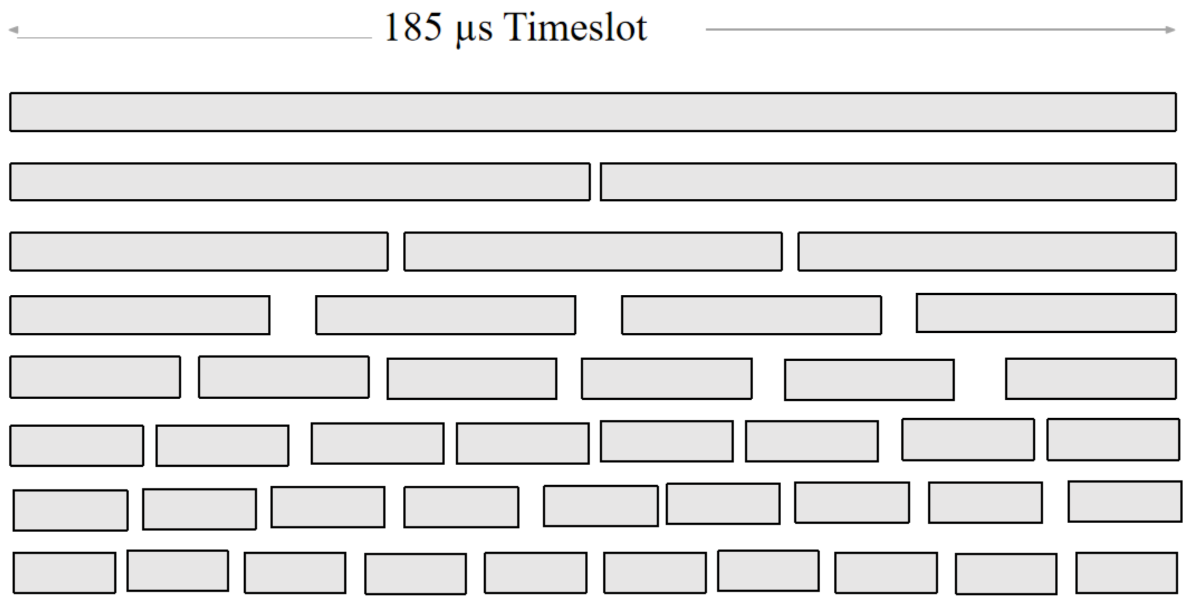
1. **Contending Once:** TXOP reduces contention by requiring the sender to contend for medium access only once during the transmission opportunity.
2. **Burst Transmission:** TXOP enables the sender to transmit bursts of data frames consecutively without repeated contention for each frame.
3. **Short Interframe Space:** After sending a data frame, a short interframe space is observed, ensuring atomic access and providing preferential access to the medium.
4. **Elimination of Back-Off:** Unlike the traditional model, TXOP eliminates the need for back-off after each frame, contributing to a more streamlined and efficient transmission process.

The Airtime used by Frames

In the concept of data transmission, maximizing throughput is a constant goal. One key strategy that contributes to this goal is the concept of aggregation. Before delving into aggregation, let's explore how advancements in standards paved the way for this innovative approach.

Modulation	Coding	Nss1 SGI 160Mhz	Airtime for 1500 Byte Frame	Number of Frames in same airtime
BPSK	1/2	65.0	184.62	1
QPSK	1/2	130.0	92.31	2
QPSK	3/4	195.0	61.54	3
16-QAM	1/2	260.0	46.15	4
16-QAM	3/4	390.0	30.77	6
64-QAM	2/3	520.0	23.08	8
64-QAM	3/4	585.0	20.51	9
64-QAM	5/6	650.0	18.46	10

The higher the data rates the more frames that can be transmitted in the same amount of time.



Evolution of Standards and Increased Speeds:

Over the evolution of standards, there has been a consistent improvement in data transmission speeds. This improvement is reflected in the Modulation Coding Scheme (MCS) rates, showcasing the raw data rates at which frames can be transmitted. With each standard iteration, the time taken to transmit a single frame has substantially decreased.

Example Scenario:

Consider the example of using BPSK modulation with a coding rate of one-half. At a physical data rate of 65 megabits per second, it takes approximately 184 microseconds to transmit a 1500-byte frame. As speeds increase, say to 650 megabits per second with 64 QAM modulation, the same time slot now allows for the transmission of 10 frames.

The Birth of Aggregation:

The increase in speeds has given rise to the concept of aggregation. Traditionally, once access to the medium was obtained, a single frame was transmitted, followed by a back-off period. Now, with higher speeds, the same time slot can accommodate multiple frames. This evolution enables the burst transmission of frames in quick succession, introducing the concept of aggregation.

Significance of Air Time:

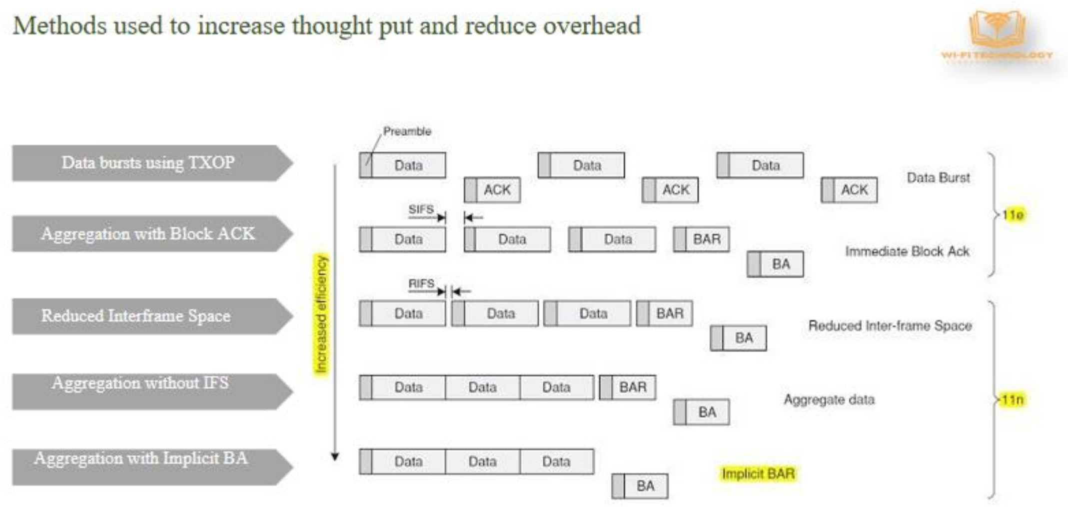
The amount of time a transmission occupies in the air is directly related to the probability of errors. Prolonged air time without acknowledgment increases the likelihood of errors, akin to driving blind without eyes. To mitigate this, it becomes crucial to restrict air time while maintaining efficient data transmission.

Aggregation as a Solution:

Aggregation addresses the challenge of restricted air time. By sending more information within the same time slot without increasing the probability of error, throughput is enhanced. The core idea is to transmit a burst of frames in quick succession, optimizing the use of available air time.

Aggregation emerges as a powerful strategy in the pursuit of maximizing data throughput. By leveraging advancements in standards and higher speeds, this approach allows for efficient transmission, reducing air time, and increasing overall data throughput without compromising reliability.

Methods used to increase throughput and reduce overhead



Individual Frame Acknowledgement:

- Sending a data frame and immediately receiving an acknowledgement.
- The process repeats for each frame individually.

Basic Aggregation:

- Instead of waiting for individual acknowledgements, frames are sent consecutively.
- Introduction of the concept of a "block ack."

Block Acknowledgement:

- Sender waits to receive acknowledgements for a set of frames.
- The receiver responds with a block acknowledgement.
- Block acknowledgement includes a bitmap allocating one bit per frame.
- The bitmap indicates which frames were successfully received and which were not.

Retransmission:

- Frames not acknowledged are retransmitted in the next batch.

Efficiency Improvements in 802.11n:

Reduced Interframe Space:

- Method to pack data frames more closely.

Variations in Block Acknowledgement:

- Immediate Block Acknowledgement.
- Delayed Block Acknowledgement.
- Implicit Block Acknowledgement.
- These variations aim to optimize medium utilization and channel efficiency.

Bursting Data:

- The fundamental concept behind these methods is to burst data frames.
- Efforts to improve overall efficiency and utilization of the communication medium.

Continuous Improvement:

- Mention of additional methods introduced in 802.11n.
- Constant evolution in techniques like reduced interframe space and various block acknowledgement methods.

Concept of Aggregation

Analogy of Aggregation:

- Aggregation is likened to transporting people from point A to point B.
- Each person represents a packet of data.
- The goal is to efficiently transport all these "packets" (people) to the destination.

Individual Car Approach:

- Each person (packet) is placed in an individual car.
- The highway represents the communication channel.
- Results in congestion as each person takes up a whole car, causing inefficiency.

Efficiency Comparison:

- The inefficiency arises because the person (packet) occupies a small portion of the car's capacity.
- The weight and volume of the car become overhead for transporting a single person.

Alternative Approach - Train Analogy:

- An alternative is putting multiple people (packets) on a single vehicle (train).
- Draws an analogy to putting many people on a train in a more space-efficient manner.

Efficiency Improvement with Aggregation:

- Aggregation consolidates multiple packets into one container (train).
- Significantly reduces overhead as compared to the individual car approach.
- Results in improved efficiency in utilizing the communication channel.

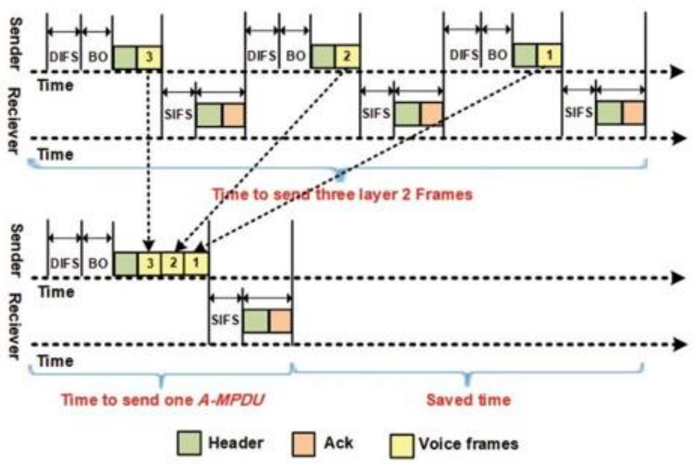
Realistic Consideration:

- Acknowledges that the depicted scenario of many people on a single vehicle might be more of a fun example.
- Emphasizes the principle of aggregation, transporting more information with less overhead.

Summary:

- Aggregation allows for the transport of a larger amount of information in one container with minimal overhead.
- Improves efficiency in utilizing the available communication medium.

Frame Aggregation



Traditional Transmission Process:

- Traditional method involves waiting, back-off, and sending individual data frames.

- Each transmission includes a frame header, data frame, waiting time (SIFS), and acknowledgment.

Inefficiency in Traditional Approach:

- Multiple transmissions involve repeated processes, leading to inefficient use of airtime.
- Each transmission has its own back-off and acknowledgment phases.

Introduction of Frame Aggregation:

- Frame aggregation consolidates multiple transmissions into one burst.
- Highlights that the yellow blocks represent the payload, i.e., the actual data transmission.

Efficiency Gained by Aggregation:

- Instead of individual transmissions, all three payloads are combined into one burst.
- Only one Distributed Inter-Frame Space (DIFS) and one back-off are needed for the entire burst.
- After transmitting the aggregated frame, the system waits for a single acknowledgment.

Airtime Optimization:

- By aggregating frames, significant airtime is saved.
- Reduced overhead and more efficient utilization of the communication medium.

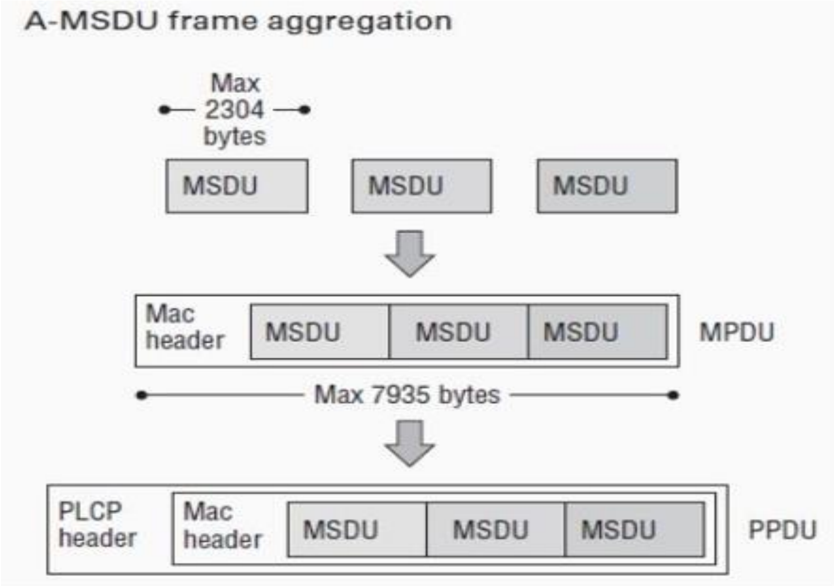
Simplified Process with Aggregation:

- Contrasts the complexity of multiple transmissions with the simplicity of a single burst in frame aggregation.
- Emphasizes the streamlined process: one DIFS, one back-off, one transmission, and one acknowledgment.

Benefits of Frame Aggregation:

- Frame aggregation is fundamental to optimizing airtime and improving overall efficiency.
- Illustrates how a basic example of aggregation can lead to substantial time savings in data transmission.

Types of Frame Aggregation



MSDU Aggregation

- **Definition:** MSDUs encompass packets received by the MAC from upper layers, including IP headers, forming the Maximum Service Data Unit.
- **Aggregation Process:** Involves grouping multiple IP packets or MSDUs together and applying a single MAC header to create an aggregated frame.
- **Frame Structure:** The resulting frame comprises multiple MSDUs with a unified MAC header, intended for transmission through lower layers.
- **Transmission Stages:** As the frame traverses protocol layers, it transforms into a Protocol Data Unit (PPDU) with the addition of a Physical Layer Convergence Protocol (PLCP) header.

Purpose and Benefits:

- **Efficiency Boost:** Aggregating multiple IP packets into a single frame streamlines data transmission, enhancing network efficiency.
- **Overhead Reduction:** Utilizing a sole MAC header for a collection of MSDUs significantly decreases overhead, optimizing network resources.

Significance and Efficiency Gains:

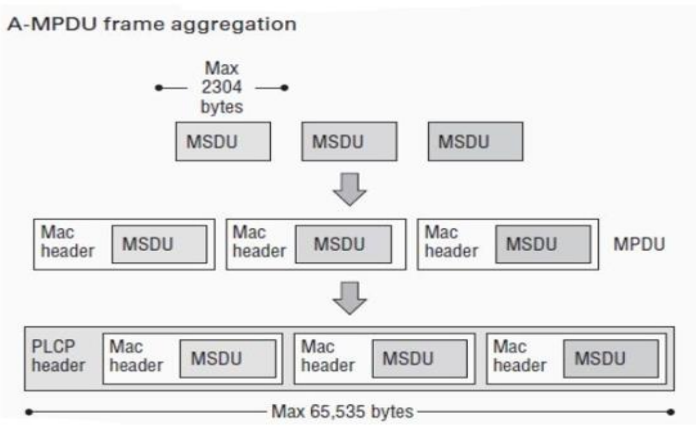
- **Optimized Transmission:** The consolidation of multiple IP packets reduces the number of headers transmitted, maximizing airtime utilization in wireless networks.
- **Enhanced Throughput:** Minimizing redundant headers facilitates higher throughput, enabling improved data transfer rates within the network.

Advantages and Use Cases:

- **Efficient Network Utilization:** Aggregating MSDUs minimizes headers, maximizing airtime usage in wireless networks.

- **Higher Throughput:** Reduced redundancy in headers supports increased data transfer rates, enhancing overall network performance.

In short , we can say that MSDU aggregation optimizes network performance by consolidating multiple IP packets into a single frame with a solitary MAC header. This approach streamlines data transmission, reduces overhead, and enhances throughput, contributing to an overall efficient network operation.



MPDU Aggregation Process:

- **Individual MAC Headers:** A-MPDU involves assigning separate MAC headers to each MSDU (MAC Service Data Unit).
- **Bundling MSDUs:** These MSDUs, each with its individual MAC header, are combined to create a single large frame at the physical layer.

Frame Structure in A-MPDU:

- **Physical Layer Encapsulation:** Multiple MSDUs, each equipped with an individual MAC header, get encapsulated into a singular substantial frame.
- **Single Physical Layer Header:** Despite the individual MAC headers, all aggregated frames receive only one physical layer header for transmission.

Efficiency and Overhead Considerations:

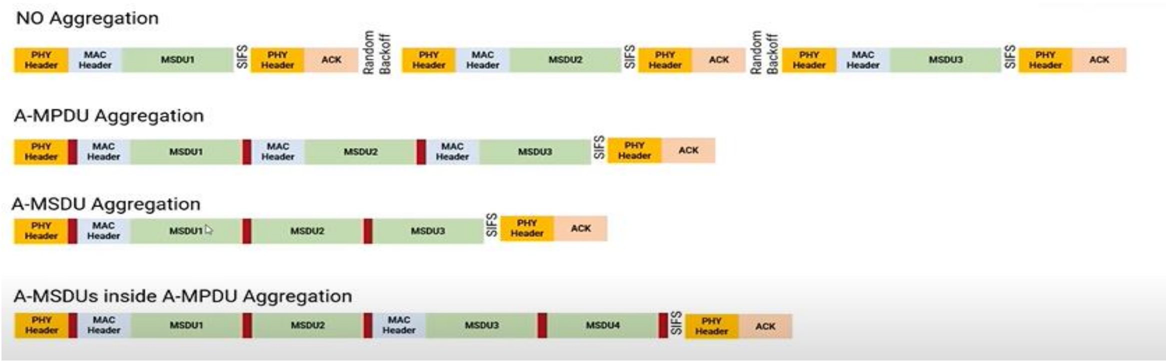
- **Overhead Aspect:** A-MPDU incurs slightly more overhead due to the inclusion of individual MAC headers for each MSDU.
- **Enhanced Protection:** Despite the overhead, A-MPDU provides increased protection due to the presence of individual MAC headers.

Transmitting Efficiency in A-MPDU:

- **Header Optimization:** Despite the individual MAC headers, the consolidation of all MSDUs into one MPDU aggregate significantly reduces the number of physical layer headers.

- **Improved Efficiency:** This header consolidation greatly enhances transmission efficiency, optimizing airtime utilization and network performance.

Types of Frame Aggregation



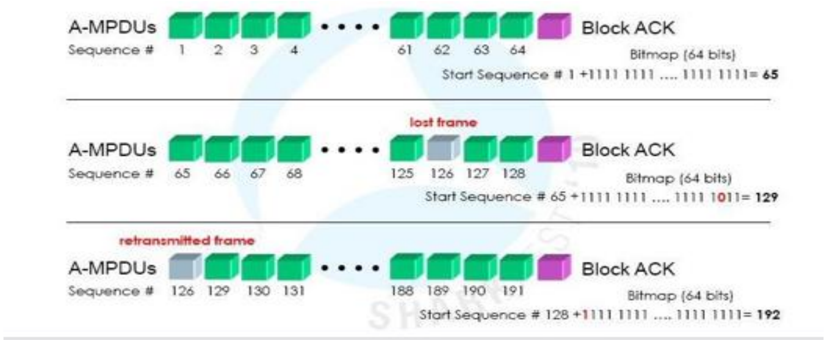
Efficiency Comparison:

- **A-MPDU Efficiency:** Each MSDU retains its individual MAC header, but they are clubbed together, saving on physical layer headers and random back-offs, significantly improving efficiency.
- **A-MSDU Efficiency:** Aggregating multiple MSDUs with just one MAC header is more efficient but less protected than A-MPDU due to the lack of individual MAC headers for each MSDU.

Overall Summary:

- Aggregation methods (A-MSDU and A-MPDU) optimize transmission by combining multiple frames or packets into larger aggregated units.
- A-MPDU saves on physical layer headers by clubbing multiple MSDUs with individual MAC headers into one aggregate, while A-MSDU uses a single MAC header for multiple IP packets or MSDUs.
- Efficiency gains come from reducing overhead, including physical layer headers, leading to improved airtime utilization in wireless transmissions.

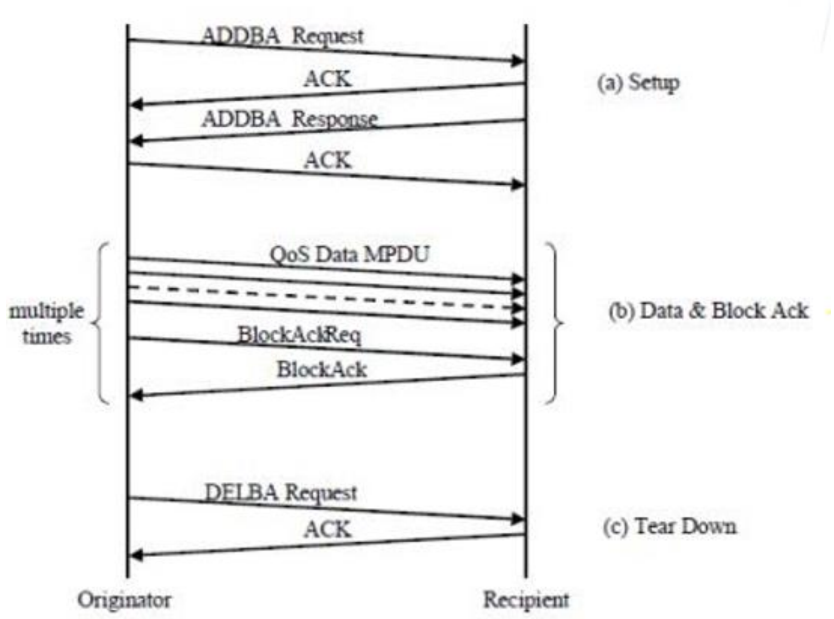
Block Acknowledgements



How Block Acknowledgment Works:

- **Purpose:** Instead of confirming each sent frame separately, block acknowledgment allows several frames to be acknowledged together, making things more efficient.
- **Use in Aggregation:** It's handy when multiple frames are bundled together, reducing the need for individual acknowledgments.

Step-by-Step Process:



Checking Receiver Support:

- The sender first checks if the receiver can handle block acknowledgments by asking with an "Add Block ACK" request.
- The receiver responds with an "Add Block ACK" response, confirming its capability.

After Sending Data:

- Once all the data is sent, the sender asks for a block acknowledgment using a special request frame.
- This block acknowledgment contains a map (like a checklist) showing which frames weren't received by the receiver.

Retransmission Opportunity:

- With this checklist, the sender knows which frames were missed and can resend just those frames, improving reliability.

Closing the Session:

- To end this method's usage, the sender can send a message called "Delete Block Ack," signaling the completion of block acknowledgment usage.

In Simple Terms:

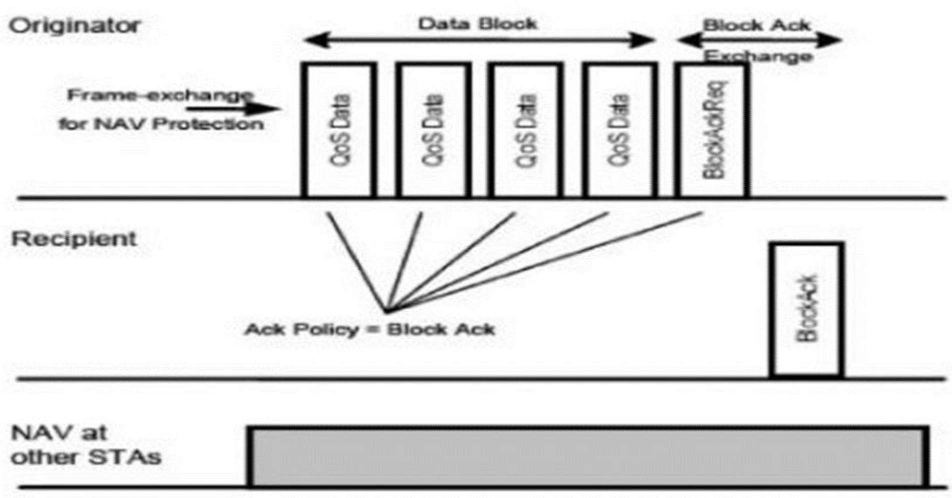
- **Confirming Receiver Support:** The sender checks if the receiver can handle this efficient acknowledgment method.
- **Requesting Acknowledgment:** After sending data, the sender asks for a receipt for all the frames sent together.
- **Finding Missed Frames:** If some frames were missed, the sender gets a list and can resend only those missed frames.
- **Ending the Process:** To finish, the sender says, "We're done using this special acknowledgment now."

Why It Matters:

Block acknowledgment simplifies how devices confirm received data, especially when lots of data is sent at once. It helps make sure nothing gets lost in transmission and is a more efficient way to handle acknowledgments in a wireless network.

Immediate vs Delayed Block ACK

Immediate Block Ack (IBA):



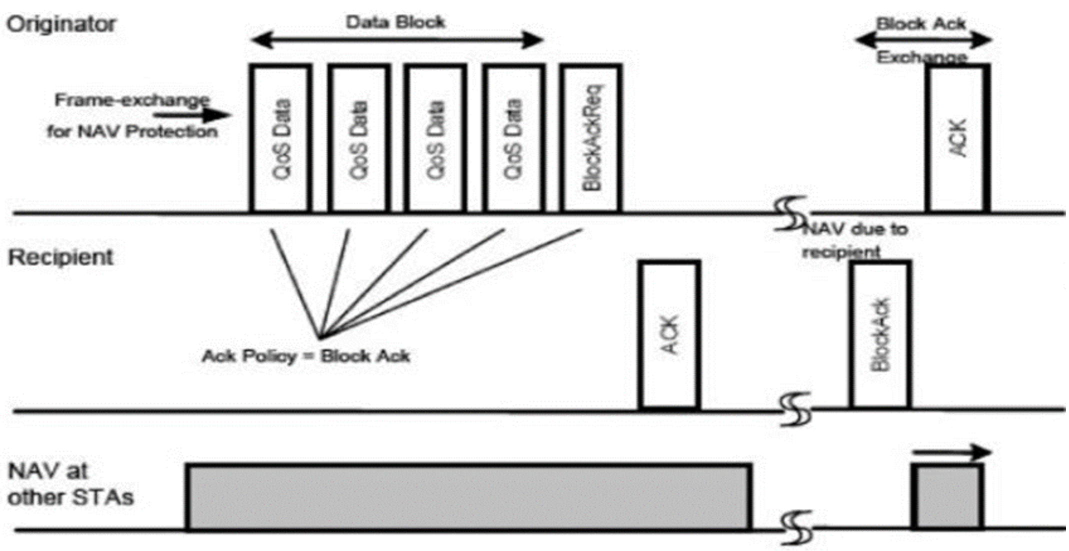
For Fast Response:

- Ideal for high-speed, low-delay data traffic.
- Sends a burst of frames and swiftly requests acknowledgment.
- Receiver processes promptly and sends an immediate block acknowledgment.

Hardware Demand:

- Relies on high-speed computation, usually handled by dedicated hardware.
- Enables quick error calculations and data collection.

Delayed Block Ack (DBA):



Tolerance for Latency:

- Suited for applications comfortable with a bit of delay.
- Sends a burst of frames with a block ack request.
- Receiver acknowledges with a standard acknowledgment first.
- Processes data and later sends a block acknowledgment.

Buffering Consideration:

- Transmitter needs to buffer frames during the acknowledgment delay.

Why Computation Matters:

Behind-the-Scenes Work:

- Both mechanisms rely heavily on fast computation.
- Technological advancements drive rapid processing and error tolerance.
- Hardware implementation ensures the efficiency needed for quick operations.

Choosing the Right Mechanism:

Immediate Block Ack:

- Best for applications requiring immediate acknowledgment.
- Essential for real-time tasks to prevent buffering delays.

Delayed Block Ack:

- Offers flexibility for applications comfortable with moderate latency.

- Acknowledgment delay allows the receiver more time for computations.

Effects of Aggregation on Throughput

HT Mixed Mode 1500 Bytes		WITHOUT Aggregation		WITH Aggregation	
PHY Type	PHY Rate	Throughput	% Medium Wastage	Throughput	% Medium Wastage
11n 20MHz 1SS	72.2Mbps	32.45 Mbps	55%	67.76 Mbps	6%
11n 20MHz 2SS	144.4Mbps	42 Mbps	71%	132.99 Mbps	8%
11n 20MHz 3SS	216.7Mbps	45.16 Mbps	79%	193.71 Mbps	11%
11n 20MHz 4SS	288.9Mbps	48.05 Mbps	83%	251.28 Mbps	13%
11n 40MHz 1SS	150Mbps	43.21 Mbps	71%	137.94 Mbps	8%
11n 40MHz 4SS	600Mbps	52.24 Mbps	91%	469.4 Mbps	21%

- Aggregation significantly impacts throughput in Wi-Fi.
- Research analysis indicates varying levels of efficiency based on data rates and aggregation.

Data Rate and Aggregation:

Low Data Rates:

- Without aggregation, high overhead (91%).
- With aggregation, reduced overhead (21%).
- Wastage still exists due to low data rates.

High Data Rates:

- Without aggregation, higher medium utilization.
- With aggregation, increased throughput and reduced wastage.
- Aggregation is more effective at higher speeds.

Visualizing Medium Wastage:

Low Data Rates (No Aggregation):

- Overhead frames transmitted at low data rates.
- Results in significant medium wastage.

Low Data Rates (With Aggregation):

- More time allocated, more data sent, but at low data rates.
- Wastage is still present, though less than without aggregation.

High Data Rates (With/Without Aggregation):

- Transmitting at high data rates leads to higher efficiency.
- Aggregation at high data rates results in significantly less wastage.

Key Takeaways:

Aggregation Efficiency:

- Most beneficial in modern Wi-Fi standards (e.g., 11 AC, 11 ax).
- Yields maximum efficiency at higher data rates.
- Significant impact on throughput in these standards.

Data Rate Impact:

- At lower standards and speeds, the efficiency gain from aggregation is limited.
- Higher data rates showcase substantial differences in throughput with and without aggregation.

Packet Size Consideration:

- Smaller packet sizes show marginal differences.
- Substantial gains with aggregation for larger packet sizes.

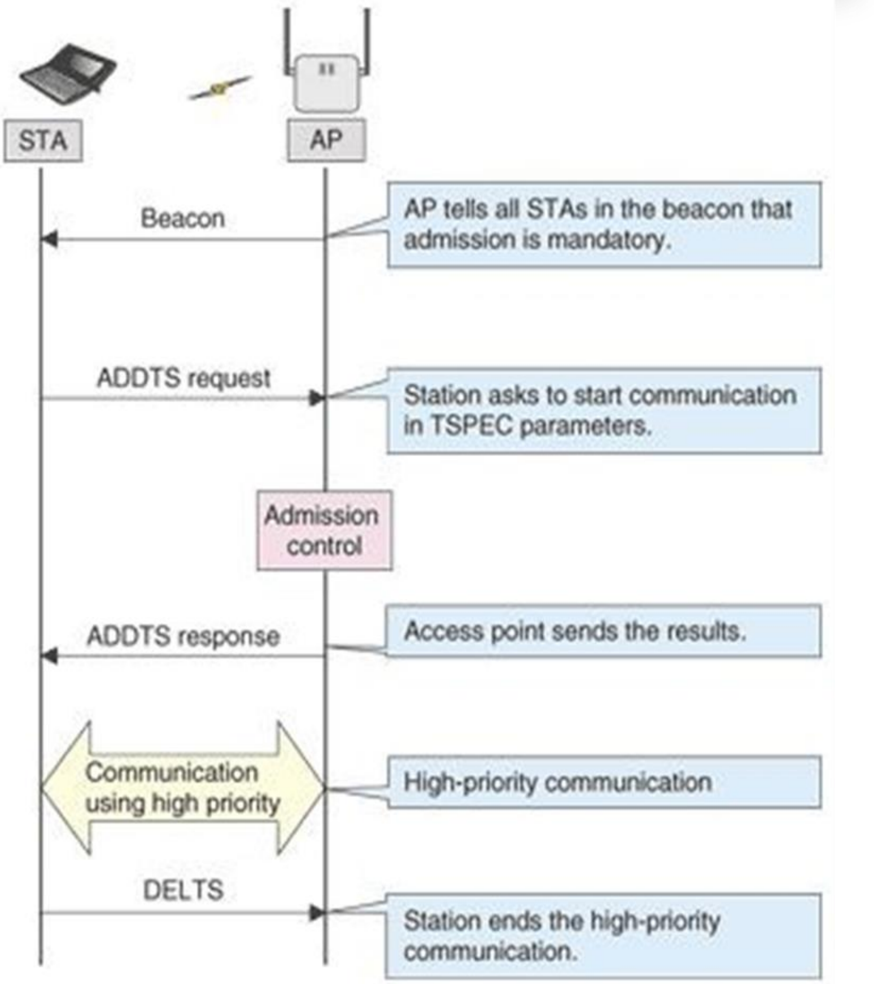
Conclusion:

- Aggregation proves highly useful in standards allowing higher transmission speeds.
- Efficiency gains are substantial, particularly at higher data rates.
- Considerable impact on Wi-Fi throughput, emphasizing the importance of aggregation in modern standards.

802.11e Admission Control

- Admission control in Wi-Fi networks doesn't aim to enhance medium utilization; instead, it focuses on selectively admitting clients into the network.
- In scenarios where a new client seeks connection, the access point (AP) may reject the request based on the current load. This ensures that existing clients aren't adversely affected by additional load.

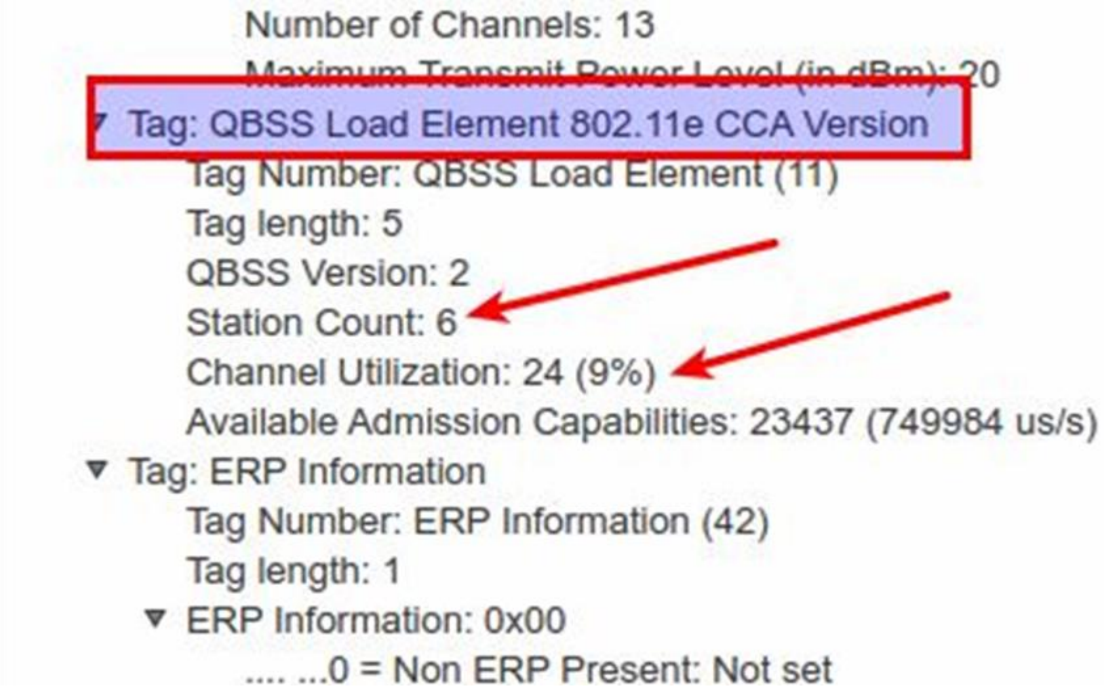
- Additionally, when an existing client wants to transmit data, it sends a request specifying the required medium time and data amount. The AP evaluates its current load to either accept or reject the request.



- This concept can be compared to highway traffic control, where the goal is to limit the number of vehicles entering to minimize congestion. Similarly, admission control reduces network congestion by controlling the admission of devices.
- For instance, during morning traffic, there's limited entry to the highway via traffic lights, restricting the number of vehicles entering during peak hours.
- The TSPEC (traffic specifications) negotiation procedure in IEEE 802.11e involves the station requesting QoS details through an ADDTS (add traffic stream) request. This includes mean data rate, packet length, and physical rate.
- The AP then evaluates the request based on its current load, deciding whether to accept or reject it. The station can initiate high-priority communication only upon AP approval, ensuring efficient utilization and preventing network congestion.
- Once communication concludes, the station sends a DELTS (delete traffic stream) message, facilitating dynamic control and adapting to changing network conditions.

- TSPEC negotiation is a proactive approach to prevent wireless link congestion. Stations are informed about congestion before initiating communication, ensuring comfortable use of real-time applications like VoIP and video. Admission control minimizes unnecessary traffic, enhancing overall network efficiency.

QBSS Element



- In Wi-Fi, the QBSS element, part of the 11e standard, is like a Wi-Fi menu that the access point (AP) shares when you're connecting to it.
- It's a bit like being at an airport deciding where to eat. Each food stall shows a sign with info—QBSS does something similar for your Wi-Fi connection.
- It tells your device how many clients are already connected to the AP and how busy the Wi-Fi is.
- When your device is choosing a Wi-Fi connection, it checks this QBSS info.
- If it sees the AP is loaded with lots of devices and the Wi-Fi is busy, it might look for another access point.
- It's like picking a less crowded food stall to get your meal faster.

QBSS element info includes:
Station Count: Shows how many devices are connected to the AP.
Channel Utilization: Indicates how busy the Wi-Fi channel is as a percentage.
Available Admission Capacity: Signals how much time is left for new connections, helping with admission control.
This helps devices find an access point that's not too busy, ensuring better Wi-Fi for everyone in that area.

Note: You can explore an impressive Aggregation demonstration on YouTube starting from the 47:55 timestamp. Feel free to check it out for real-time experience. (https://www.youtube.com/watch?v=IkKTE3Lryk4)