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EFFICIENT FINE-GRAINED 802.11AX BSR-BASED OFDMA RU ALLOCATION

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ABSTRACT

Proposed herein are techniques that provide a simple Institute of Electrical and Electronics Engineers (IEEE) 802.11ax (WiFi6®) uplink (UL) orthogonal frequency-division multiple access (OFDMA) throughput improvement by exploiting existing standards and enterprise traffic patterns.

DETAILED DESCRIPTION

802.11ax (WiFi6) introduced a strict uplink (UL) multi-user (MU) Trigger-based (TB) transmission ability based on access point (AP) scheduling and resource allocation. The primary assumption is that the AP queries the current load (per Access Category (AC)/Traffic Identifier (TID) queue depth (QDepth)) from stations (STA) with coarse-grain buffer-status-report (BSR) poll (BSRP) messages and triggers UL MU transmissions in the future accordingly. Thus, 802.11ax demand information is limited coarse-grain QDepth reported per TID/AC learned from an AP-triggered BSRP/BSR transaction (Solicited BSR) or STA report (Unsolicited BSR). This approach, while simple, introduces a number of inherent inefficiencies that are highlight and addressed in this proposal.

The implicit assumption is that this QDepth should govern the resource allocation (i.e., the number of resource units (RUs) assigned per STA). However, this has fundamental flaws. For example, a scaling factor or SF (16, 256, 2048, 32768) is used to represent the base number of octets (e.g., one can represent 1x16 or 2x16=32 but not 24 specifically) necessitating a rounding up function. Further, the range of values that can be represented in an unsolicited BSR (U-BSR) [9.2.4.5.6 Queue Size] is different than a solicited BSR (BSR) [9.2.4.6a.4] since the former has both a SF and a corresponding start point (1024 for SF=256, 17408 for SF=2048, 148480 for SF=32768). Additionally, any excess allocation results in Physical Layer Convergence Procedure (PLCP) Protocol Data Unit (PPDU) padding (i.e., wasted bandwidth (BW)).

These representation limitations contribute to an inefficiency that increases with congestion or STA density. That is, with small QDepth (e.g., <4 Kilobytes (KB)) the allocation error is 0-15 bytes (B), however, with congestion and inevitable QDepth growth the allocation error grows from 0-32767.

It is important to note that while over-allocation won't generally occur when total demand exceeds available capacity (i.e., a STA always has excess QDepth after being served by an AP), the nature of enterprise traffic (e.g. congestion-avoiding Transmission Control Protocol (TCP) connections, rate-adapting video, etc.) makes it highly likely that the offered load will be held just below the capacity and, thus, inefficient RU padding will be significant. Simulation results indicate that for an enterprise traffic mix (e.g., voice/streaming video/data) and constant modulation and coding scheme (MCS) 8/11 rates, between 20% and 35% of the UL TB PPDU is padding waste. While some of this waste may be caused by MU-PPDU alignment issues, it has been observed that a majority of the waste is simply under-use of the RU offered to a STA based on its BSR.

This proposal provides a solution to such issues by defining an Extended BSR Information Element (IE) (e.g., a vendor specific IE (VSIE)) to represent the absolute byte count of each TID/AC, either with an absolute counter (independent of the Quality of Service (QoS)-Control in a U-BSR or BSR-Control field in a BSR) or as a relative (delta) byte count (mathematically dependent on the QoS-Control in a U-BSR or BSR-Control field in a BSR). This extended BSR (E-BSR) element is included for each AC/TID present in the base BSR in the delta case or for each AC/TID in the absolute case.

Figure 1, below, illustrates example details of this solution. Generally, the solution proposed herein involves looking for a trend in padding loss (e.g., 25% average over 1s) that may be corrected by engagement of a fine-grained allocation mode (FGAM) in which an AP scheduler can compute the real number of bytes in each TID queue and use this computation for precise RU allocation for a given STA.

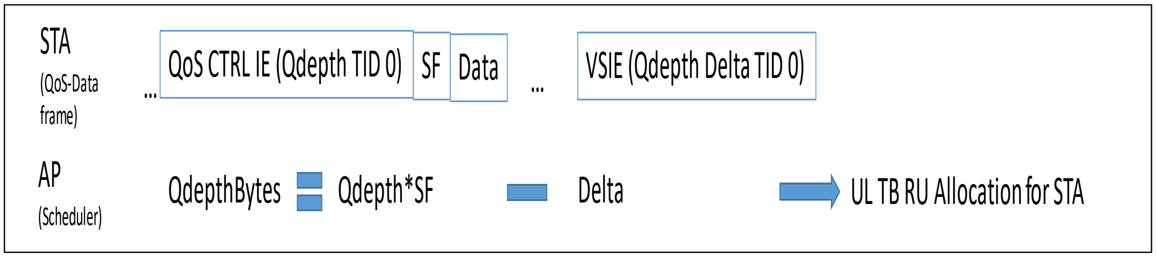

Figure 1

With this solution, various potential scheduling behaviors are possible. For example, in one instance a STA may include an Extended BSR for every U-BSR or BSR and the AP may use the IE for the FGAM. In another instance, a STA may only include the Extended BSR (U-BSR or BSR) when the byte-count involves an inaccurate SF (e.g., 256, 2048) and AP may use this for the FGAM. In yet another instance, an AP may monitor the extra 'padding' bytes included in received (Rx'ed) UL MU PPDUs (e.g., over 1s) and enable reporting of the extended BSR from a STA if a threshold (e.g., 10%) is reached. Like-wise, the AP may disable the mode when padding losses are negligible.

These scheduling examples are not meant to be limiting, as many other scheduling rules may be enabled by virtue of the Extended BSR. Furthermore, although the solution proposed herein is considered best for current WiFi architectures where 802.11ax chipsets perform RU allocation by default, it is to be understood that other HW architectures are possible.

It should be noted that for the FGAM, the scheduler will parse the Extended BSR (and standard (STD) IE, if needed) to arrive at a total byte count for each reported AC/TID. Using the precise count, the scheduler can (e.g., using a current MCS in next trigger) make its own RU allocation/transmit opportunity (TXOP) length calculation and compare that to what the chipset (hardware) allocates. If there is a non-negligible savings, the scheduler can then over-ride the hardware (HW) allocation. Additionally, self-induced PPDU length normalization padding is known in advance by the AP RU scheduler and can be deducted from the measured PPDU padding (e.g., BSR reports 1024B, the AP allocates 1040B to align with TXOP, and the STA uses 900B - measured padding = 1040 - 900 =140 real padding=140-16=124).

The FGAM involves an assumption that system steady-state will be reached whereby past padding losses will also occur in the future, which is why measurements are performed over a suitable time-frame to minimize the effect of TCP/video-stream start-up affects. In both simulation and lab results, it has been observed that a reasonably stable running average padding loss emerges after a few seconds, which points to a conclusion that such losses aren't a transient state, but rather something more sustained that can be exploit in real-time.

In summary, this proposal provides a simple 802.11ax UL OFDMA throughput improvement by exploiting existing standards and enterprise traffic patterns.