A simple & scalable traffic engineering solution for 802.11s

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Abstract

- **EDCA provides the basic medium access scheme for 802.11s mesh networks. As EDCA has been designed for single-hop communication it performs poor in a multi-hop environment. Self-induced congestion is an inherent characteristic of EDCA in mesh network. To overcome the disadvantages of EDCA in the harsh environment of wireless mesh networks, we propose a simple modification based on the principles of cooperation.**

Outline

- **Self-induced congestion in 802.11s**
- **Dissimilar capacity distribution in wireless mesh networks**
- **Solutions to avoid congestion 802.11s**
- **Cooperation in 802.11 EDCA**
- **Recommendation**

Self-induced congestion in 802.11s

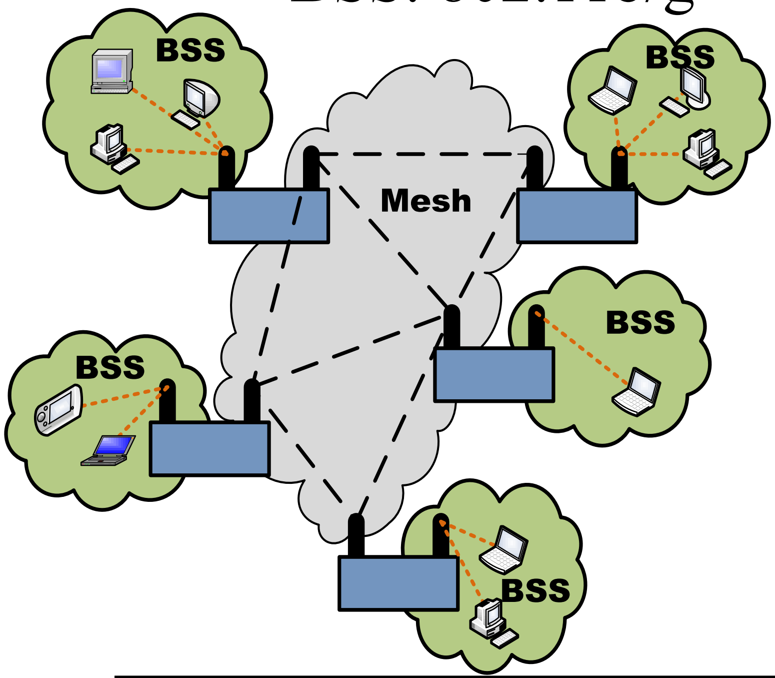
Problem

- **802.11 implements an opportunistic medium access scheme**
  - EDCA & DCF stations compete on wireless medium
  - Devices operate selfish
    - Imbalance in up- & downlink in infrastructure mode, etc.
      - "All against one AP"
    - Maximization of share of capacity

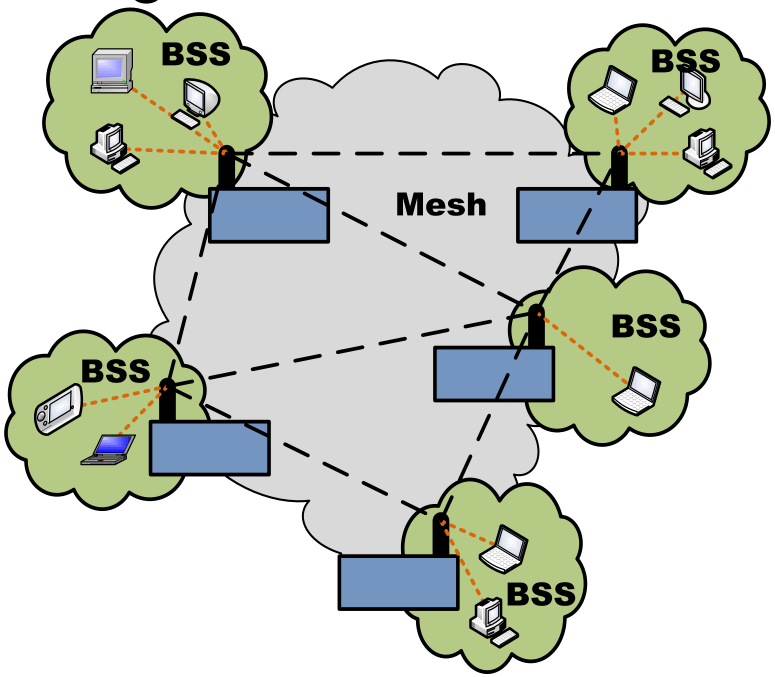
- **802.11 assumes similar conditions for each device**
  - All traffic delivered via central AP
    - 99% of all 802.11 WLAN have star topology
  - AP in radio range of all devices
  - AP involved in each frame exchange
    - Up- & Downlink
      - DLS yet not used

Single-frequency channel operation

- **Current products**
  - Mesh: 802.11a
  - BSS: 802.11b/g



- **Future products**
  - Mesh & BSS share single transceiver

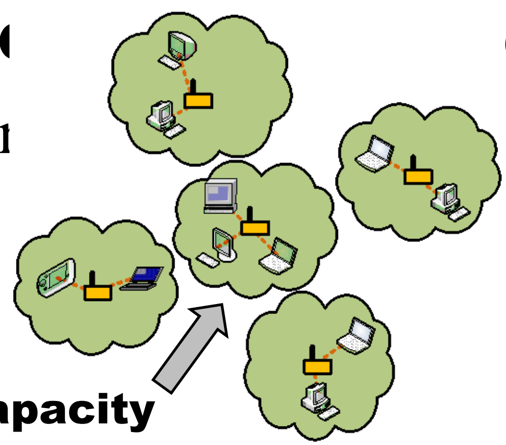


Shared medium & multiple hops

- **Selfish operation of 802.11 devices**
  - Useful in single hop environment
  - Opportunistic approach
  - Grab as much as possible
  - **Stupid for Mesh networks**
- **Frames are forwarded over multiple hops**
- **MPs mutually provide forwarding service**
  - MPs should not contend
  - **MPs should cooperate**

Neighborhood capture [1]

- **Devices with less neighbors access wireless medium more frequently**
- **Capacity available at edge of netw**
  - Edge unawar of center

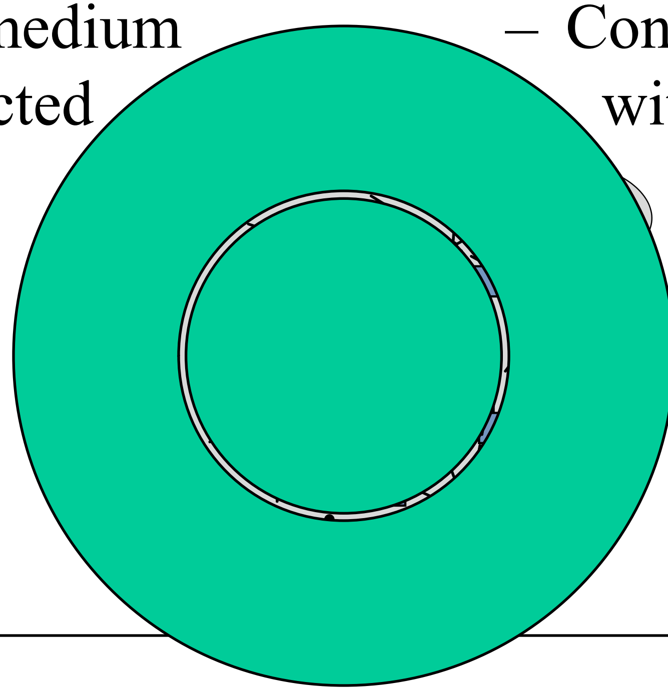


- **Center network suffers from competition**
  - Less capacity available
- **→ Forwarders in a esh network get easily congested**
  - Traffic aggregates & no priority over edge

Dissimilar capacity distribution in wireless mesh networks

Capacity distribution in Mesh

- **Edge devices have low amount of neighbors**
  – Wireless medium often detected as idle
  – Sufficient capacity
- **Center devices have high amount of neighbors**
  – Constant competition with neighbors
    – Wireless medium seldom detected as idle
  – Capacity not sufficient



Desired behavior: Refrain from access to wireless medium until next hop has forwarded

- **May be difficult to detect if frames were forwarded**
  - The acknowledgments send by the intended receiver of the forwarder may be out of range → It may be impossible to detect a successful frame forwarding
- **May require an additional timeout**
- **May not work with non-omnidirectional transmissions**
  - E.g. beamforming in 802.11n
- **Each Mesh link has a unique encryption key**
  - Mesh header including Mesh sequence number is in frame body

→ Not possible, not implementable

Solutions to avoid congestion in 802.11s

Solution 1: Multiple frequency channels

- **Pro**
  - Unlicensed bands are available for free
    - Inefficient designs tolerable
  - Provide dedicated links between neighboring MPs
    - Links become independent
  - Increase spatial frequency reuse distance
    - Low interference possible
  - Form “logical” but not physical mesh
    - No sharing of common resource needed
- **Con**
  - Additional hardware required
    - Expensive
      - Some markets do not tolerate minor, additional cost
    - Not applicable in all scenarios
  - Adjacent channel interference
    - Multiple transceivers in the same band are not independent to each other
    - No orthogonal operation possible
    - Expensive work-around needed
  - Not described in 802.11s
    - Not to be considered by 802.11s?
    - Vendor specific

Solution 2: Use MDA

- **MDA inherently avoids congestion**
  - Neighbor MPs aware of their schedules
  - Capacity can be allocated to center network
- **MPs mutually inform about planned transmissions**
- **Mesh forms backbone network for aggregated traffic**
  - Data rates average

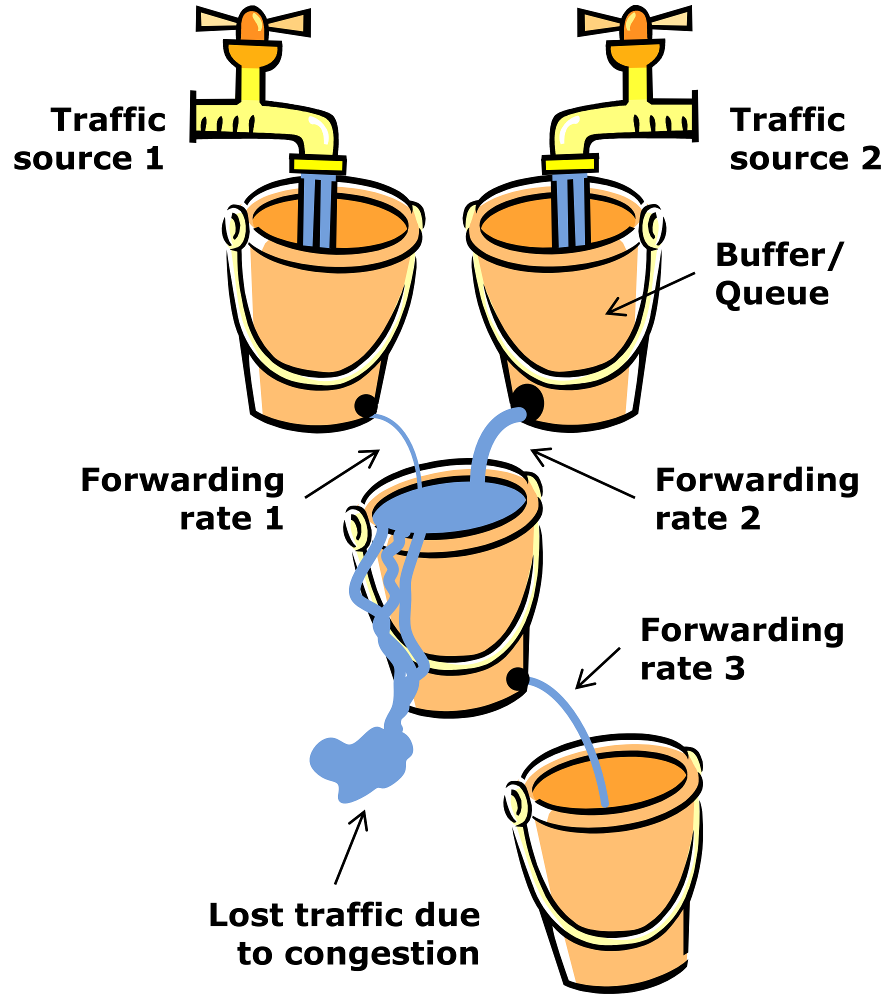
Solution 3: Modify EDCA

- **Provide inherent congestion avoidance**
  - Modify channel access to deal with forwarded traffic
- **Introduce cooperative approach**
  - It's of an MPs own interest that its peer MP can forward traffic
- **How to achieve cooperation?**
  - Provide sufficient capacity to you peer MP
  - Allow the next hop peer MP to forward the traffic
    - In a single frequency channel Mesh, the next hop peer MP uses the same frequency channel
  - → Refrain from access to the wireless medium

A simple modification to the 802.11 EDCA

A model for the wired world

- **Traffic aggregates in the Mesh network**
  - Congestion avoidance, back-pressure … deal with an inherent problem
- **Leaky bucket does <u>not</u> show whole picture**
- **Missing: Wireless links <u>not</u> independent!**
  - Neighboring MPs **<u>share</u>** the wireless medium
  - → Common resource



Cooperation in wireless: Self-limitation

- **An MP becomes congested if it does not have sufficient capacity to handle traffic that is to be relayed**
  - Neighbors need to help out
  - Support next hop

- **Advantages**
  - Self-limiting system
    - The more an MP requires others to forward traffic, the more it throttles itself
  - Each MP provides its next hop peer MP with at least the same capacity of the wireless medium that itself used for the frame exchange

Cooperation in 802.11 EDCA

Solution

- **For each frame *f* that an MP A transmits to another MP B subject to being forwarded, MP A shall wait for the duration of the frame *f* before accessing the wireless medium again**
- **Cooperative design**
  - If MP A requires MP B to forward a frame, MP A shall support MP B in providing the forwarding service
  - MP A should wait a least for a period that is equal to its own frame transmission before accessing the wireless medium again

Definition of waiting time *w*

- **With DCF, the waiting time *w* equals the duration of the full frame exchange sequence**
  - Including optional RTS/CTS, duration for fragmented frame transmissions and all necessary acknowledgments
- **With EDCA, the waiting time *w* equals the duration of the TXOP used for transmission of the frame/frames that shall be forwarded**
  - Includes everything
    - RTS/CTS
    - Block ACK
    - ...

Generalized solution for 802.11s

- **In 802.11s, all MPs use EDCA for frame exchange**
  - With EDCA, any frame exchange is part of a TXOP
    - → The TXOP is the basic medium allocation unit

- **If an MP requests the frame forwarding service of one of its peer MPs, the MP shall refrain from access to the wireless medium for a duration *w* that equals the duration of the frame exchange sequence during its last TXOP.**

Means to implement *w*

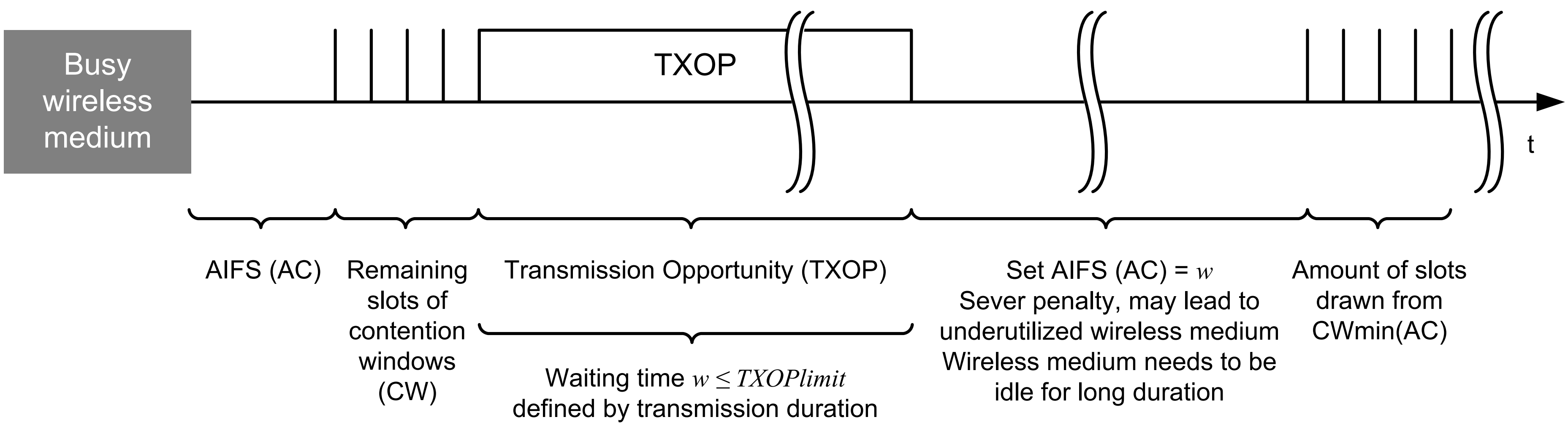
- **Adjustable medium access parameters with EDCA**
  - AIFS
    - Minimum idle period
    - Via AIFSN
  - Contention Window
    - Initial size CWmin
    - Current Size CW
    - Maximum size CWmax
- **Transmission duration**
  - TXOP
    - Shall be considered for further improvement

1. **Set**
   $AIFS = w$
   for next contention
2. **Add**
   $\lceil w/aSlot \rceil$
   to next CW
3. **Set**
   $CWmin = \lceil w/aSlot \rceil$
   draw CW from
   [0, CWmin]
4. **Suspend backoff until timer**
   $t = NOW + w$
   expires

Solution 1:
Frame exchange duration dependent AIFS

Solution 1: Modify AIFS of next backoff

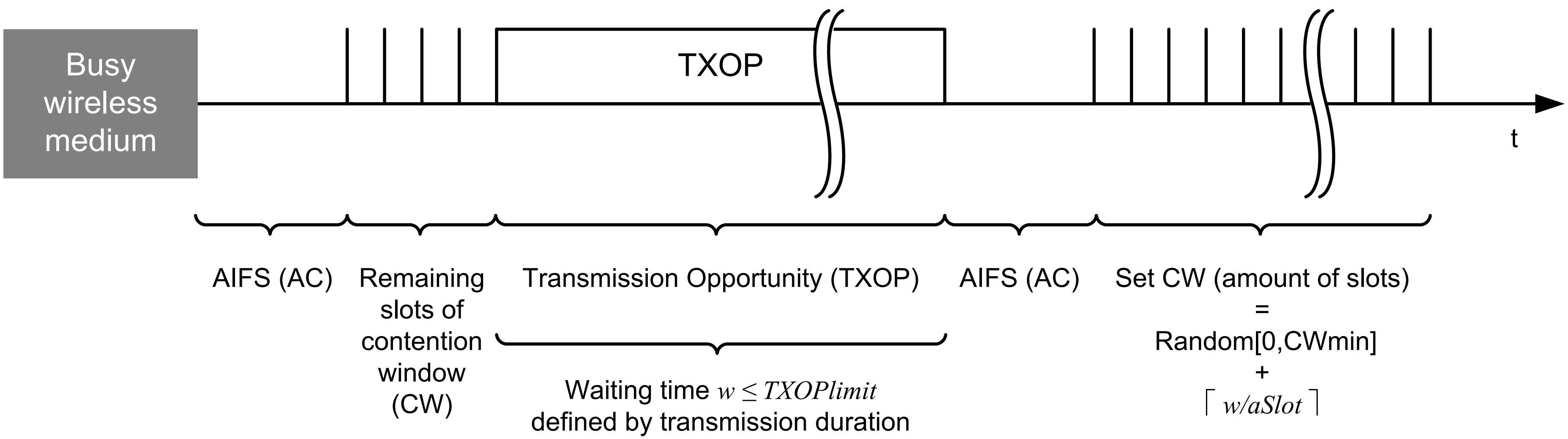
- **Set AIFS = w for next contention**
  - Sever penalty for transmitting MP
  - Wireless medium required to be idle for a period equal to the MP's last frame exchange sequence
    - May underutilize the wireless medium
    - May lead to starvation



Solution 2: Frame exchange duration dependent addition to the CW

Solution 2: Add ⌈*w/aSlot*⌉ to CW of next backoff

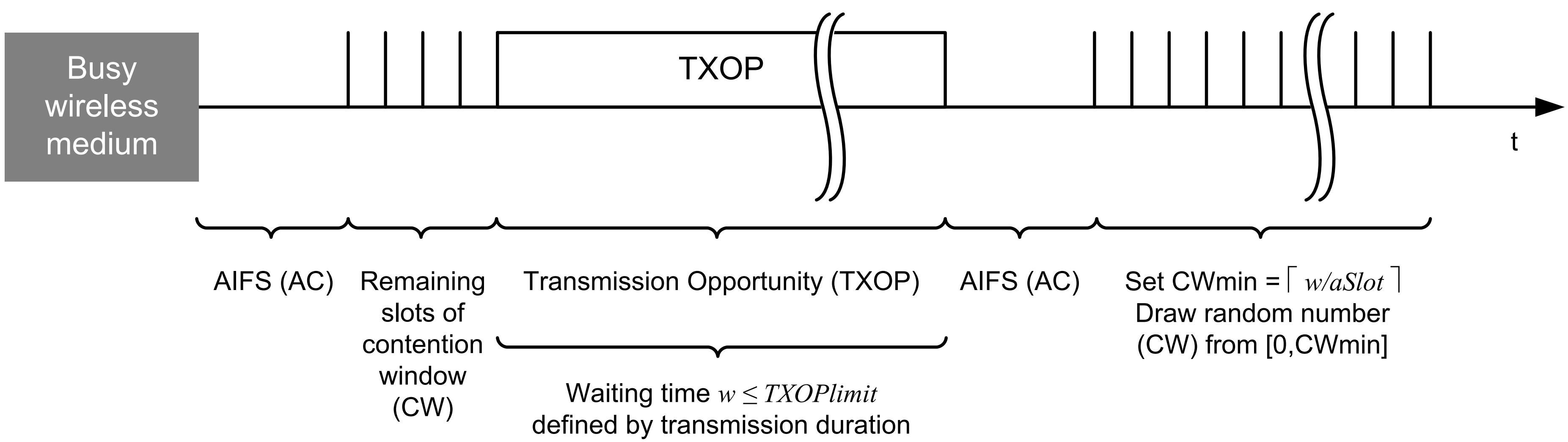
- **Random number of slots CW drawn from [*0, CWmin*] enlarged by ⌈*w/aSlot*⌉ for next contention**
  - CW may become very large
  - No uninterrupted idle wireless medium required as in solution 1



Solution 3: Frame exchange duration dependent CWmin setting

Solution 3: Modify CWmin of next backoff

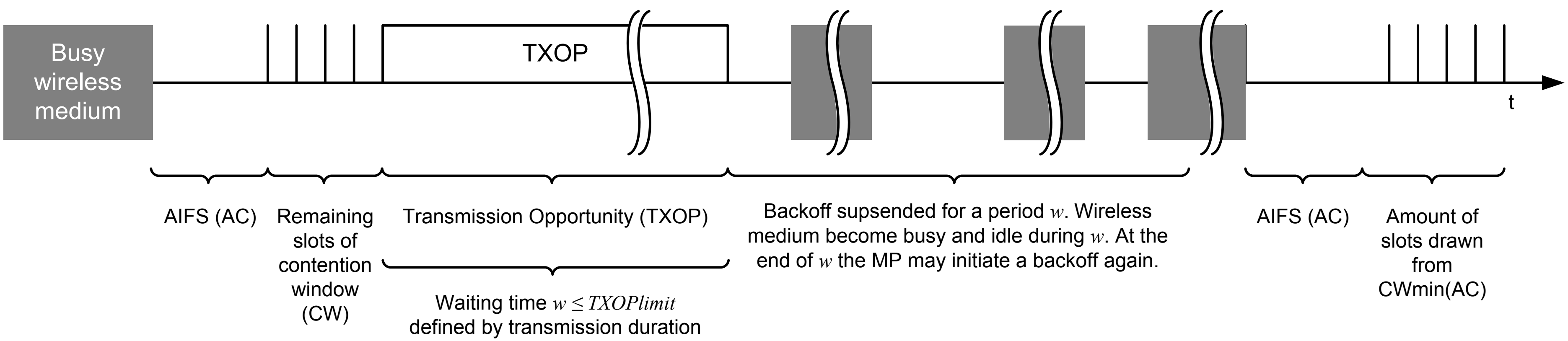
- **Set CWmin $= \lceil w/aSlot \rceil$ for next contention**
  - On average, the *CW* duration will be ~ *w/2*
  - Easy to implement
  - May not provide full self-throttling needed for sufficient forwarding capacity



Solution 4(a):
Frame exchange duration dependent backoff suspension

Solution 4(a): Suspend next backoff for a period *w*

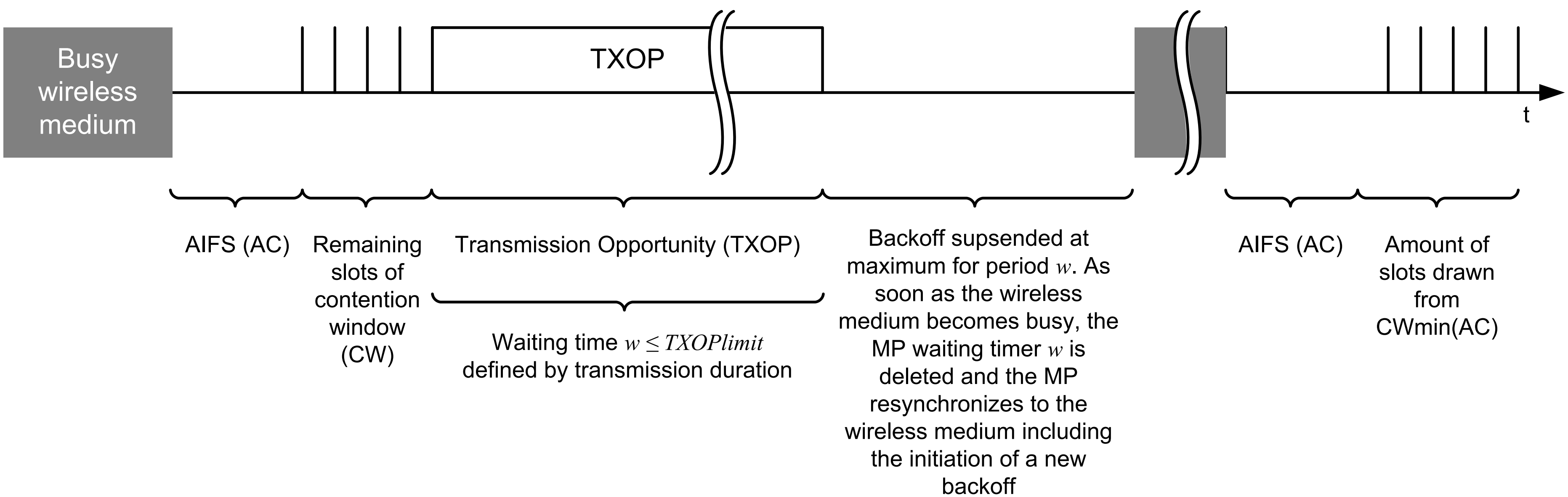
- **MP does not initiate a new backoff until a period w following its last TXOP has expired**
  - The forwarding MP may find the wireless medium idle and does not need to contend with the forwarding service requesting MP
  - Penalty seems to be acceptable



Solution 4(b): Frame exchange duration dependent backoff suspension with early resynchronization to the wireless medium busy/idle state

Solution 4(b): Suspend next backoff until wireless medium becomes busy

- **MP does not initiate a new backoff until a period *w* following its last TXOP has expired *or* until the wireless medium becomes busy and idle again**
  – MP provides access to the WM for a least one other MP
  – May not guarantee the priority needed for the forwarding MP



Recommendation

Recommended modification of EDCA

- **Solution 3 is easy to implement**
  - Frame exchange duration dependent CWmin setting
  - Requires to record the duration of the last frame exchange sequence/TXOP
  - In any case, the device performs a backoff and therefore draws a random number from *[0, CWmin]*
  - CWmin can be easily adopted
  - Mean penalty ≈ ½ * last frame exchange duration
- **Provides compromise between full penalization and purely opportunistic EDCA behavior**

References

- **[1] M. Benveniste, “Neighborhood Capture” in Wireless LANs, Submission IEEE 802.11-01/596, November 2001**

Backup slides

Remarks

- **Modifications possible**
  - Example: Set $CWmin = k * \lceil w/aSlot \rceil$ where k ∈]0;1]
    - Modifies penalty
- **May be adjustable or administrator/user configurable**
  - Needs default value set in standard
- **Shall all Access Categories (ACs) of an MP be penalized?**
  - Any medium access reduces the forwarders possibility to detect an idle wireless medium
    - From a resource sharing point of view, it does not matter which AC access the wireless medium