Error-Sensitive Adaptive Frame Aggregation in 802.11n WLANs

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Outline

1. Introduction
2. Background and Related Studies
3. ESAFA - Error-Sensitive Adaptive Frame Aggregation
4. Performance Evaluations
5. Conclusions and Future Works

1. Introduction

- What is 802.11n WLAN?
  - new drafting 802.11 wireless LAN standard with more than 100Mbps throughput
  - PHY layer improvements using:
    - MIMO, OFDM, 40MHz channel bonding
  - MAC layer improvements using:
    - A-MSDU and A-MPDU frame aggregation

	802.11a	802.11b	802.11g	802.11n
Standard Approved	July 1999	July 1999	July 2003	Not Yet Approved
Max Data Rate	54Mbps	11Mbps	54Mbps	600Mbps
Modulation	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
RF Band	5GHz	2.4GHz	2.4GHz	2.4GHz or 5GHz
No. Spatial Streams	1	1	1	1, 2, 3, or 4
Channel Width	20MHz	20MHz	20MHz	20 or 40MHz

1. Introduction

- Lin and Wong have proposed an Optimal Frame Aggregation (OFA) for AMSDU frame under different BERs in 802.11n WLANs [Lin, 2006].
  - However, Voice and Video multimedia traffic requirements are not considered in the algorithm

- Address the weaknesses in OFA algorithm:
- Proposed Error-Sensitive Adaptive Frame Aggregation (ESAFA) to improve both delay and loss rate in the 802.11n WLANs

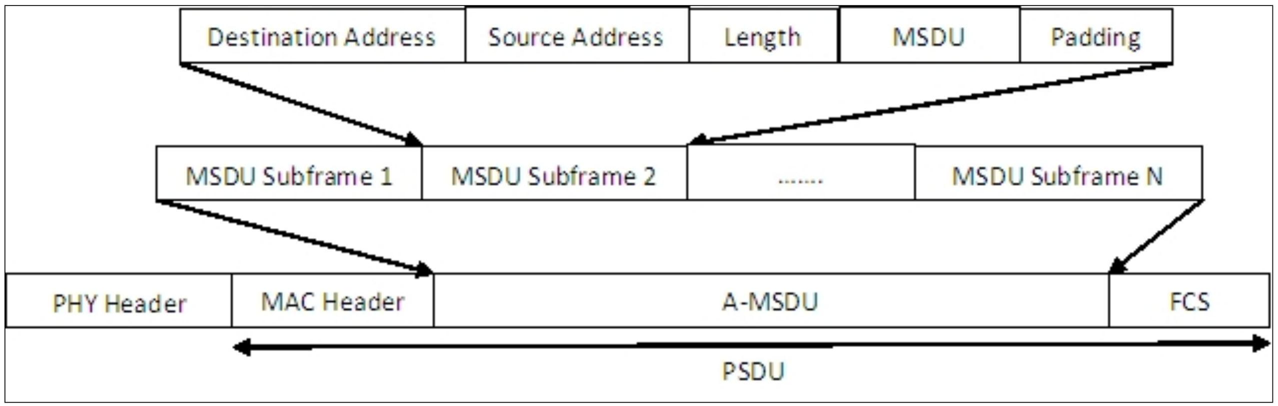
2. Background and Related Studies

- A-MSDU Frame Aggregation
- A-MPDU Frame Aggregation
- Two-Level Frame Aggregation
- Block Acknowledgement
- OFA – Optimal Frame Aggregation

2.1 A-MSDU Frame Aggregation

- A-MSDU: Aggregated MAC Service Data Unit.
- Top MAC layer receives packets from the Link Layer
  - Aggregated multiple MSDUs with a single MAC header
- Same source and destination addresses for all A-MSDU subframes
- Maximum A-MSDU size is 8KB
- No retransmission for corrupted A-MSDU subframe

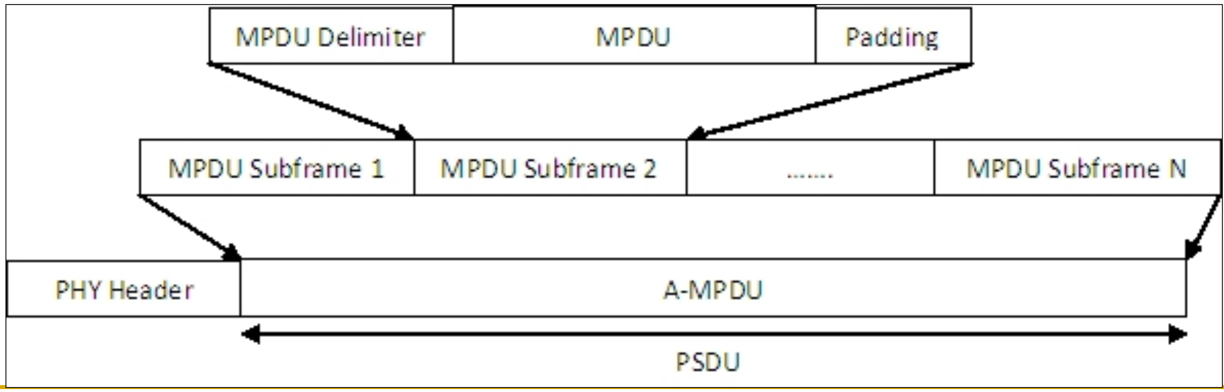
A-MSDU Frame Format



2.2 A-MPDU Frame Aggregation

- A-MPDU: Aggregated MAC Protocol Data Unit.
- Aggregating multiple MPDU subframes with a single PHY header
- Same destination address for all A-MPDU subframes; they can have different source address
- Maximum A-MPDU size is 64KB
- Retransmission for corrupted A-MPDU subframe by Block Acknowledgement (BA) mechanism

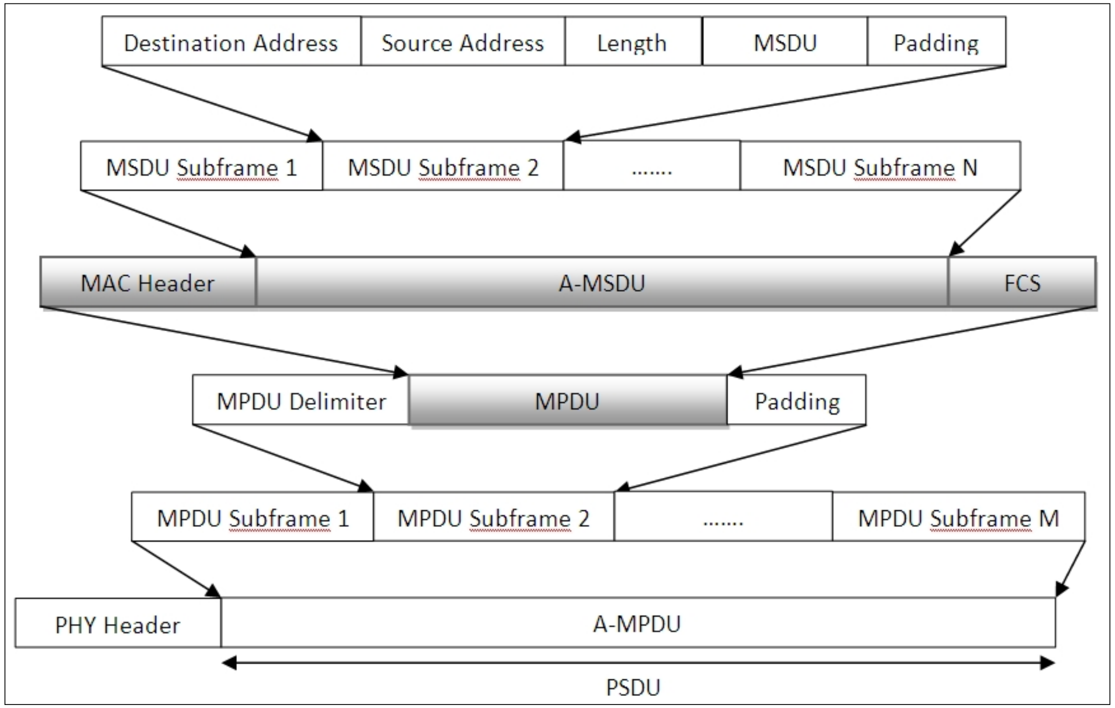
A-MPDU Frame Format



2.3 Two-Level Frame Aggregation

- Combine both the benefits of A-MSDU and A-MPDU aggregation to reduce the overhead of 802.11n protocol
- One MPDU subframe is made up by one AMSDU frame

Two-Level Frame Aggregation



2.4 Block Acknowledgement

- A new mechanism in IEEE 802.11n to acknowledge a block of packets effectively.
- Sender
  - send an Add Block Acknowledgment (ADDBA) frame to the receiver
- Receiver
  - accepts frames that have sequence numbers within the current window
  - the status of each MPDU subframe is updated in the Block Acknowledgement (BA) frame, either Received or Corrupted.
  - sending back a BA frame to the sender

Optimal Frame Aggregation (OFA)

- Wong and Lin have suggested an Optimal Frame Size for A-MSDU Aggregation in 802.11n WLANs [Lin, 2006].
- Rationale:
  - An optimal aggregated frame size L* for maximizing the AMSDU throughput
  - L* is sensitive to BER.
- The Optimal Frame size algorithm is as follow:
  1. Determines the L*-BER curve from their analytical model using an average number of stations N in the network.
  2. Sender obtains an estimation of the channel BER before sending an aggregated A-MSDU frame
  3. Consult the L*-BER curve for an optimal frame size L* in the particular BER
  4. Construct the AMSDU frame with size L*.

Optimal Frame Aggregation (OFA)

- Limitations on this algorithm:
  - Using a static pre-calculated L*-BER curve
  - Does not evaluate the two-level aggregation in 802.11n
  - Lost rate and delay for voice and video multimedia traffic is not considered

3. Error-Sensitive Adaptive Frame Aggregation (ESAFA)

- Design Rationales

1. Support application-specific QoS
   - In terms of FER - Frame error rate
2. Observe relationship among channel BER, application-required FER, and frame length
3. Utilize 802.11n two-level frame aggregation

ESAFA Design Rationales

- 1. Support application-specific QoS
  - In terms of FER - Frame error rate
- Voice and Video traffic requirements:
  - QoS requirement for Voice traffic
    - delay tolerable: less than 1-2% of packets with delays greater than 30ms
    - loss rate tolerable: 2-5%
  - QoS requirement for streaming video traffic
    - delay tolerable: < 4-5seconds
    - loss rate tolerable: < 5%

ESAFA Design Rationales

- 2. Consider relationship among channel BER, application-required FER, and frame size (FS)
- Given BER and FS, the FER can be calculated as,

  $$FER = 1 - (1 - BER)^{**} FS \qquad (1)$$

- From Eq (1), given FER and FS, BER becomes:
- $$BER = 1 - 10 \wedge ((Log_{10} (1 - FER)) / FS) \qquad (2)$$
- From Eq (1), given FER and BER, FS becomes:

  $$FS = Log_{10} (1\text{-}FER) / Log_{10} (1\text{-}BER) \qquad (3)$$

ESAFA Design Rationales

- By using the suggested Optimal Frame Size (OFS) in the OFA scheme
  - we calculated the FER in table 1.

BER	10^{-6}	$1*10^{-5}$	$2*10^{-5}$	$5*10^{-5}$	10^{-4}
OFS	8000*8	4500*8	2500*8	1500*8	1000*8
FER	6.19%	30.23%	32.96%	45.12%	55.07%

- The FER results are not tolerable if we are using Voice/ Video multimedia traffic where the FER loss requirements would normally be less than 5%.

ESAFA Design Rationales

- Tables 2 (a), 2(b), and 2(c) show more data for the relationship of FER and FS (MPDU subframe size) under various BER channels.

(a) BER = 10^{-6}

BER	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
FS	120*8	480*8	959*8	1918*8	3839*8
FER	0.09%	0.38%	0.76%	1.5%	3%

(b) BER = 10^{-5}

BER	10^{-5}	10^{-5}	10^{-5}	10^{-5}	10^{-5}
FS	120*8	480*8	959*8	1918*8	3839*8
FER	0.95%	3.8%	7.3%	14%	26%

(c) BER = 10^{-4}

BER	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-4}
FS	120*8	480*8	959*8	1918*8	3839*8
FER	9%	31%	53%	78%	95%

- **In order to achieve a tolerable FER, it is necessary to adjust FS in response to BER.**

ESAFA Design Rationales

- 3. Utilizaging 802.11n two-level frame aggregation (FA)
  - In the first level, AMSDU, no corrupted subframe is retransmitted
    - A single bit error triggers the drop of the entire frame.
  - In the second level, the sender retransmits any corrupted MPDU subframe through the BA mechanism
  - Thus, ESAFA uses two-level FA by adjusting the second-level MPDU frame size according to the current BER and the required FER tolerance

ESAFA Algorithm Description
Variables defined

Let ***X*** *be the maximum FER tolerable by a particular multimedia traffic.*

Y *(Y<X) be the minimum FER below which the frame size can be increased to boost the throughput.*

R *be the current FER, using the average ratio of corrupted sub-frames in an AMPDU.*

mBER *be the measured BER condition calculated from R by the sender,*

currentFS *be the current MPDU subframe size*

Note:

- *R = (Total number of corrupted sub-frames in an AMPDU)/ (Total number of sub-frames in an AMPDU)*
- *R* is calculated by the sender based on the BA frame received by the receiver.
- *R*, the current FER, determines the increasing/ decreasing/ keeping of the MPDU subframe size.

ESAFA Algorithm Description

1. **Obtain the *mBER* in the network by substituting *R* and *currentFS* into Eq (2).**

   $$mBER = 1 - 10 \wedge ((Log_{10} (1 - S)) / currentFS)$$

2. **Adjust MPDU subframe size to satisfy the FER requirements *X* based on *R*, the current FER**

   a. If R > X

   //Bad channel condition, decrease the MPDU size by using *X* in eq (3)

   $$Current\ S := log10(1 - X) / log10(1 - mBER)$$

   b. else if R < Y

   //Good channel condition; increase the MPDU size by using Y in eq (3) to boost throughput

   $$currentFS = Log_{10} (1\text{-}FER) / Log_{10} (1\text{-}BER)$$

   c. Use *currentFS* for the next MPDU size

   //Note that no frame adjustment is needed for the condition $Y \leq R \leq X$.

ESAFA Algorithm Description

Alternating Step 2b: Smooth increase of frame size

2b. else if R < Y

//Good channel condition; increase the MPDU size by using Y in eq (3) to boost throughput

currentFS = currentFS + 100 bytes

4. Performance Evaluations

- Simulations settings
  - Implemented the algorithm on NS-2 version 2.30
  - Network topology is a typical WLAN with a single access point and multiple wireless clients.
  - PHY data rate is 144Mbps.
  - Set *X* to be 5%
  - Set *Y* to be *0.8X*.
  - Simulate under different BER conditions and each simulation run lasts for 10 seconds.

Performance Evaluations

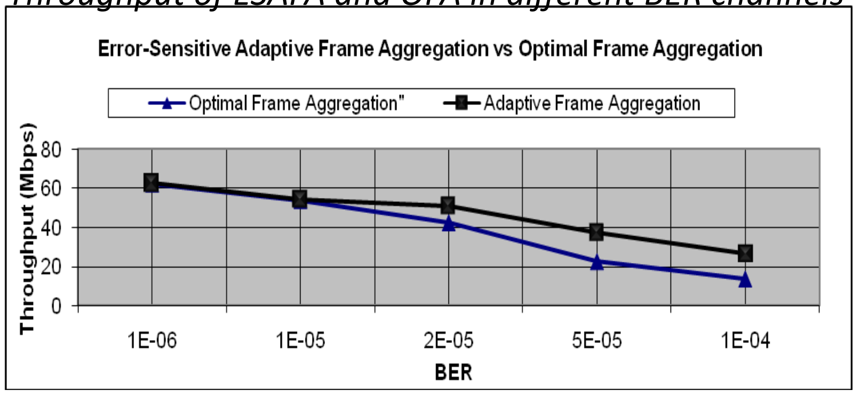
- Performance Measurements
  - Throughput
    - refers to the maximum rate at which the MAC layer can successfully transfer packets from senders to the receivers
  - Average delay
    - refers to the average duration from the time a packet is ready to be sent at the sender's interface queue until it is correctly received by the receiver; this also includes the retransmission time.
  - Percentage delay
    - refers to the percentage of packets where delay is greater than a delay upper limit
    - Important for real-time applications such as VoIP where delay is critical
    - selected 30ms as the delay upper limit in the percentage delay
  - Measured FER
    - represents the average percentage of corrupted MPDU sub-frames in an AMPDU
    - evaluates if ESAFA satisfies the application FER requirement

Performance Evaluations

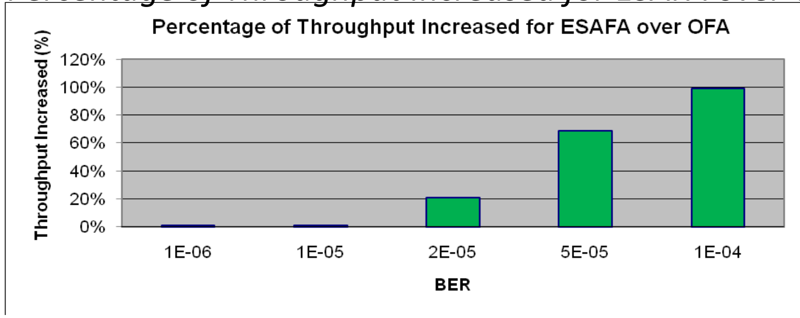
- *Throughput comparison between the ESAFA and OFA schemes*

- Throughput stays around the same at about 62Mbps in low BER
- A gradual throughput increase for ESAFA scheme compared to the OFA under high BER
- The percentage of throughput increased for ESAFA over OFA reaches around 80% in very high BER channel

Throughput of ESAFA and OFA in different BER channels



Percentage of Throughput Increased for ESAFA over OFA

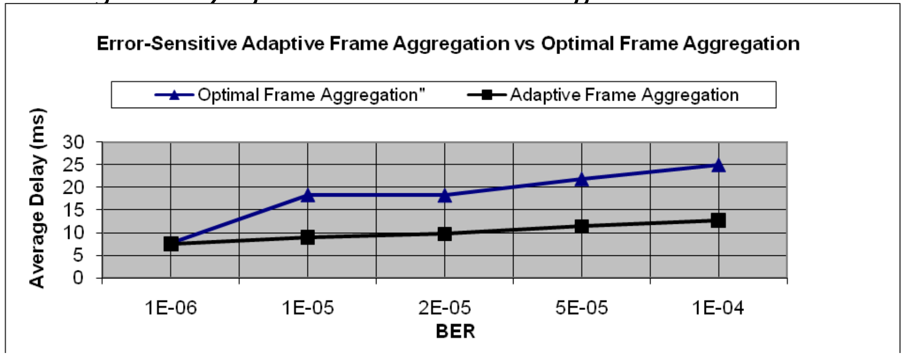


Performance Evaluations

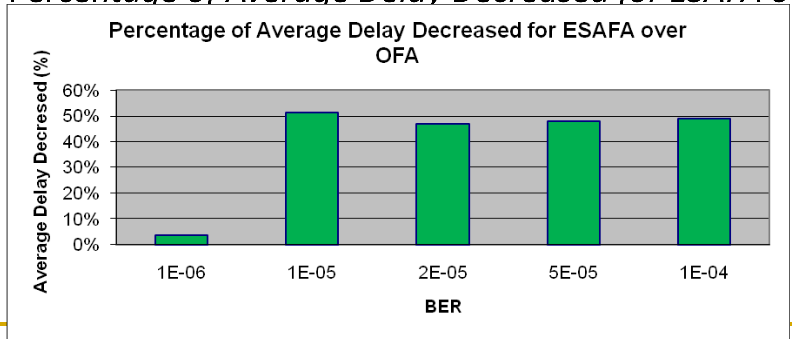
- *Average Delay comparison between the ESAFA and OFA schemes*

- OFA has a larger average delay under higher BER channel
- ESAFA can keep the average delay low for different BER channels
- The average delay is decreased by around 50% under different channel conditions.

Average Delay of ESAFA and OFA in different BER channels



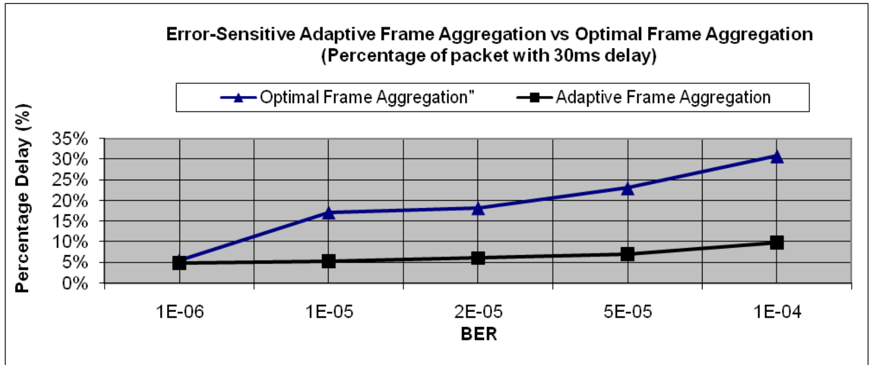
Percentage of Average Delay Decreased for ESAFA over OFA



Performance Evaluations

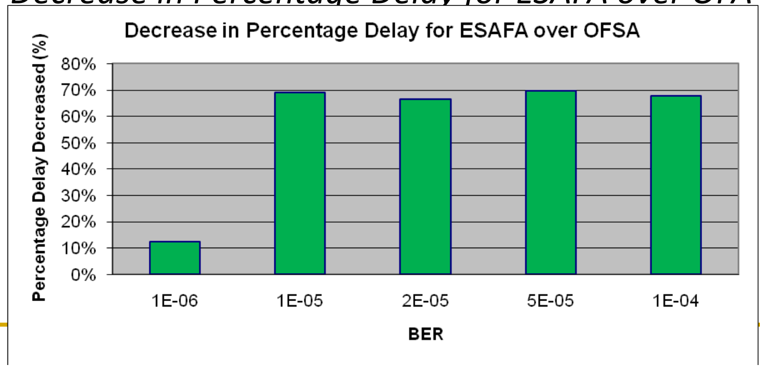
- *Percentage Delay comparison between the ESAFA and OFA schemes*

Percentage of packet with more than 30ms delay for ESAFA and OFA in different BER channels



- OFA gets around 20% - 30% of packet with delay more than 30ms in high BER channel
- The ESAFA scheme maintains the percentage delay at around 5%-10% across different BER conditions

Decrease in Percentage Delay for ESAFA over OFA



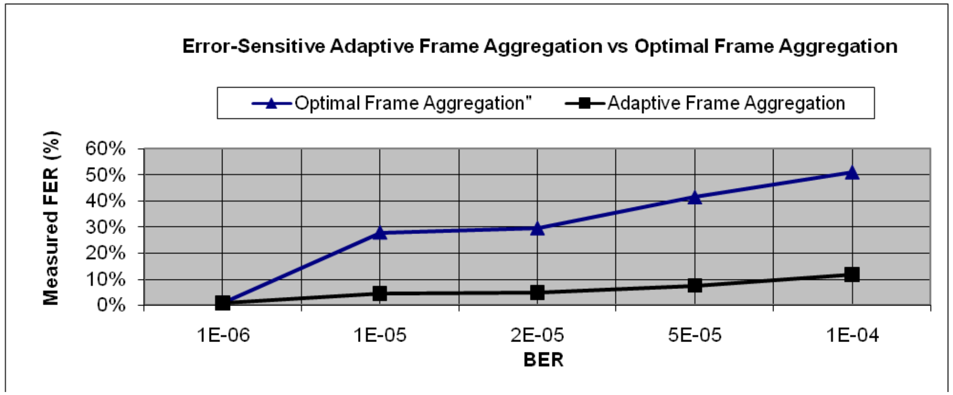
- the percentage delay of ESAFA is decreased by around 10% under low BER channel
- however, the percentage delay of ESAFA is decreased by around 65% in high BER channel

Performance Evaluations

- *The measured FER in the MAC layer between the ESAFA and OFA schemes*

- the FER of OFA are close to the analytical FER data
- Promising result show that the measured FER of the ESAFA scheme can be kept at around 5-10% even under high BER channel
- This is close to the application FER requirement 5% where we input in the simulation.

Measured FER for ESAFA and OFA in different BER channels



Conclusions

- Designed ESAFA, an Error-Sensitive Adaptive Frame Aggregation algorithm
  - adds the factor of maximum FER tolerable by a particular Voice/Video application traffic into frame aggregation.
- Simulation results show that the proposed ESAFA scheme outperforms the OFA.
  - Improve both delay and loss rate in the 802.11n WLANs.
  - The delay compared to OFA is decreased by around 50% under different channel conditions.
  - The measured FER of the ESAFA can be kept at about the same as the loss rate requirement for Voice / Video traffic even under high Bit-Error-Rate (BER) channel.

Future Works

- Extend and evaluate 802.11n
  - In MANET and Mesh environments
- Can also evaluate
  - 802.11e QoS requirement with 802.11n frame aggregation

Thank you!

Q & A

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