Wireless Networks for Mobile Applications

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Standard

Gruppi di standardizzazione IEEE 802.11	Descrizione
IEEE 802.11	lo standard originale: bitrate da 1 a 2 Mbps, spettro 2.4 Ghz, livello fisico sia radio che infrarosso
IEEE 802.11a	54 Mbit/s, 5 GHz, lanciato nel 2001
IEEE 802.11b	sviluppo di IEEE 802.11 (1999), da 5.5 a 11 Mbps
IEEE 802.11d	estensioni per roaming internazionale
IEEE 802.11e	estensioni per qualità del servizio
IEEE 802.11f	standard per Inter Access Point Protocol (IAPP[2])
IEEE 802.11g	54 Mbit/s, 2.4 GHz, retrocompatibile con IEEE 802.11b
IEEE 802.11h	selezione dinamica dei canali e controllo della potenza trasmissiva (compatibile con direttive europee)
IEEE 802.11i	integrazioni e estensioni per la sicurezza (2004)
IEEE 802.11j	estensioni per direttive giapponesi
IEEE 802.11k	estensioni per misurazione dei parametri radio
IEEE 802.11n	estensioni per throughput elevati (oltre 200 Mbps) mediante tecnologia MIMO (trasmettitori e ricevitori multipli)
IEEE 802.11p	accesso wireless per sistemi veicolari (WAVE)
IEEE 802.11r	estensioni per roaming veloce
IEEE 802.11s	estensioni per reti wireless mesh
IEEE 802.11t	metodi e metriche per misurazione e predizione delle prestazioni
IEEE 802.11u	internetworking con reti non 802.11 (cellulari)
IEEE 802.11v	gestione e amministrazione delle reti wireless

Recent Standards

- IEEE 802.11n (Wi-Fi 4 – new denomination by Wi-Fi Alliance)
- IEEE 802.11ac (Wi-Fi 5)
  - Expanded use of MIMO (up to 8) and wider band (160MHz) than 802.11n
  - Up to 500 Mbps for each single connection
- IEEE 802.11ax (Wi-Fi 6)
  - Frequency: between 1 and 7 GHz (and not only 2.4 and 5 GHz)
  - Up to 11 Gbps in test
  - Lower latency (less than half with respect to 802.11n)
  - Modified MIMO: UL MU-MIMO (uplink multiuser multiple-input multiple-output)
- IEEE 802.11be (Wi-Fi 7)
  - Frequency: 2.4, 5 and 6 GHz
  - Modified MIMO: CMU-MIMO (coordinated multiuser MIMO)
- IEEE 802.11mc
  - Indoor localization (1-2 m precision)
    - using Wi-Fi Round Trip Time (Wi-Fi RTT)

IEEE 802.11e, Introduction

- Originally IEEE 802.11 standard defined exchanges using:
  - DCF (Distributed Coordination Function)
  - PCF (Point Coordination Function)

- IEEE 802.11e introduced:
  - ***PRIORITY SCHEME***
    EDCA Enhanced DCF Channel Access
    (WMM Wi-Fi Multi Media)

  - ***PARAMETIZED QOS SCHEME***
    HCCA Hybrid Coordination Function Channel Access
    (WMM-SA Wi-Fi Multi Media Scheduled Access)

DCF

- DCF is the basic access method

- CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance
    - Look for activity, if free then wait (DIFS + contention) and transmit if still free
    - If busy, random back-off a number of Slots (min 31, max 1023)
    - Count down slots as long as Medium is not busy
    - When count down is zero, if packet fails (collision), back-off with increased random window, up to a preconfigured upper limit

802.11 Contention Window

- Random number selected from [0,cw]
- Small value for cw
  - Less wasted idle slots time
  - Large number of collisions with multiple senders (two or more stations reach zero at once)
- Optimal cw for known number of contenders & know packet size
  - Computed by minimizing expected time wastage (by both collisions and empty slots)
  - Tricky to implement because number of contenders is difficult to estimate and can be VERY dynamic

802.11 Adaptive Contention Window

- 802.11 adaptively sets cw
  - Starts with cw = 31
  - If no CTS or ACK then increase to 2*cw+1 (63, 127, 255)
  - Reset to 31 on successful transmission
- 802.11 adaptive scheme is unfair
  - Under contention, unlucky nodes will use larger cw than lucky nodes (due to straight reset after a success)
  - Lucky nodes may be able to transmit several packets while unlucky nodes are counting down for access
- 802.11 Adaptive Contention Window does not provide QoS

PCF

- PCF is a priority that is centrally controlled
    - PC (Point Coordinator), usually also the AP (Access Point)
- CP (Contention Period) and CFP (Contention Free Period)
  - After each Beacon
  - Uses PIFS to keep control (shorter than any DCF)
  - PC keeps list of stations eligible for polling

PCF

- PCF drawbacks:
  - Fixed to length of time after a Beacon, synchronized to Beacon intervals
    - Not compatible with voice or video streams requiring, say, 10, 20 or 30ms intervals
  - No mechanism to reserve BW or characterize the traffic
  - No back-to-back packets
  - *Note: PCF is not used in practice*

QoS Support Mechanisms of 802.11e :

EDCA :

- Introduction of 4 Access Categories (AC) with 8 Traffic Classes (TC)
- MSDU (Max Service Data Unit) are delivered through multiple back offs within one station using AC specific parameters.
- Each AC independently starts a back off after detecting the channel being idle for AIFS
- After waiting AIFS , each back off sets counter from number drawn from interval [1,CW+1]
- newCW [AC] >= ((oldCW[TC] + 1) * PF) - 1

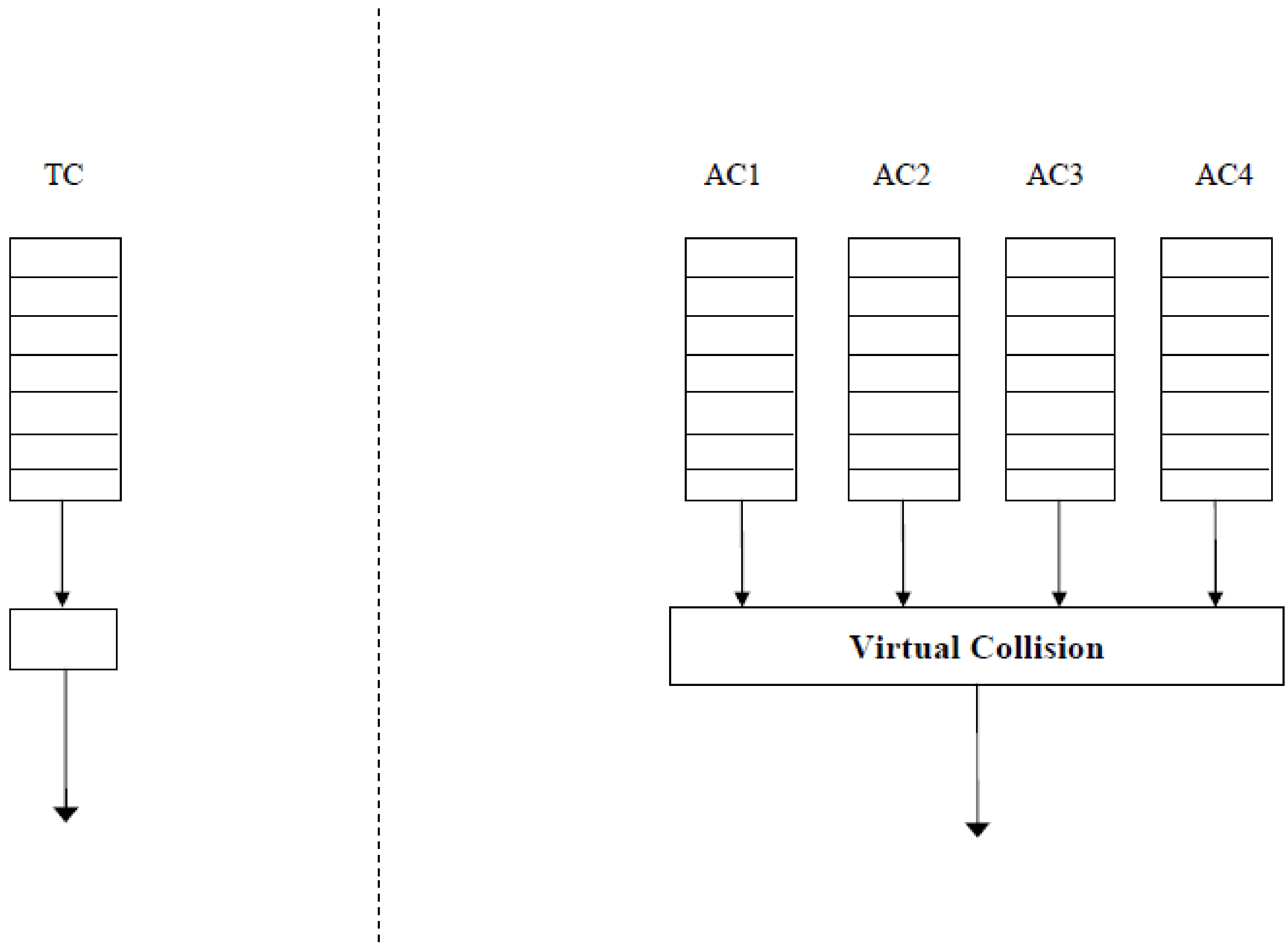
Backoff algorithm
see in next slides…

	AC_VO [0] (voice)	AC_VI [1] (video)	AC_BE [2] (best effort)	AC_BK [3] (background)
AIFSN	2	2	3	7
CWmin	3	7	15	15
CWmax	7	15	1023	1023

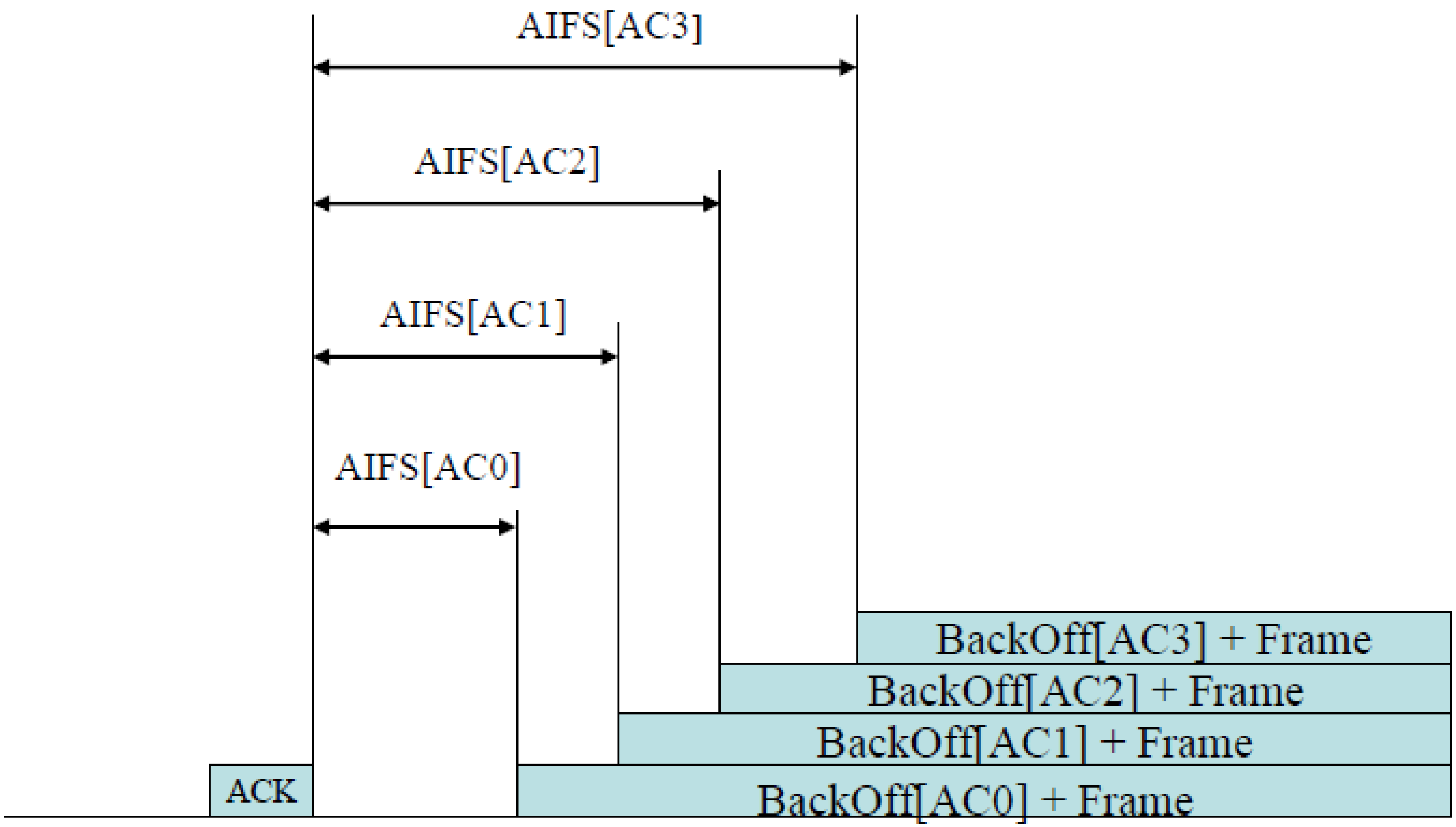
Prioritized Channel Access is realized with the QoS parameters per TC, which include :

- AIFS[AC] (Arbitration Inter-frame Space)
- CWmin[AC]
- PF[AC] (Persistence Factor)

EDCA



Access Category based Back-offs



EDCA – Priority Scheme

EDCA is effectively DCF with 4 priorities.

User Priority 802.1D	Access Class	Designation
1 & 2	AC0	Background
0 & 3	AC1	Best Effort
4 & 5	AC2	Video
6 & 7	AC3	Voice

Highest Priority

Bursting is possible: AC2 (AC_VI) TXOP limit 3ms

AC3 (AC_VO) TXOP limit 1.5ms

By setting different min and max back-off slots, one stream has an advantage over another. These max & min back-offs are configurable through the management interface, but choosing the optimum values for every scenario is not obvious

EDCA Channel Access

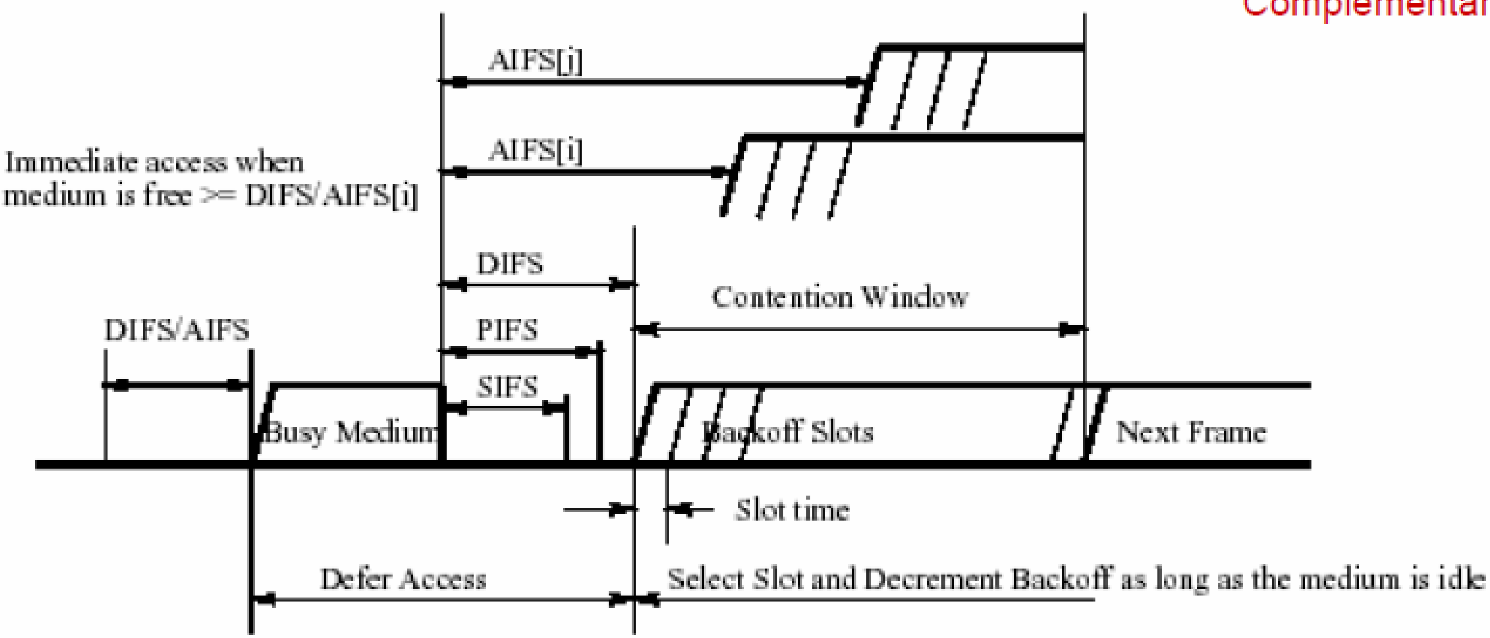
Slot Time = 9μs

SIFS Time = 16μs, .11a
= 10μs, .11g

Default Parameter Set

	CWmin		CWmax		AIFSN
	OFDM	CCK	OFDM	CCK	
AC_BK	15	31	1023		7
AC_BE	15	31	1023		3
AC_VI	7	15	15	31	2 or 1 (AP)
AC_VO	3	7	7	15	2 or 1 (AP)

Orthogonal Frequency-Division Multiplexing (OFDM)
Complementary Code Keying (CCK)



Example:

	AC[0]	AC[1]	AC[2]
AIFSN	2	4	7
CWmin	7	10	15
CWmax	7	31	255
PF	1	2	2

Example :

$$AIFS[AC] = AIFSN[AC] * aSlotTime + SIFS$$

PIFS - 25 µsec (*Used in HCCA*)
SIFS - 16 µsec
Slot Time - 9 µsec

AIFS[0] = (2 * 9) + 16 = 34 µsec = DIFS

AIFS[1] = (4 * 9) + 16 = 52 µsec → (52 – 34) / 9 = 18/9 = 2 Slots

AIFS[2] = (7 * 9) + 16 = 79 µsec → (79 – 34) / 9 = 45/9 = 5 Slots

Example :

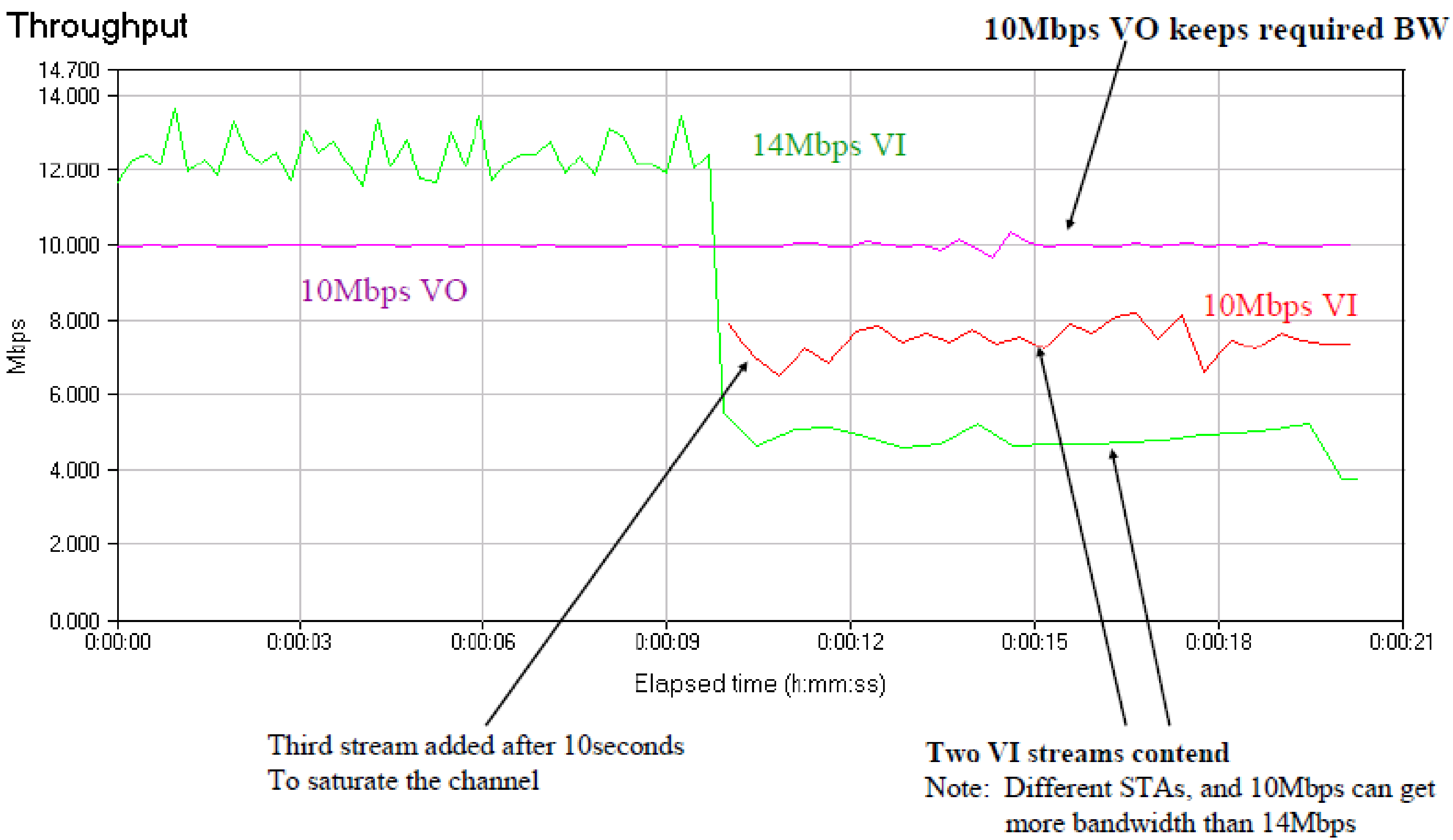
Back-off Algorithm :

802.11 : $CW_{RANGE} = [\ 0\ ,\ 2^{2+i} - 1\ ]$

802.11e : newCW[AC] = [(oldCW[AC] + 1) * PF] - 1

	Collision1	Collision2	Collision3
AC[0]	[(7+1)*1]-1 = 7 (0 - 7)	(0-7)	(0-7)
AC[1]	[(10+1)*2]-1 = 21 (0 - 21)	[(21+1)*2]-1 = 43 (0 – 31)	(0 – 31)
AC[2]	[(15+1)*2]-1 = 31 (0 – 31)	[(31+1)*2]-1 = 63 (0 – 63)	[(63+1)*2]-1 = 127 (0 – 127)

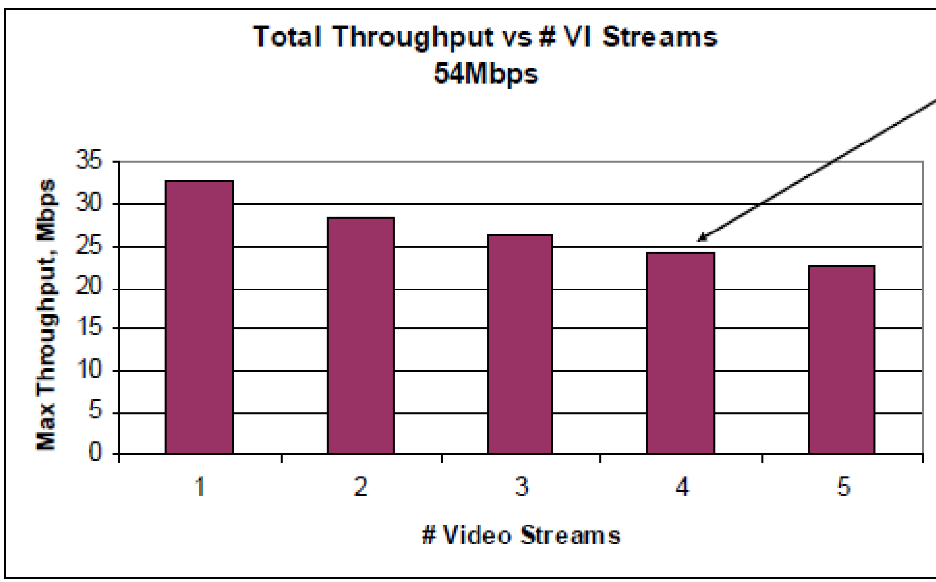
EDCA/WMM Test Example



EDCA Video – Capacity drops with # streams

As number of video streams increases, the contention also increases.

Theoretical maximum throughput on channel as number of video streams increases.



Four 6Mbps streams is theoretical maximum for a 54Mbps channel
In practice it will be lower than this

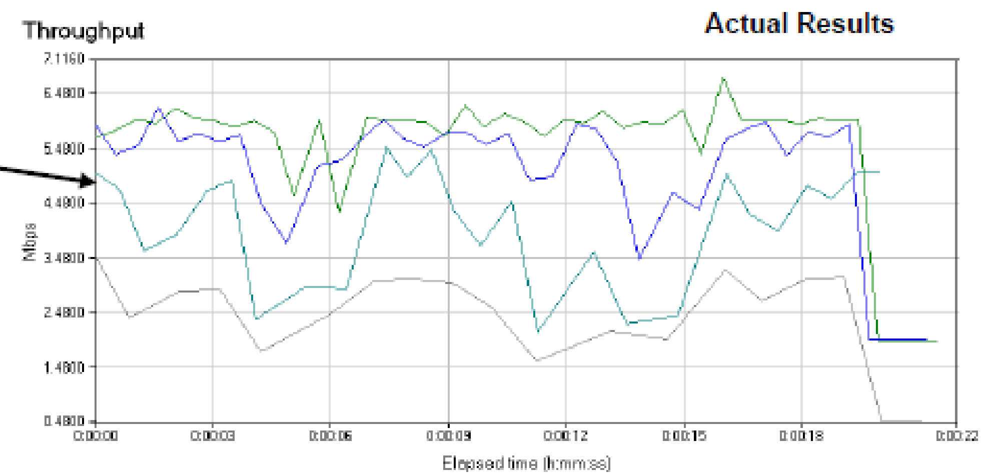
EDCA

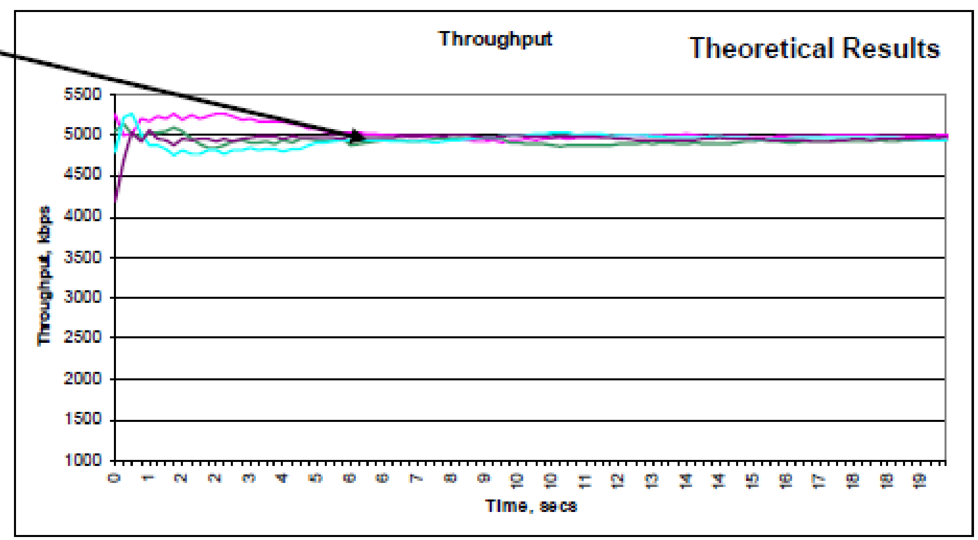
- Advantages of EDCA
  - Voice and Video streams have priority over data
  - Works well if network is lightly loaded, such as a Voice based network
  - No stream set-up instructions required
  - EDCA Power Save is big advantage over legacy power save
- BUT
  - Still based on “Fairness”, lower priority must still get through
  - Streams of the same Priority compete; not able to guarantee access, Latency, BW or Jitter
  - EDCA relies on every individual STA and the AP to control the priorities and access to the medium. Variations in QoS performance do occur in practice

Admission Control is used to overcome some of these disadvantages

EDCA – Over subscribed

- Four 6Mbps streams, EDCA AC_VI at 36Mbps
- ***Small variations in STAs result in throughputs that are not equal***
- Theoretical results show about 5Mbps for each STA (total ~20Mbps)





[1] STAs A and B were not set for bursting.

PROBLEMS IF CHANNEL IS OVER SUBSCRIBED

SOLUTION - ADMISSION CONTROL!!

Admission Control

- EDCA/WMM has no guarantees for QoS, but Admission Control can be used to improve situation:
  - Limit admission to an Access Category (VO and VI)
    - Limits the latency of QoS streams
    - Prevents too many streams such that bandwidth cannot handle them

Admission Control

- AP advertises ACM bit in Beacon to indicate if admission control is mandatory for any Access Category
- To use AC that has ACM bit set, STA sends AddTS (Add Traffic Specification) Request Action Frame to AP that includes a TSPEC
  - Nominal MSDU size
  - Mean Data Rate
  - Min PHY Rate
  - Surplus Bandwidth Allowance (SBA)
- AP runs the admission control algorithm and communicates back to the station the admission decision using AddTS Response Action frame
  - Medium Time
- STA checks “Used Time” over 1 second periods
  - If Used Time > Medium Time , STA must cease using that AC’s EDCA parameters

TSPEC Element

TSPEC Body format

Octets: 3	2	2	4	4	4	4	4	4
TS Info	Nominal MSDU	Maximum MSDU Size	Minimum Service Interval	Maximum Service Interval	Inactivity Interval	Suspension Interval	Service StartTime	Minimum Data Rate

RED indicates Used in Admission Control TSPEC

4	4	4	4	4	2	2
Mean Data Rate	Peak Data Rate	Maximum Burst Size	Delay Bound	Minimum PHY Rate	Surplus Bandwidth Allowance	Medium Time

Returned by AP for Admission Control

TS Info Field TSPEC Element

23 17	16	15 14	13 11	10	9	8	7	6 5	4 1	0
Reserved	Reserved (Schedule)	Reserved (TSInfo Ack Policy)	User Prority	PSB	Aggregtion	0	1	Direction	TID	Reserved

801.D User Priority

1=APSD

Access Policy EDCA, HCC

Up Down Bi

0-7 WMM 8-15 HCCA

Note: Often TID 0-7 = UP

Admission Control

- Improvement on EDCA/WMM in attempt to contain the higher priority streams and offer protection to streams already in progress
- TSPEC requires inputting of the basic parameters of the QoS stream
  - STA sends the TSPEC
- As streams still contend, bandwidth efficiency is not optimum

HCCA (WMM-SA) Parametized QoS

HCCA is extension of PCF, uses Contention Free Periods (CFP)

- Hybrid Controller (HC) can initiate HCCA, CFP:
  - Provides CF-Poll to station to provide TXOP
  - Specifies start time and maximum duration (hence other stations do not attempt to access the medium)
  - Station (STA) transmits within SIFS and then using PIFS periods
  - If no transmission after a PIFS, HC takes over and issues new TXOP or end of CFP.
  - CFPs can be synchronized to the individual source traffic intervals instead of the Beacon intervals

WMM-SA: Wireless MultiMedia – Scheduled Access

TXOP: Transmission Opportunity

HCCA (WMM-SA) Parametized QoS

In contrast to PCF, in which the interval between two beacon frames is divided into two periods of CFP and CP, the HCCA allows for CFPs being initiated at almost anytime during a CP.

- This kind of CFP is called a Controlled Access Phase (CAP)

A CAP is initiated by the AP, whenever it wants to send a frame to a station, or receive a frame from a station, in a contention free manner.

During a CAP, the Hybrid Coordinator (HC) , i.e., the AP, controls the access to the medium.

During the CP, all stations function in EDCA.

Another difference: the HC is not limited to per-station queuing and can provide a kind of per-session service.

- stream coordination in any fashion, not just round-robin.

TSPECs for HCCA (WMM-SA)

The QoS requirements such as jitter, latency, bandwidth etc are defined by the TSPEC

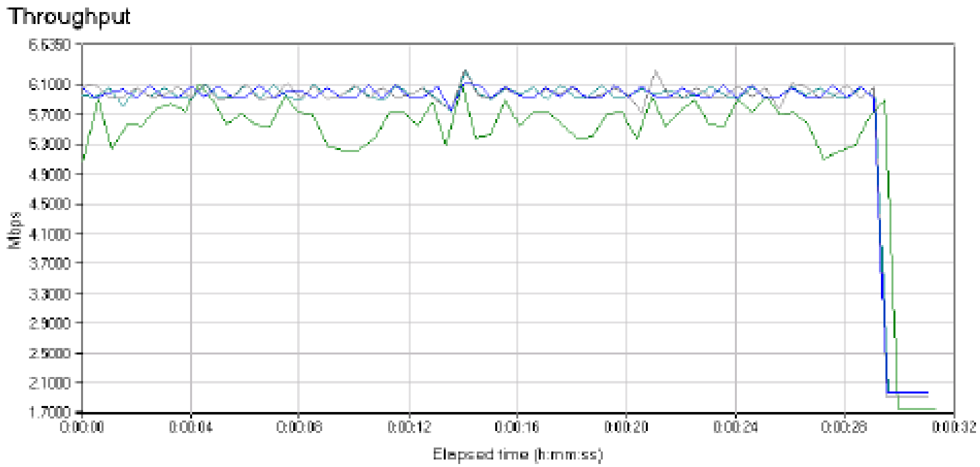
'Standard' TSPECs exist for:

- **Voice**
- **Multi-Media (Video)**
- **Audio**

TSPEC Parameters
Element ID
Length
TS Info
Nominal MSDU Size
Maximum MSDU Size
Minimum Service Interval
Maximum Service Interval
Inactivity Interval
Minimum Data Rate
Mean Data Rate
Maximum Burst Size
Minimum PHY Rate
Peak Data Rate
Delay Bound
Surplus Bandwidth Allowance

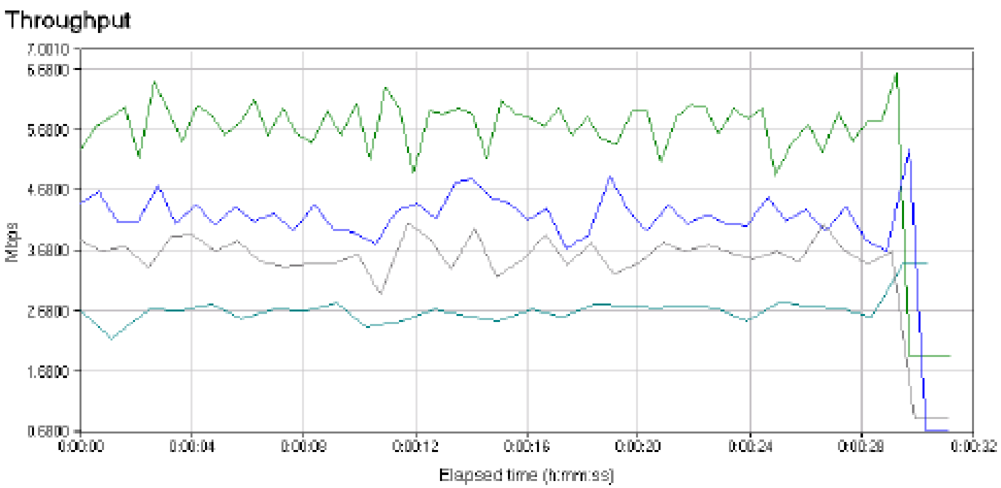
HCCA Efficiency - Measurement

As HCCA uses contention free periods to send the streams, the bandwidth efficiency is good. Examples below show that the practical difference.



WMM-SA
Four 6Mbps up-streams at 36Mbps
3 using WMM-SA

- **~24Mbps** throughput



WMM
Four 6Mbps up-streams on 4 different WMM certified devices. WMM AC_VI. STAs connected at 36Mbps

- **~16.5Mbps** throughput

HCCA - Summary

- Efficient use of Bandwidth
  - Contention free periods used
  - Returns channel as soon as packets sent for that TXOP
- “Guarantees” latency
  - Important in high bandwidth streaming applications
  - Regularly grants TXOPs as required by the TSPEC
- “Guarantees” Bandwidth
  - For quality video stream, for example, data rate must be assured
  - Very efficient use of available bandwidth, e.g. # of simultaneous voice calls is much higher than WMM allows (due to limited back-off slots)
- Overcomes most OBSS problems
  - All STAs and APs that hear the QoS Poll will obey the TXOP
  - ACKs from QSTAs should include Duration Field with outstanding TXOP time – extends range of CFP to other networks
  - Overlapping HCCA networks do have TXOP problems, this is being solved in 802.11aa

BUT

- Requires a complex Scheduler and added complexity

QoS Requirements

- 802.11 QoS can be considered as:
  - EDCA Admission Control
  - HCCA
- Both schemes require TSPECs
- TSPECs require knowledge of certain parameters of the desired QoS stream, at least:
  - Nominal MSDU size
  - Mean Data Rate

  For HCCA
  - Maximum Service Interval

IEEE 802.11n – High Throughput

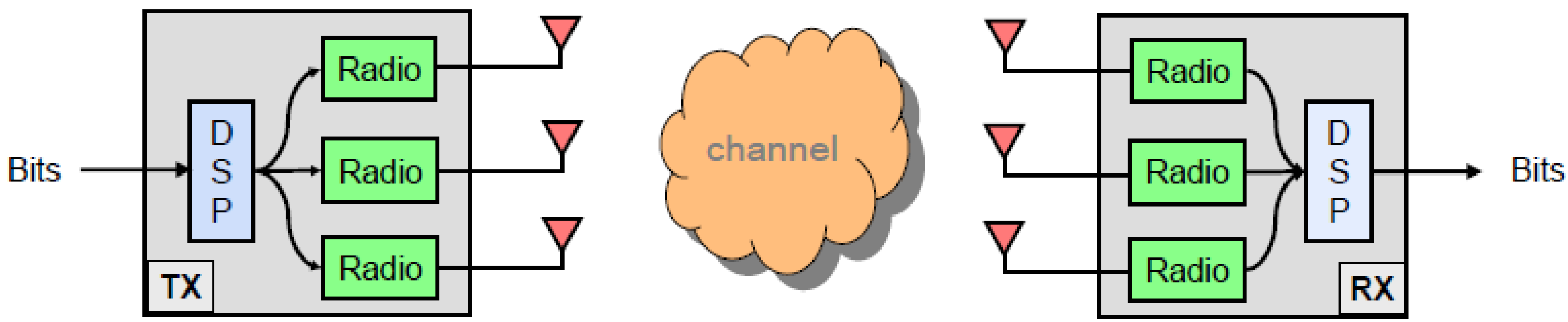
- Enabler of new consumer, enterprise applications
  - Video distribution, more bandwidth for QoS applications, greater range, throughput
- High Data rates (64-600Mbps)
  - A typical 2 transmitter MIMO device will support a 300Mbps data rate when using 40MHz channel
  - 144Mbps data rate when using 20MHz channel
- Legacy mode support
  - Support for Legacy a/b/g, e.g. 802.11n AP and a/b/g STAs
  - Support for Mixed Mode e.g. 802.11n AP and a/b/g/n STAs
  - Green Field 802.11n-only

New components in IEEE 802.11n

- **PHY Enhancements**, applicable to both 2.4GHz and 5GHz
  - The new PHY supports OFDM modulation with additional coding methods, preambles, multiple streams and beam-forming
  - Multiple Input Multiple Output (MIMO) Radio Technology With Spatial Multiplexing
  - High throughput PHY – 40 MHz channels – Two adjacent 20 MHz channels are combined to create a single 40 MHz channel.
- **MAC Enhancements**
  - Two MAC aggregation methods are supported to efficiently pack smaller packets into a single MPDU
  - Block Acknowledgement – A performance optimization in which an IEEE 802.11 ACK frame need not follow every unicast frame and combined acknowledgements may be sent at a later point in time.

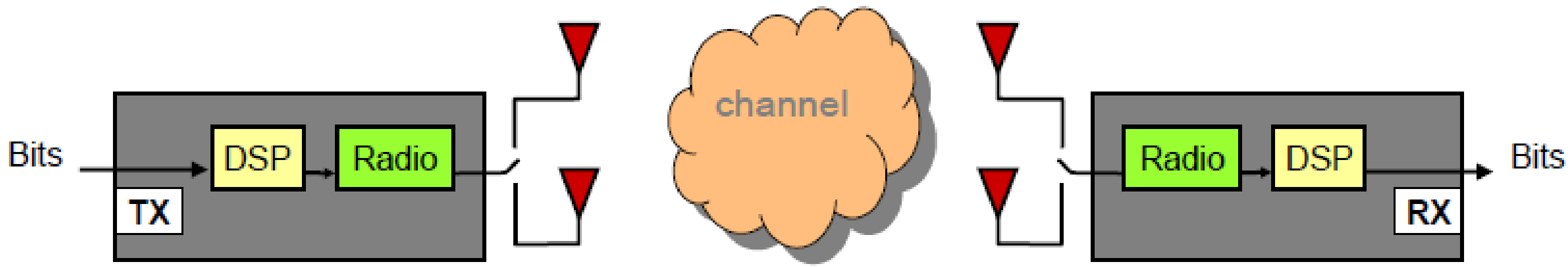
What is MIMO?

- Multiple Input Multiple Output (MIMO)
  - Transmit and Receive with multiple radios simultaneously in same spectrum



- Compare to traditional Single Input Single Output Radio (with optional receive diversity)

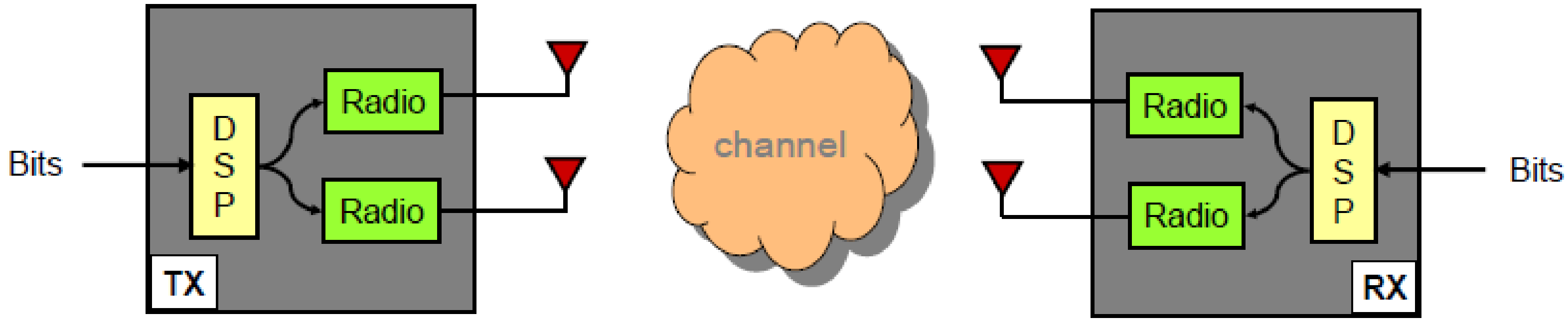
Conventional (SISO) Wireless Systems



Conventional "Single Input Single Output" (SISO) systems were favored for simplicity and low-cost but have some shortcomings:

- Outage occurs if antennas fall into null
  - Switching between different antennas can help
- Energy is wasted by sending in all directions
  - Can cause additional interference to others
- Sensitive to interference from all directions
- Output power limited by single power amplifier

MIMO Wireless Systems



Multiple Input Multiple Output (MIMO) systems with multiple parallel radios improve the following:

- Outages reduced by using information from multiple antennas
- Transmit power can be increased via multiple power amplifiers
- Higher throughputs possible
- Transmit and receive interference limited by some techniques