Module contents

- ★ **Overview**
- ★ Data-rate
- ★ Throughput
- ★ Response times
- ★ Capacity
- ★ Power consumption

Overview

Performance means different things depending on application and user interest:

- ★ *Data-rate* - Raw bit rate, comparison purposes, technology oriented
  - What is maximum speed that the technology allows?
- ★ *Throughput* - File transfer time, real-life practice, office automation
  - How long does it take to transfer files?
- ★ *Response times* - Transaction handling, includes more than just transfer time
  - how long does it take to complete a transaction?
- ★ *Capacity* - Sharing bandwidth among users
  - How many stations can coexist in one cell?
- ★ *Power consumption* - Battery operated equipment
  - How long will the battery last?

Overview

Performance expectations differ per application:

- ★ Transaction processing
  - ★ Require fast responses (same as wired LAN)
  - ★ Characterized by short message (impose low network load)
  - ★ Raw data-rate is of limited important (as long as network load stays low)
- ★ Office Automation
  - ★ response times less critical
  - ★ medium to high network load
  - ★ network capacity is key aspect to keep under control

Overview

Performance expectations differ per application:

- ★ Multimedia
  - ★ Require un-interrupted execution of multimedia files (movie clips)
  - ★ Characterized by large files
  - ★ Raw data-rate and capacity are critical (need to be maximized)
- ★ CAD/CAM
  - ★ Characterized by large files
  - ★ High network load
  - ★ Need for capacity is critical (need to be maximized)

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Data-rate

- Data-rate (or bit-rate) expressed in Mbit/s
- Relates to the data only (not the preamble)
- Determined by technology:
  - DBPSK - 1 Mbps
  - DQPSK - 2 Mbps
  - CCK - 5.5/11 Mbps
- MAC Management frames and multicast frames are xmitted at lower data-rate to be able to reach stations with different speed capabilities
  - Multi-cast traffic can be configured to high speed (in the AP), in combination with the cell-size (=distance between APs).

Data Rate
Auto fallback

Auto Rate Select

- ★ Start at highest possible data-rate (= 11 Mbps)
- ★ Fall-back to next lower data-rate
  - when 2 subsequent transmissions fail (ACKs missed)
- ★ Upgrade to next higher data-rate
  - after 10 successful transmissions (ACKs)
  - after 10 seconds
  - try next higher data-rate
    - if fails, go back to “Low”
    - if successful, go to normal rate
- ★ AP follows STA

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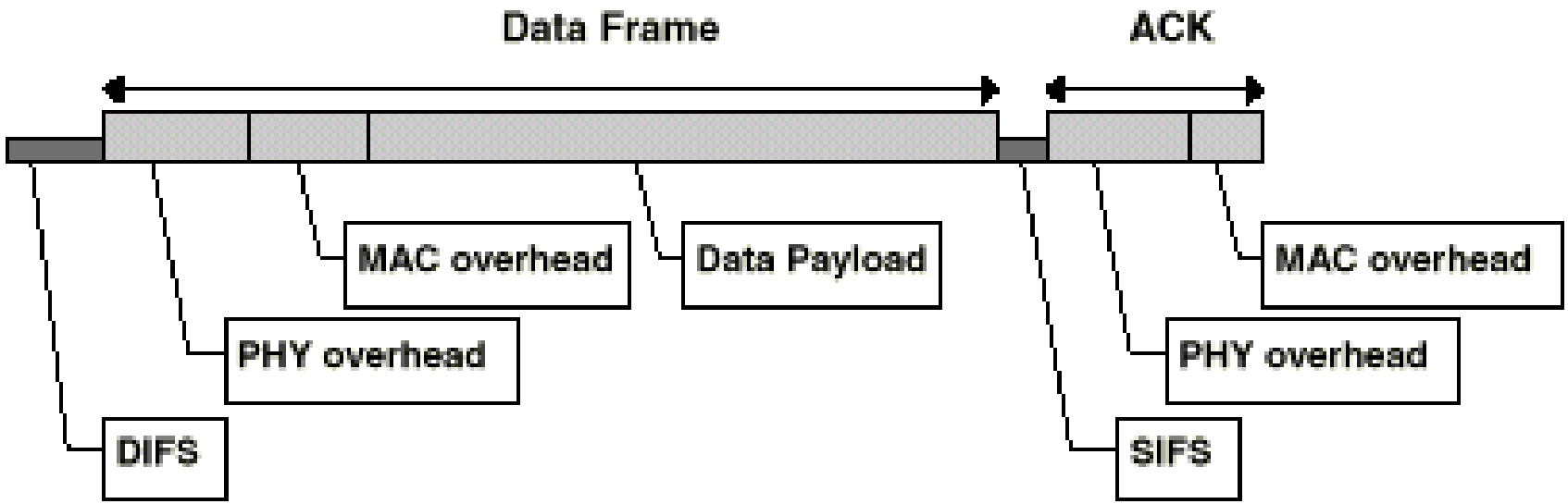
Throughput

- Typically expressed in Kbytes/sec
- Throughput lower than bit-rate due to
  - IEEE 802.11 Management & Control frames xmit at lower data rate
  - Contention window (required to avoid collisions)
  - Inter-frame spacing in the media
  - Sources of interference
  - Network Operating System overhead (protocol stacks)
  - Other users that share the media
- Throughput as perceived by users differ also due to
  - Path between station and access point (need for re-transmissions)
    - Distance
    - Environment (walls, sources of interference)
  - File size

Throughput

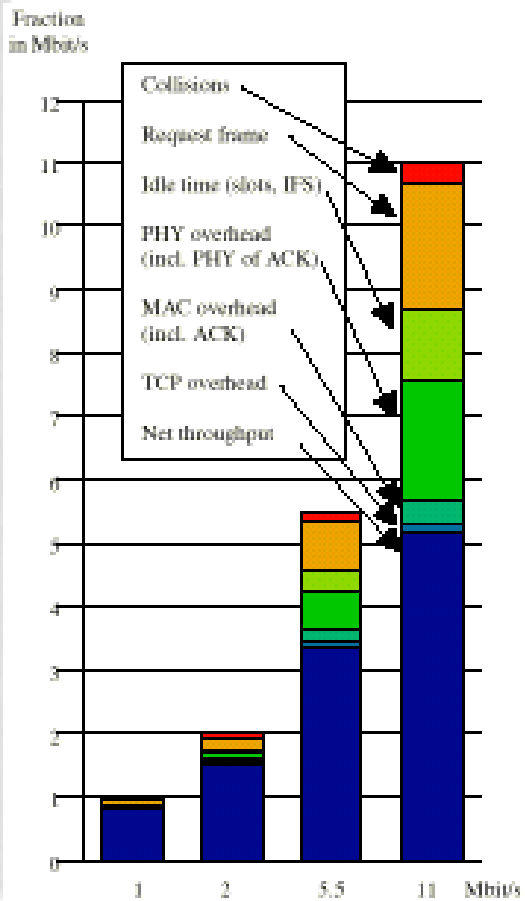
Impact of IEEE 802.11 MAC



802.11 frame structure

Throughput

Impact of IEEE 802.11 MAC



IEEE 802.11b, 802.11a AND 802.3 FRAME STRUCTURE AND OVERHEAD RELATED PARAMETERS

	802.11b	802.11a	802.3
Bit rates	1, 2, 5.5, 11 Mbit/s	6, 9, 12, 18, 24, 36, 48, 54 Mbit/s	10, 100 Mbit/s (1000 Mbit/s is not shown)
DIFS	50 µs	25 µs	IFS 9.6 µs, 0.96 µs
Slot time	20 µs	6 µs	51.2 µs , 5.12 µs
Preamble and PHY header	192 µs	10, 7, 6, 5, 4, 3, 3, 3 µs	6.4 µs, 0.64 µs
MAC overhead	34 byte	34 byte	18 byte
Payload data	46 – 1500 byte (0 – 2312 byte without 802.3 infrastructure)	46 – 1500 byte (0 – 2312 byte without 802.3 infrastructure)	46 – 1500 byte
Short IFS	10 µs	13 µs	N.A.
Preamble and PHY header	192 µs	10, 7, 6, 5, 4, 3, 3, 3 µs	N.A.
MAC overhead per ACK	14 byte	14 byte	N.A.

Throughput

Depends on configuration

	Data rate (Avaya Wireless 11 Mbps)			
	11 Mbps	5.5 Mbps	2 Mbps	1 Mbps
IBSS (station to station)	5.04	3.44	1.59	0.87
Single BSS (station to station via WP)	2.85			
ESS (wireless station to wired station)	4.66			

All values are in Mbps

Source: Testing at WCND using WhatsUpGold throughput test (packet size = 8192 Bytes)

★ Throughput in Single BSS lower than IBSS or ESS as result of intra-cell relay function (traffic travels twice through the medium, invoking defers as part of CSMA/CA)

Throughput

Depends on protocol stacks

Measurements using WLAN at 2 Mbit/sec

Protocol	Measured Throughput	
NETBEUI	180 Kbytes/sec	1.44 Mbit/sec
TCP/IP	144 Kbytes/sec	1.15 Mbit/sec
IPX/SPX	155 Kbytes/sec	1.24 Mbit/sec

Source: Testing at WCND

Throughput

Depends on number of stations in cell

Measurements using WLAN at 2 Mbit/sec

Number of stations	Measured Throughput	
2	177 Kbytes/sec	1.42 Mbit/sec
3	177 Kbytes/sec	1.42 Mbit/sec
4	167 Kbytes/sec	1.34 Mbit/sec
5	166 Kbytes/sec	1.33 Mbit/sec
6	160 Kbytes/sec	1.28 Mbit/sec
7	159 Kbytes/sec	1.27 Mbit/sec

Source: Testing at WCND
File size: 10 Kbytes
Protocol: IPX/SPX

AVAYA communication

Throughput

Depends on file size

Measurements using WLAN at 2 Mbit/sec

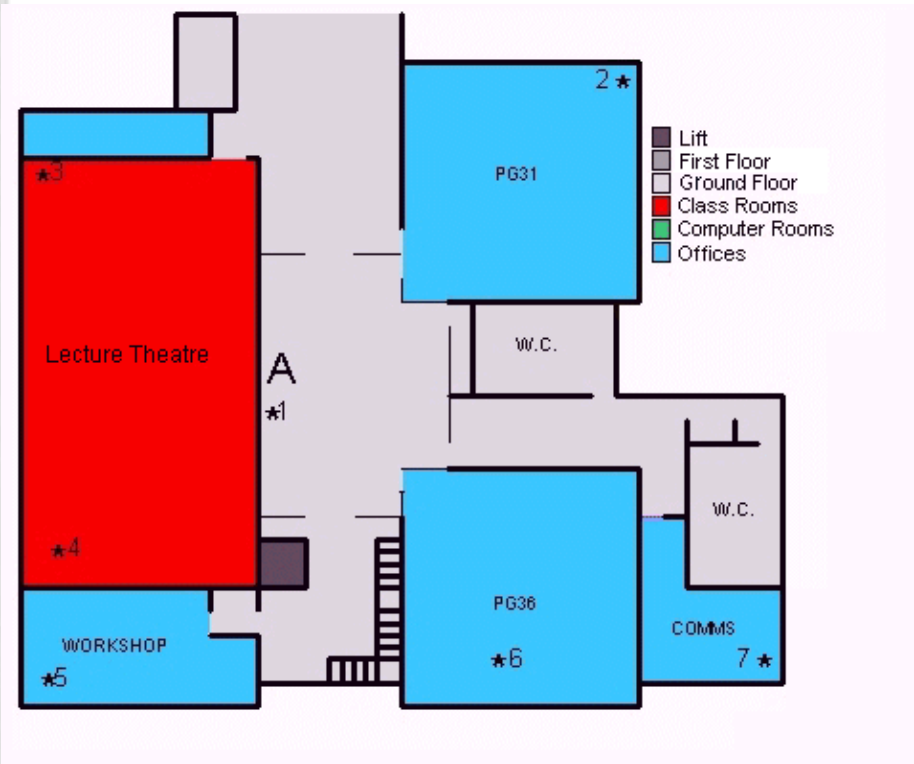
File size	Measured Throughput	
100 Kbytes	236 Kbytes/sec	1.88 Mbit/sec
500 Kbytes	184 Kbytes/sec	1.47 Mbit/sec
1 Mbytes	181 Kbytes/sec	1.44 Mbit/sec

Source: Canterbury Christ Church College
Number of stations: 1
Protocol: TCP/IP

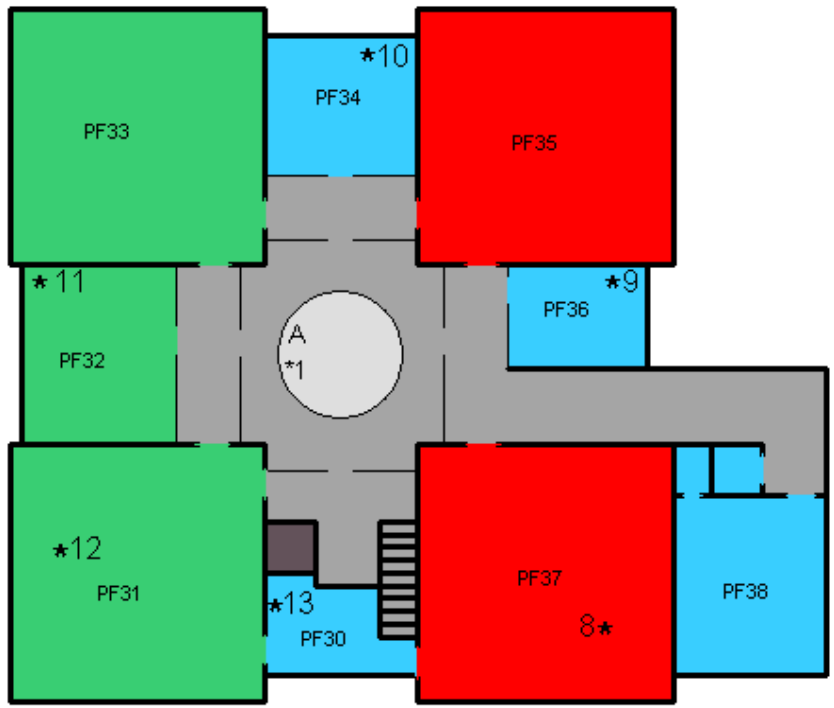
Throughput

Depends on path between station and AP

Ground floor



1st floor



Source: Canterbury Christ Church College

Throughput

Depends on path between station and AP

Measurements using WLAN at 2 Mbit/sec

Position	Measured Throughput	
1	206 Kbytes/sec	1.65 Mbit/sec
2	204 Kbytes/sec	1.63 Mbit/sec
3	200 Kbytes/sec	1.60 Mbit/sec
4	202 Kbytes/sec	1.62 Mbit/sec
5	202 Kbytes/sec	1.62 Mbit/sec
6	202 Kbytes/sec	1.62 Mbit/sec
7	200 Kbytes/sec	1.60 Mbit/sec
8	163 Kbytes/sec	1.30 Mbit/sec
9	182 Kbytes/sec	1.45 Mbit/sec
10	200 Kbytes/sec	1.60 Mbit/sec
11	201 Kbytes/sec	1.61 Mbit/sec
12	199 Kbytes/sec	1.59 Mbit/sec
13	200 Kbytes/sec	1.60 Mbit/sec

Source: Canterbury Christ Church College
Number of stations: 1
File size(s): 100 Kbytes, 500 Kbytes, 1 Mbytes (measurements are averages)
Protocol: TCP/IP

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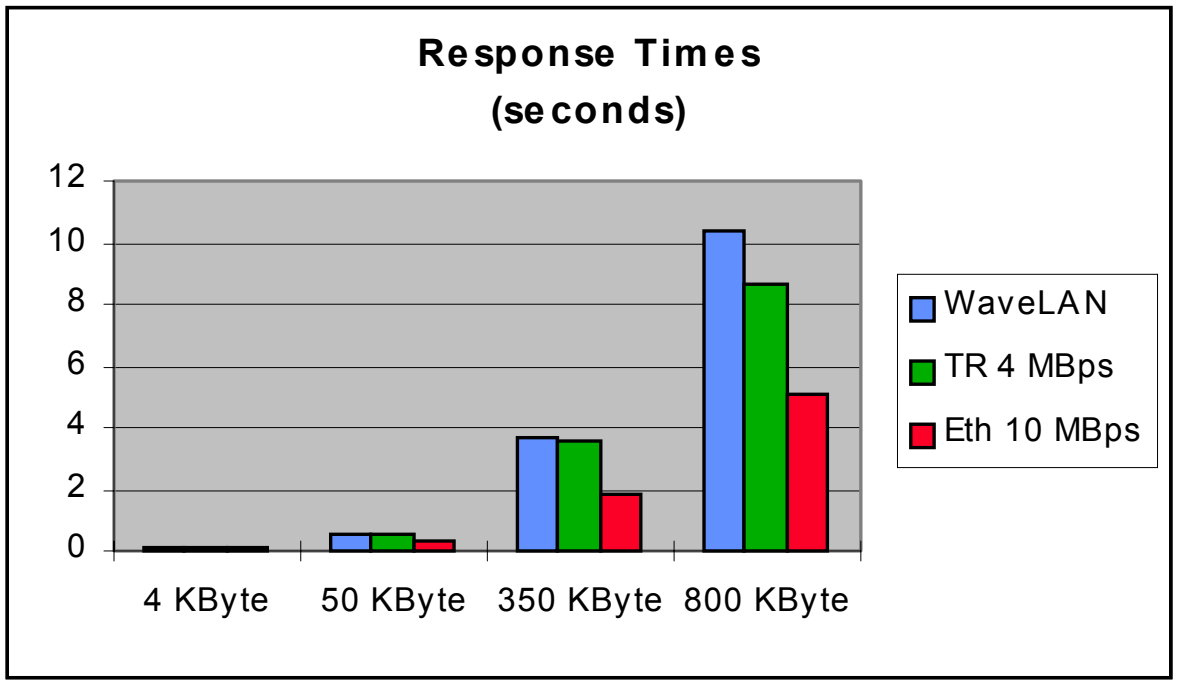
Response times

- ★ Typically expressed in seconds
- ★ Key aspect in transaction processing
- ★ Network load is small (short messages)
- ★ Depends less on factors that determine throughput
  - ★ Network Operating System overhead (protocol stacks)
  - ★ Other users that share the media
  - ★ Inter-frame spacing in the media
  - ★ path between station and access point (need for re-transmissions)
- ★ But more on server application
  - ★ Time it takes to turn around of the transaction-request

Response times



	4 Kbytes	50 Kbytes	350 Kbytes	800 Kbytes
WaveLAN	0.14	0.53	3.70	10.4
Token Ring	0.14	0.54	3.60	8.60
Ethernet	0.11	0.30	1.80	5.11

AVAYA communication

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Capacity

Number of stations per “radio-cell” depends on

- ★ Bandwidth requirements per station
  - ★ user profile
- ★ Available bandwidth per cell
  - ★ net capacity per cell depending on protocol and path : 1.1 - 1.8 Mbit/sec (for a 2 Mbit/sec data rate)
  - ★ maximum data-rate (11 Mbit/sec maximum)
- ★ Dimension (coverage) of the cell
- ★ Number of co-located cells
  - ★ can be increased by using additional channels

Capacity

Bandwidth requirements

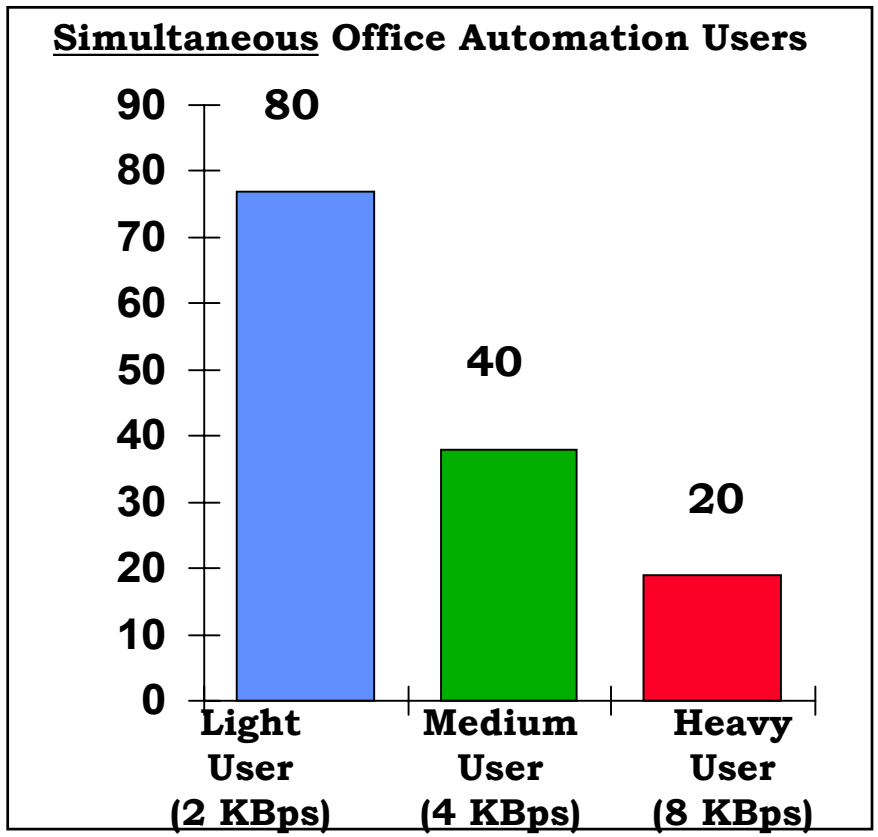
Differ per application:

- ★ Transaction processing
  - ★ < 8 Kbit/sec
- ★ Office Automation
  - ★ < 64 Kbit/sec (depending on user profile)
- ★ Multimedia
  - ★ 100-800 Kbit/sec
- ★ CAD/CAM
  - ★ >1.5 Mbit/sec

Capacity

Office automation user profiles

- ★ Single cell
- ★ Raw cell capacity : 2 Mbit/sec
- ★ User profiles:
  - ★ Light user
    - 16 Kbit/sec
  - ★ Medium user
    - 32 Kbit/sec
  - ★ Heavy user
    - 64 Kbit/sec



Capacity

Dimension of the cell

- ★ Cell size scaling
- ★ Changes carrier detect and defer thresholds
  - ★ Carrier Detect threshold - indication for station to accept/reject signal
  - ★ Defer threshold - indication to station to defer for transmission from other station in the cell
- ★ Expressed in terms of “Distance between APs”
  - ★ Large
  - ★ Medium
  - ★ Small
- ★ Cell size to match application:
  - ★ small cell for high band width high capacity
  - ★ Large cell for low bandwidth low capacity

Capacity

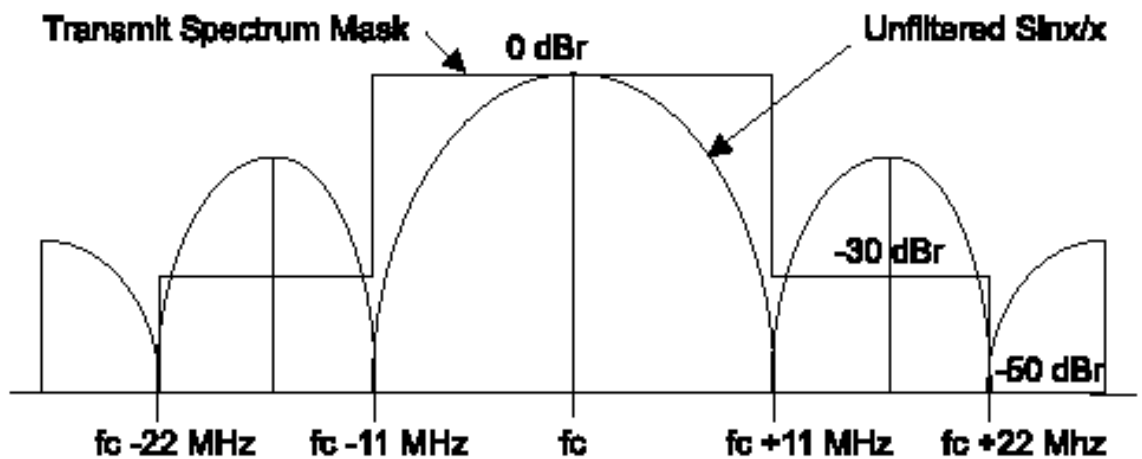
Dimension of the cell

	"Distance between AP" parameter setting		
	Small	**Medium**	**Large**
Cell diameter (open office)	~ 60 meter	~ 90 meter	> 100 meter
Carrier detect threshold	- 85 dBm	- 90 dBm	- 95 dBm
Defer threshold	- 75 dBm	- 85 dBm	- 95 dBm
Cost impact	Highest	Less	Lowest

Capacity

Multi-channel networks

★ Avaya Wireless operates in 2.4 GHz ISM band 2400-2483.5 MHz, but requires a frequency band of app. 22 MHz



Capacity

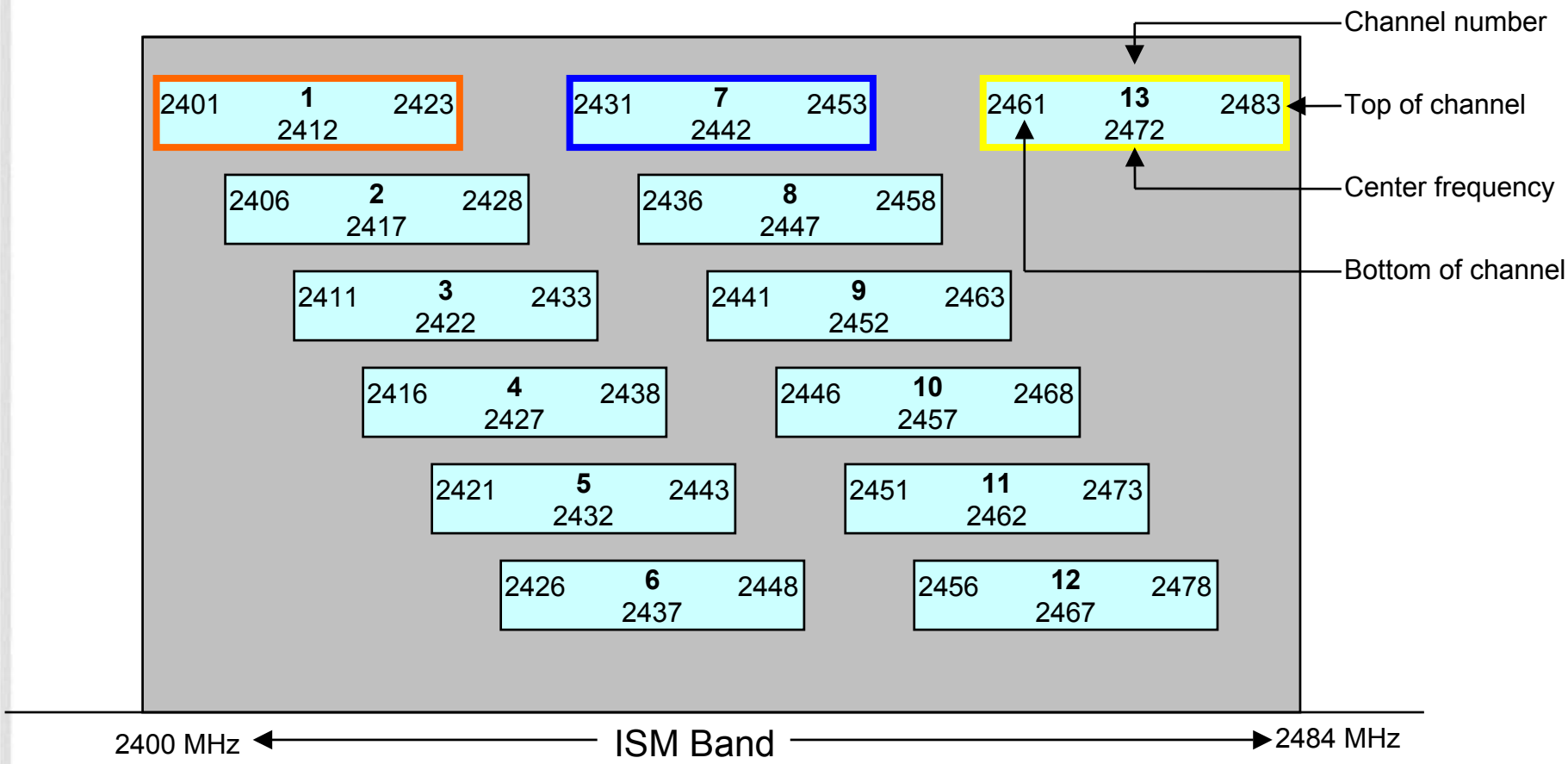
Multi-channel networks

Regulatory domain defines allowed channel set:

Channel ID	FCC (worldcard)	ETSI	France	Japan
1	2412	2412	-	2412
2	2417	2417	-	2417
3	2422	2422	-	2422
4	2427	2427	-	2427
5	2432	2432	-	2432
6	2437	2437	-	2437
7	2442	2442	-	2442
8	2447	2447	-	2447
9	2452	2452	-	2452
10	2457	2457	2457	2457
11	2462	2462	2462	2462
12	-	2467	2467	2467
13	-	2472	2472	2472
14	-	-	-	2484

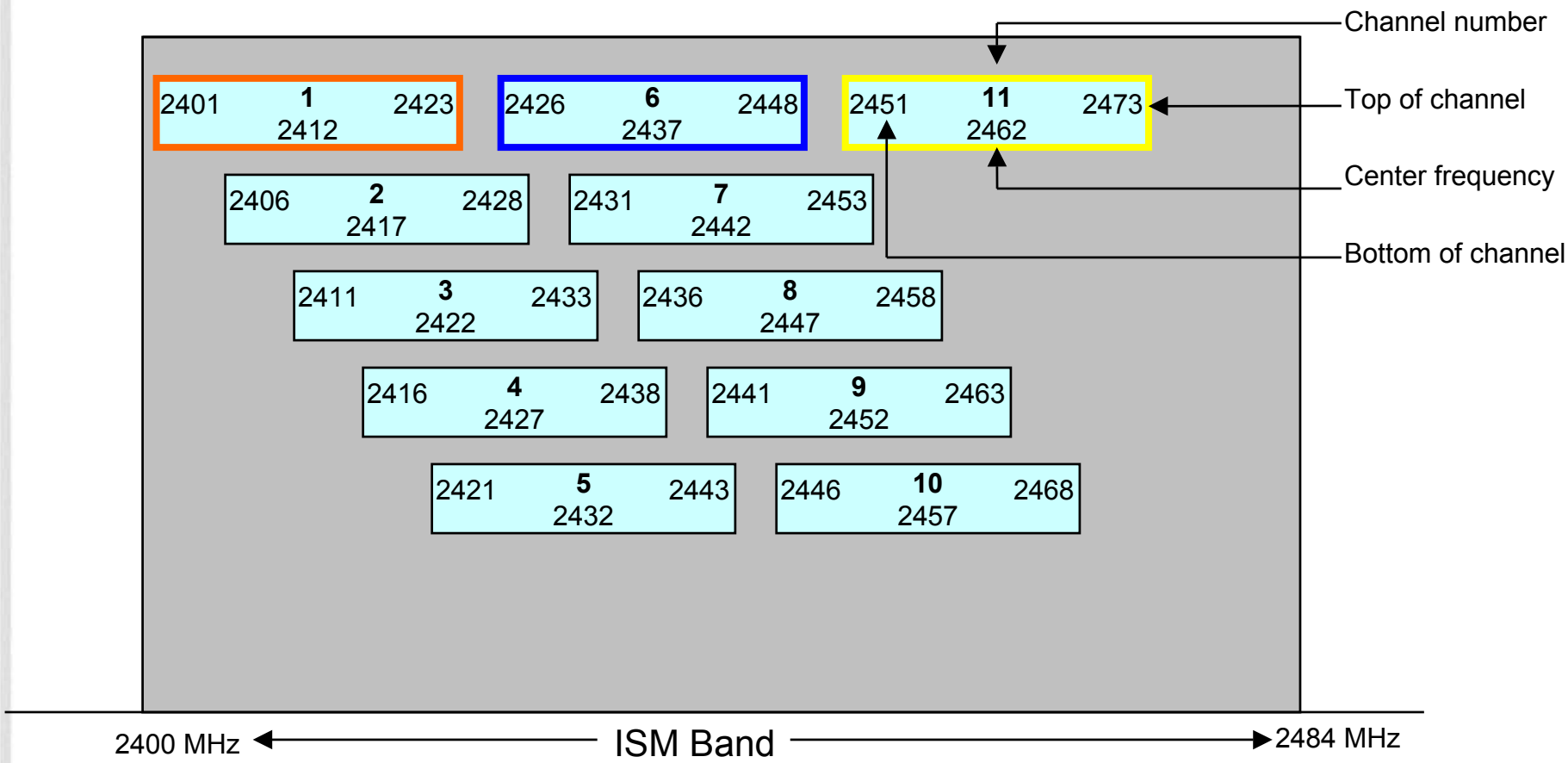
Capacity

Multi-channel networks - ETS



Capacity

Multi-channel networks - FCC (Worldcard)



Capacity

Multi-channel networks - where allowed ?

- Multiple channels within 2.4 GHz band, can be used based on regulatory domain
  - ETS (most of Europe, Australia, ..): 1 .. 3 channels
  - North America: 1 .. 3 channels
  - World: 1 .. 3 channels
  - Japan: 1 .. 3 channels
  - France: single channel

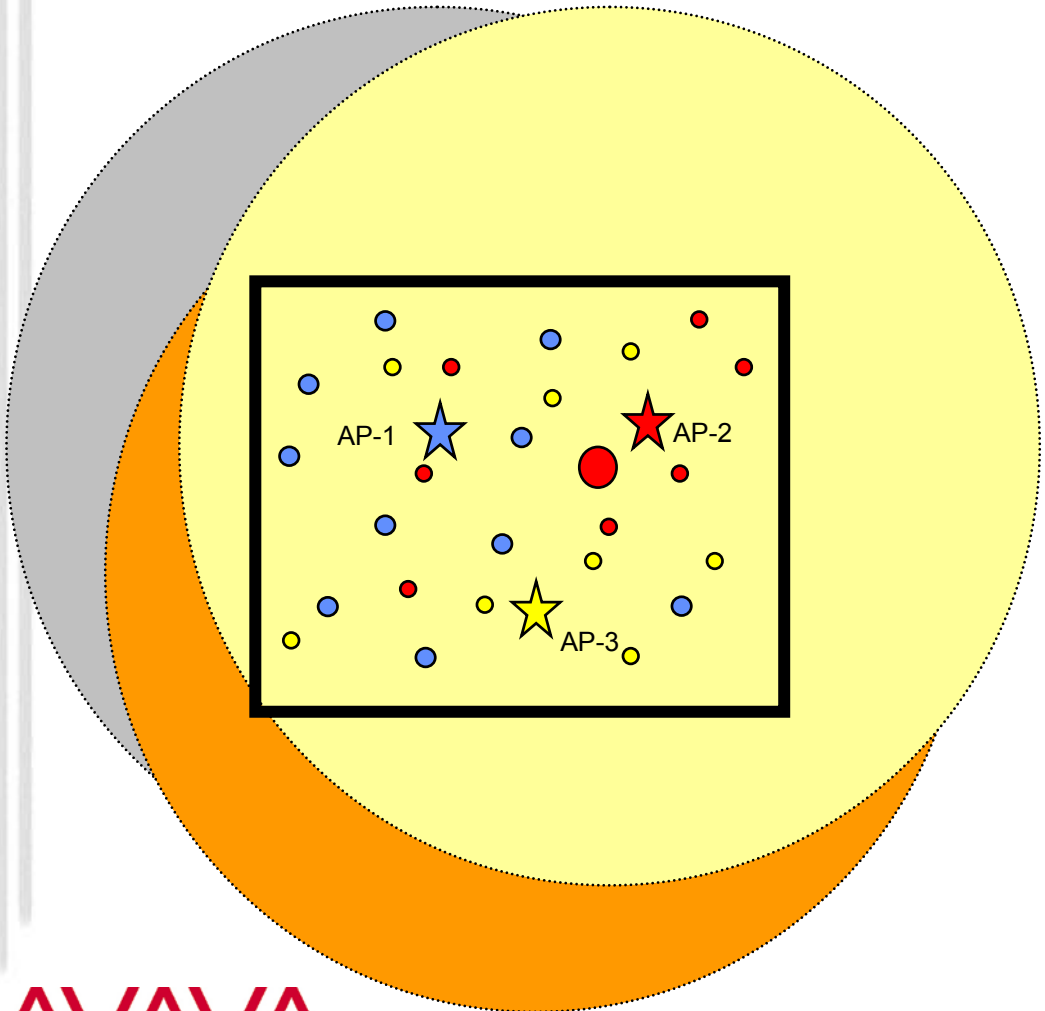
Capacity

Multi-channel networks

- Network Capacity can be increased by using different channels (by co-locating or stacking cells):
  - Multiple APs covering the same area but using different frequencies.
  - Can lead to capacity increase of factor 3-4 depending on proper AP placement, and allowable channels
- Warning:
  - Use multiple channels only when there is a need for additional capacity.
  - If extra capacity is not needed, select one channel for the complete network and choose the channel that has least interference

Capacity

Multi-channel networks



- Three APs (identified by a colored star) cover a rectangular area (e.g. Class room)
  - AP-1 set to channel 1
  - AP-2 set to channel 6
  - AP-3 set to channel 11
- 25 stations in the class room (represented by colored dots) associate to one of the APs

Performance impacting factors

Multi-channel networks - channel separation

- ★ Using two PC Cards in one AP-1000 requires:
  - ★ One PC Card to be connected to a range extender
  - ★ two channel systems (versus three channel systems shown earlier

ETSI Domain

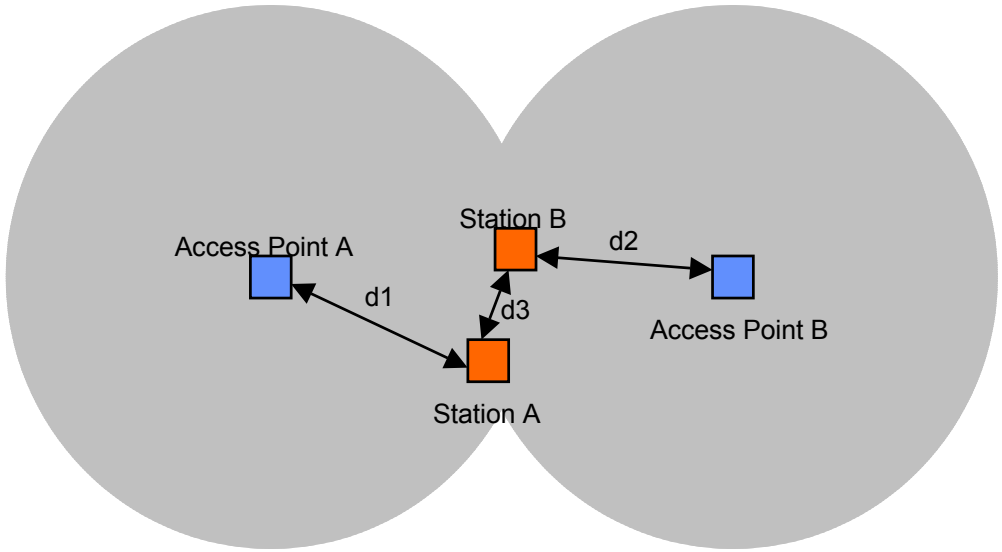
Adapter-1's Channel #	Adapter-2's Channel #												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1									✓	✓	✓	✓	✓
2										✓	✓	✓	✓
3											✓	✓	✓
4												✓	✓
5													✓
6													
7													
8													
9	✓												
10	✓	✓											
11	✓	✓	✓										
12	✓	✓	✓	✓									
13	✓	✓	✓	✓	✓								

Note: a ✓ symbol indicates a channel combination that can be used.

Capacity

Multi-channel networks - Near-far behavior

- ★ Impact of physically nearby station that operates in different channel
- ★ Seen as interference - no defer
- ★ Minimum distances need to be observed to allow good operation



Station-A's channel	Station-B's channel				
Channel 1	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
Distance d3	5-10 meter	1-4 meter	1-2.5 meter	1-2 meter	1-1.5 meter

d1 = d2 = 20 meter

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Power consumption

Power consumption can be reduced by Standard 802.11 Power Save Mode:

★ Improves battery life

★ Impacts throughput

★ Not recommended for all applications

Power consumption

How Power Management works

- Station under Power Management can be in two states:
  - Awake
  - Doze (sleep)
- Traffic to be transmitted to the station is buffered by the Access-Point, when station is in doze state
- Station wakes for (nth) Beacon and examines TIM (TIM = Traffic Indication Map), which is inside Beacon
- When traffic is present station polls the Access-Point for each buffered frame
- When station needs to transmit it wakes up for transmission, and goes back to sleep immediately

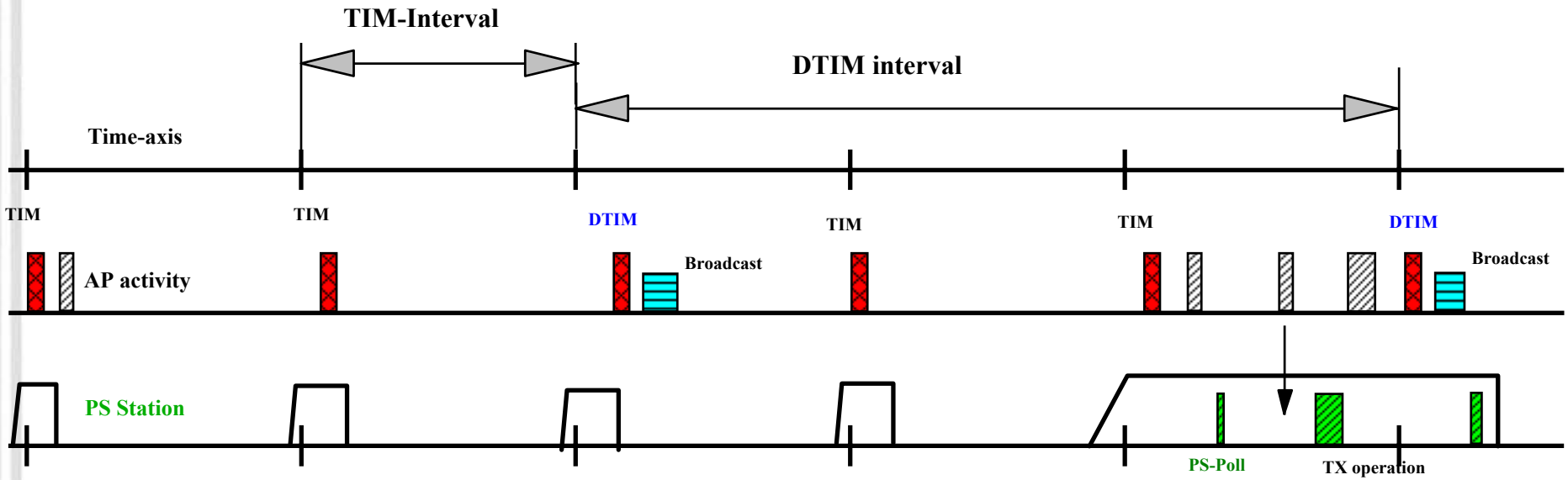
Power consumption

How Power Management works

- ★ Station can be configured to receive multi-cast messages
- ★ Access-Point will buffer multi-cast traffic and send it following a DTIM (=Delivery Traffic Information Message) inside the Beacon
- ★ DTIM interval can be configured at the Access-Point in terms of # of beacons between subsequent DTIM messages:
  - ★ e.g every nth beacon (where n is user configuration parameter)

Power consumption

How Power Management works



Power consumption

Impact of Power Management

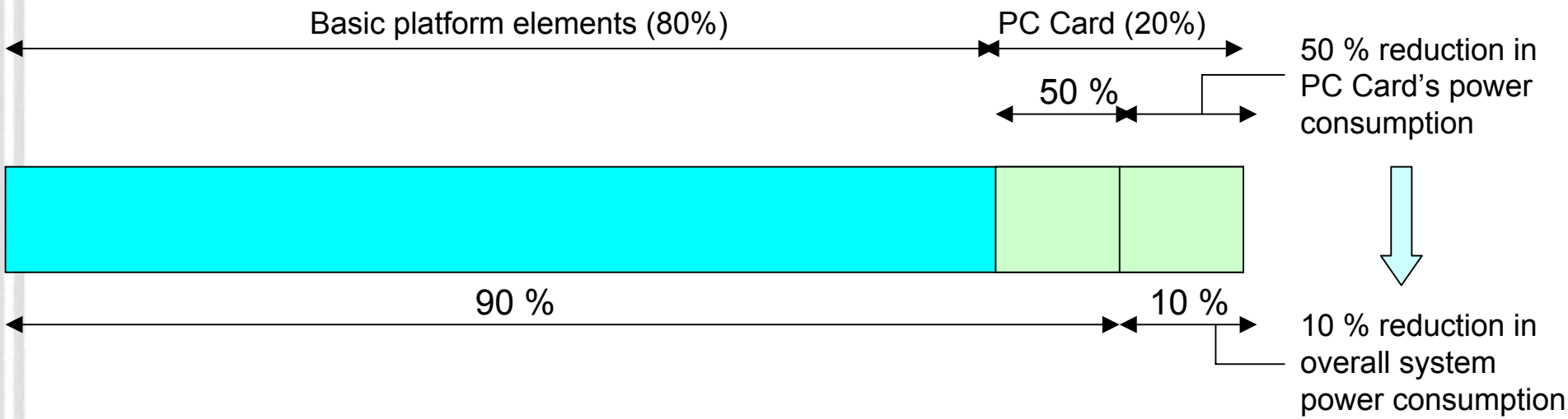
- ★ Improves battery life
- ★ Reduced amount of power consumed by the network card
  - ★ Overall battery life improvement more significant when network card's power consumption represent large portion of total
  - ★ Overall battery life improvement insignificant when platform station consumes substantial amount of power for non-network elements
- ★ Impacts throughput
  - ★ Transmission of large files will suffer from reduced performance
  - ★ Transaction oriented processing will not perceive performance impact

Power consumption

Impact of Power Management

★ Platform that consumes more power for other elements

- ★ Disk
- ★ Screen
- ★ Memory

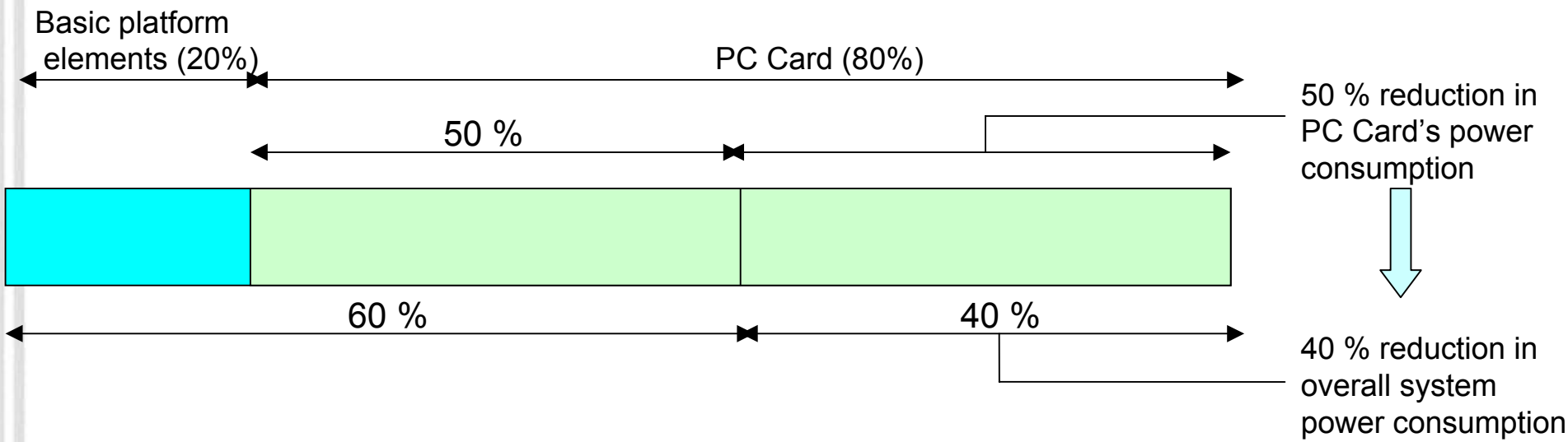


Power consumption

Impact of Power Management

★ Platform that is designed for low power

- ★ no back-light on screen
- ★ no rotating media
- ★ low power processor



Power consumption

Impact of Power Management

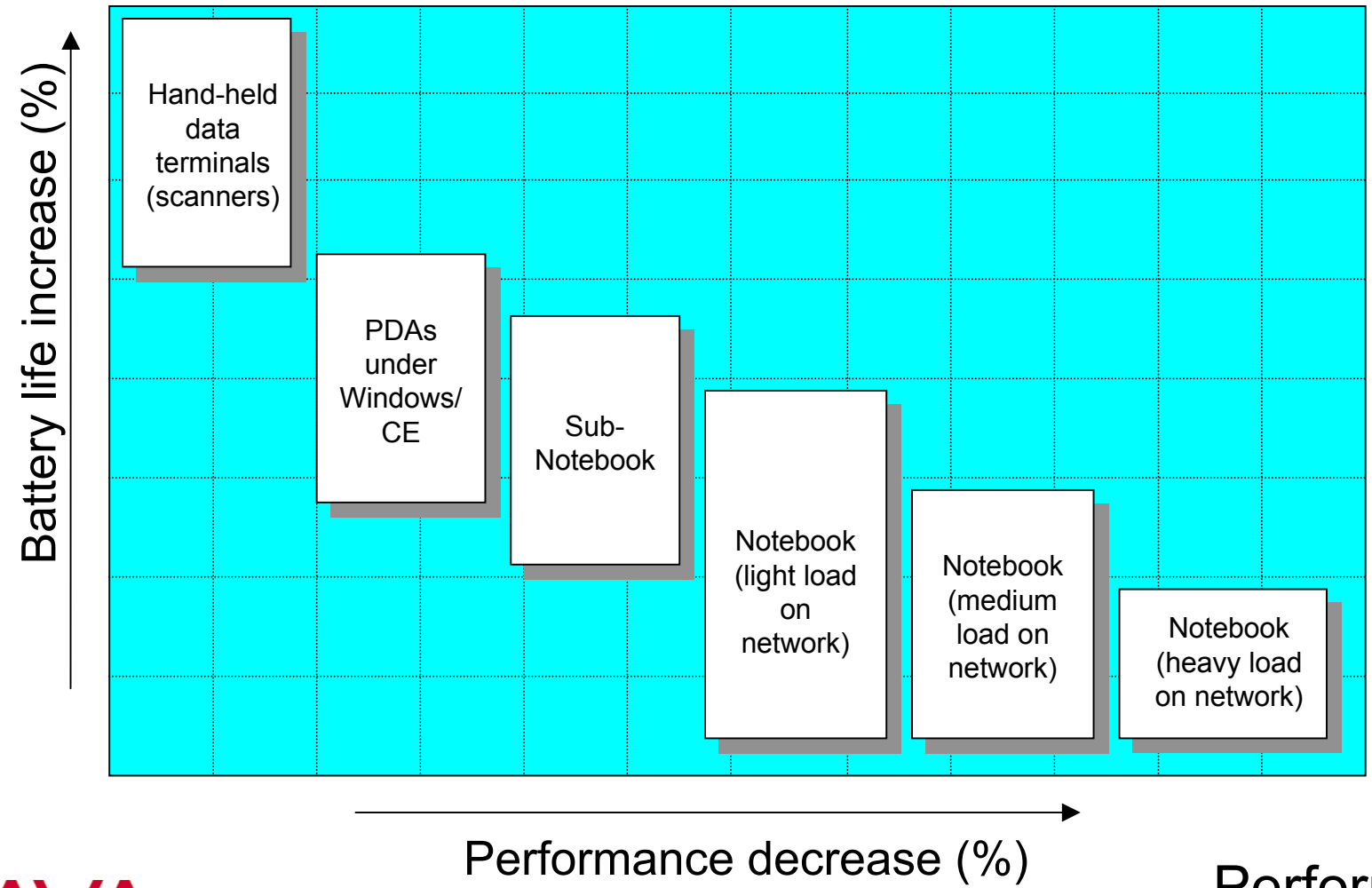
★ Throughput measurements on notebook computer

★ Large file (7.01 Mbytes) transmission)

	Network disk to Notebook	Notebook to network disk	Average Battery life
With Power Management	213 sec	422 sec	128 minutes
Without Power Management	62 sec	89 sec	102 minutes

Power consumption

Applicability of Power Management



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