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# Performance study of block ACK and reverse direction in IEEE 802.11n using a Markov chain model

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The 802.11n standard introduced several key features including Block acknowledgement (ACK) and reverse direction. In this paper researchers study the interdependencies of Block ACK and RD mechanisms using a discrete bi-directional Markov chain model under non-saturated traffic loads. Researchers present a mathematical model to derive throughput, delay, and packet loss probability. This research developed an analytical model to track and trace the performance fluctuation issues of 802.11n networks using Markov Chains.

A new ACK mechanism is being introduced in the 802.11e standard known as BA. Unlike the traditional ACK scheme, an ACK is transmitted to reply to multiple data frames rather than per frame as in BA. The basic idea of the BA mechanism is to aggregate several ACK frames into a single frame. BA enhances wifi throughput, aggregation, channel utilization. However, when the frame consists of only one data frame it suffers from severe throughput degradation due to a couple of additional frames (e.g. BA request and BA).

There are two subclasses of Block ACK schemes: Protected and non-protected Block ACKs. To initialize the new acknowledgement policy, the originator and the recipient will exchange Add Block Acknowledgement (ADDBA) Request/Response frames. Afterwards, a data block with multiple data frames is transmitted from the originator to the recipient with Block ACK Request (BAR) at the end. The recipient sends a Block Acknowledgement (BA) frame for the entire data block. In protected Block ACK, before transmitting an entire data burst, the originator will transmit a single data frame and wait for an ACK from the recipient.

Until now, when the sender STA is allocated with a TXOP, it informs surrounding STAs about how long the wireless medium will be engaged. In 802.11n RD, receiver may request a reverse data transmission. This allows the transportation of data frames and also aggregates frames; in both directions and in one Transmission Opportunity (TXOP) period.

An analytical model is proposed to evaluate the performance of 802.11n under non-saturated load conditions. A two dimensional Markov model is developed to derive the channel throughput and end-to-end delay of successful data transmissions. To simplify the mathematical model they made the following assumption:

- Finite number of stations.
- Unsaturated load i.e. there is a certain probability that the transmission queue is empty.
- Channel is prone to errors.
- No hidden terminals.
- Packets are destroyed only through collisions exceeding the retry limit.
- Packets are of equal length.

Researchers derive both the throughput and end-to-end delays by taking into account protected Block ACKs and Reverse Direction data flows in non-saturated load conditions.

For a STA to transmit, it senses the medium to determine if another STA is in transmission. There must be a minimum time gap to identify contiguous frame sequences. a transmitting STA must ensure that the medium is idle for this period before attempting to transmit. STA selects a random backoff interval and decrements the backoff interval counter while the medium is idle. The timer value must be within the Contention Window values. A transmission is successful if an acknowledgement (ACK) frame is received. A station (STA) will increase its contention window size after each failed transmission until it reaches the maximum backoff stage. Since the maximum backoff stage and retry limit are not equal, the contention window size remains the same and STA will continue retransmitting until it reaches a retry limit. If the subsequent transmission is not successful, the packet is discarded.

- k = b(t) backoff counter at time t. b(t) value is decremented at the start of every idle slot and a contending station wins the channel when it reaches to zero. is chosen to be uniformly distributed over $k \in [0, CW_i]$. After successful transmissions if the STA has more data to send a new value would be set for b(t).
- i = s(t) backoff stages at time t. starts at 0 and is increased by 1 everytime transmissions collide. Once the CW reaches CWm, it will remain at this value until it is reset.

There is a chance that two STAs end up with the same b(t) values and transmit data simultaneously. This is called a collision. In order to avoid further collisions, the collided STAs will generate new random b(t) values. Once the CW reaches $CW_m$, it will remain at this value until it is reset. That means STA will keep transmitting the packet till it reaches the retry limit. If the transmission is still unsuccessful the packet will be dropped.

The two-dimensional process (s(t), b(t)) will be analyzed with an embedded Markov chain. Unsuccessful transmission attempt can happen due to the collision of a station with at least one of the $n-1$ remaining stations or having a frame with errors (due to channel fading and/or noise).

The unsaturated traffic behavior is characterized by defining a MAC queue. Packet arrival rate at each STA buffer from upper layer is λ pkt/s. μ represent the packet processing rate assuming that the queue has a length of K. The probability that there is at least one packet to be transmitted in the STA queue can be found by using a M/M/1/K queueing model.

A packet can be dropped when the retry limit is reached or when the sending queue is full. Total packet drop probability is the sum of both of these events. A packet is found in the last backoff stage m if it encounters m collisions in the previous stages and it is eventually discarded.
Considering the M/M/1/K queue system, where there are K frames in the system frames are dropped with probability $P_K$.

Delay can be defined as the time elapsing from the frame is inserted in the MAC buffer to is successfully transmitted. Delay is associated with two factor; medium access delay due to the number of contending stations and queueing delay.

Paper studied the characteristics of various IEEE 802.11n Block ACK methods. Analytical model is validated MATLAB based numerical study. Numerical studies shows that; increments of network size significantly reduce the throughput due to collisions. Also, protected Block ACK RD provides 32.54% higher throughput than Block ACK with RD.

Paper investigated the interdependencies of Block ACK and RD mechanisms for 802.11n using a discrete bi-directional Markov chain model under non-saturated traffic loads. Results obtained have shown that the better system performance (i.e. up to 33% higher throughput and 48% less packet dropping) can be achieved using protected Block ACK in conjunction with RD data transmission. ‘unprotected Block ACK’ wastes TXOP especially during collisions and degrades system performance significantly. To fully utilize the system performance, 802.11n stations should employ protected Block ACK mechanism with RD flows.