UNIVERSITY OF EXETER

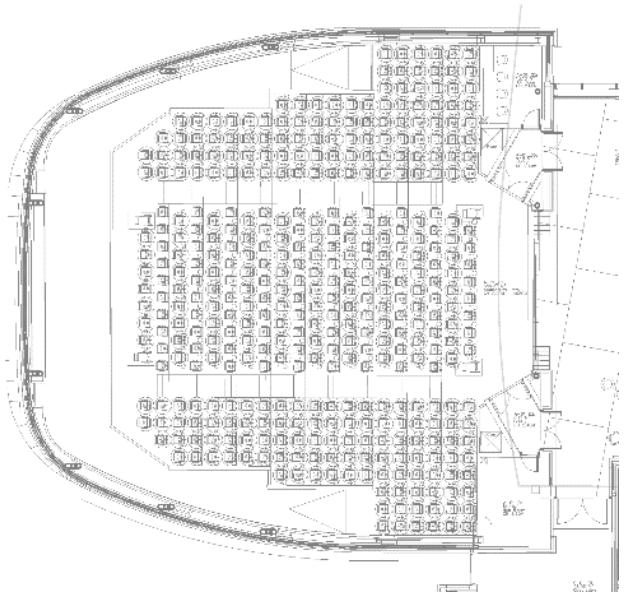
High Density WLAN design

Jon Foster, Networkshop 42, April 2014

What IS high density design?

An increasingly common sight…

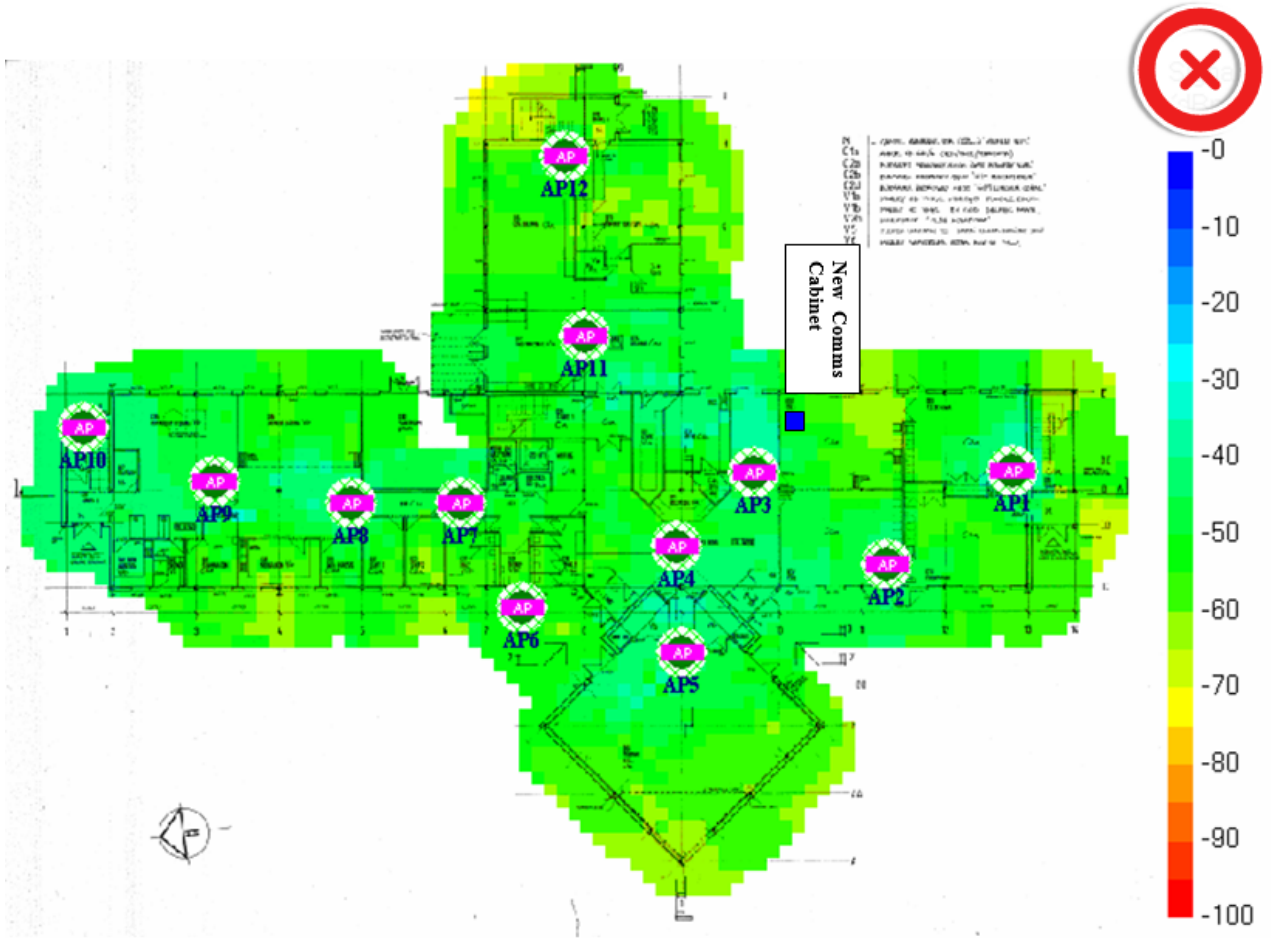
Even more high density!



What's the big deal?

Let's just ensure our map is coloured in *green*!

"…Just install another AP…"



Hopefully I can convince you that:-

- It's just a waste of money:-
- It'll make performance *worse* if we add more APs

Management Overheads… Probes…

Packet	Source	Destination	BSSID	Fl…	C…	Signal dBm	Dat…	Size	Abso…	Del…	Re…	8…	Protocol
1	Intel:48:60:70	Ethernet Broadcast	Ether…	Mx	11	-34	1.0	74	15…		0…	…	802.11 Probe Req
2	ArubaNetwo:7C:06:00	Intel:48:60:70	Aruba…	MP	11	-67	6.0	193	15…	0…	0…	…	802.11 Probe Rsp
3	ArubaNetwo:96:B6:A0	Intel:48:60:70	Aruba…	MP	11	-46	6.0	193	15…	0…	0…	…	802.11 Probe Rsp
4	ArubaNetwo:7C:06:01	Intel:48:60:70	Aruba…	MPx	11	-68	6.0	172	15…	0…	0…	…	802.11 Probe Rsp
5	ArubaNetwo:96:B6:A1	Intel:48:60:70	Aruba…	MP	11	-46	6.0	172	15…	0…	0…	…	802.11 Probe Rsp
6	ArubaNetwo:96:EB:01	Intel:48:60:70	Aruba…	MP	11	-75	6.0	172	15…	0…	0…	…	802.11 Probe Rsp
7	ArubaNetwo:96:B6:A2	Intel:48:60:70	Aruba…	M	11	-47	.0	148	15…	0…	0…	…	802.11 Probe Rsp
8	ArubaNetwo:96:EB:02	Intel:48:60:70	Aruba…	M	11	-75	6.0	148	15…	0…	0…	…	802.11 Probe Rsp
9	ArubaNetwo:7C:06:02	Intel:48:60:70	Aruba…	M	11	-6	6.0	148	15…	0…	0…	…	802.11 Probe Rsp
10	ArubaNetwo:96:EB:00	Intel:48:60:70	Aruba…	MPx	11		6.0	193	15…	0…	0…	…	802.11 Probe Rsp
11	ArubaNetwo:96:EB:01	Intel:48:60:70	Aruba…	MP	11	-73	6.0	172	15…	0…	0…	…	802.11 Probe Rsp
12	ArubaNetwo:96:EB:02	Intel:48:60:70	Aruba…	M	11	-74	6.0	148	15…	0…	0…	…	802.11 Probe Rsp
13	Intel:48:60:70	Ethernet Broadcast	Ether…	M	11	-77	1.0	74	15…	0…	0…	…	802.11 Probe Req
14	Intel:48:60:70	Ethernet Broadcast	Ether…	M	11	-30	1.0	74	15…	0…	0…	…	802.11 Probe Req

Example Management Overhead – Probing

… And Beacons!

Packet	Source	Destination	BSSID	Fl...	..	Si...	No...	Data R...	Size	Absol...	Delta Time	Relative Time	8...	Protocol
12616	ArubaNetwo:96:EF:82	90:B...	Aruba...	M	6	-80	-88	6.0	70	09:...	0.000338	8.283423	...	802.11 Probe Rsp
12617	10.173.38.239	144....	Aruba...		6	-67	-83	54.0	76	09:...	0.000372	8.283795	T..	WBT Server
12618	*ArubaNetwo:96:FA:C2*	0C:8...		C	6	-76	-88	24.0	14	09:...	0.000034	8.283829	...	802.11 Ack
12619	ArubaNetwo:96:FD:C0	Ethe...	Aruba...	MP	6	-77	-88	6.0	130	09:...	0.020296	8.304125	...	802.11 Beacon
12620	ArubaNetwo:96:FD:C1	Ethe...	Aruba...	MP	6	-77	-87	6.0	109	09:...	0.000281	8.304406	...	802.11 Beacon
12621	ArubaNetwo:96:FD:C2	Ethe...	Aruba...	M	6	-77	-87	6.0	85	09:...	0.000034	8.304440	...	802.11 Beacon
12622	ArubaNetwo:97:2E:60	Ethe...	Aruba...	MP	6	-86	-90	6.0	208	09:...	0.006064	8.310504	...	802.11 Beacon
12623	ArubaNetwo:97:2E:61	Ethe...	Aruba...	MP	6	-85	-89	6.0	187	09:...	0.000187	8.310691	...	802.11 Beacon
12624	ArubaNetwo:97:2E:62	Ethe...	Aruba...	M	6	-86	-90	6.0	163	09:...	0.000346	8.311037	...	802.11 Beacon
12625	ArubaNetwo:96:EF:80	Ethe...	Aruba...	MP	6	-79	-88	6.0	130	09:...	0.000212	8.311249	...	802.11 Beacon
12626	ArubaNetwo:96:EF:81	Ethe...	Aruba...	MP	6	-79	-88	6.0	109	09:...	0.000286	8.311535	...	802.11 Beacon
12627	ArubaNetwo:96:EF:82	Ethe...	Aruba...	M	6	-80	-88	6.0	85	09:...	0.000034	8.311569	...	802.11 Beacon
12628	144.173.3.251	10.1...	Aruba...		6	-75	-87	6.0	111	09:...	0.001202	8.312771	...	WBT Server
12629	*0C:84:DC:3F:AD:B0*	Arub...		C	6	-68	-83	6.0	14	09:...	0.000034	8.312805	...	802.11 Ack
12630	ArubaNetwo:98:83:E0	Ethe...	Aruba...	MP	6	-79	-88	6.0	208	09:...	0.004733	8.317538	...	802.11 Beacon
12631	ArubaNetwo:98:83:E1	Ethe...	Aruba...	MP	6	-79	-86	6.0	187	09:...	0.000415	8.317953	...	802.11 Beacon
12632	ArubaNetwo:98:83:E2	Ethe...	Aruba...	M	6	-78	-85	6.0	163	09:...	0.000140	8.318093	...	802.11 Beacon
12633	ArubaNetwo:96:E7:A2	HonH...	Aruba...	M	6	-78	-88	6.0	148	09:...	0.005415	8.323508	...	802.11 Probe Rsp
12634	ArubaNetwo:98:8F:C0	Ethe...	Aruba...	MP	6	-87	-94	6.0	208	09:...	0.016156	8.339664	...	802.11 Beacon
12635	ArubaNetwo:98:8F:C1	Ethe...	Aruba...	MP	6	-89	-93	6.0	187	09:...	0.000222	8.339886	...	802.11 Beacon
12636	ArubaNetwo:98:8F:C2	Ethe...	Aruba...	M	6	-91	-93	6.0	163	09:...	0.000396	8.340282	...	802.11 Beacon
12637	ArubaNetwo:96:E7:A0	Ethe...	Aruba...	MP	6	-79	-90	6.0	208	09:...	0.000486	8.340768	...	802.11 Beacon
12638	ArubaNetwo:96:E7:A1	Ethe...	Aruba...	MP	6	-78	-89	6.0	187	09:...	0.000279	8.341047	...	802.11 Beacon
12639	ArubaNetwo:96:E7:A2	Ethe...	Aruba...	M	6	-79	-92	6.0	163	09:...	0.000378	8.341425	...	802.11 Beacon
12640	Junipernet:C9:A7:F0	Mcas...	Aruba...	E	6	-79	-91	6.0	94	09:...	[illegible]	8.341459	...	802.11 Encrypted Data
12641	0C:30:21:E9:C5:F8	Ethe...	Ether...	M	6	-63	-75	1.0	144	09:...	0.002058	8.343517	...	802.11 Probe Req
12642	A8:88:08:DA:33:DF	Ethe...	Ether...	M	6	-79	-91	1.0	144	09:...	0.001612	8.345129	...	802.11 Probe Req
12643	ArubaNetwo:98:83:E0	0C:3...	Aruba...	MP	6	-79	-88	6.0	193	09:...	0.000278	8.345407	...	802.11 Probe Rsp
12644	*0C:30:21:E9:C5:F8*	Arub...		C	6	-77	-90	6.0	14	09:...	0.000034	8.345441	...	802.11 Ack
12645	ArubaNetwo:98:83:21	0C:3...	A2:F8...	MPx	6	-79	-88	6.0	172	09:...	0.000325	8.345766	...	802.11 Probe Rsp
12646	ArubaNetwo:96:FD:C1	0C:3...	Aruba...	MP	6	-77	-86	6.0	94	09:...	0.000272	8.346038	...	802.11 Probe Rsp
12647	00:69:E4:2C:4C:2F	51:3...	05:1A...	M...	6	-87	-92	6.0	172	09:...	0.000587	8.346625	T..	802.11 Probe Rsp

Do you still just want to bung another AP in?

Co-Channel Interference (CCI)

- Or, Co-operation
- AP's and Clients on the same channel will share bandwidth!
- Only one person *on entire channel* can talk at one time, AP or Client.
- One transmission will be heard a long way away as the *frame header* is sent at the basic rate – and is understood much further away!
- An extra AP isn't going to add extra capacity

In a nutshell then:-

It has been said:- **“we are reaching a point now where the expectation and demand can’t be met within our budget.”**

(Scott Armitage from University of Loughborough Writing about Halls of Residences in the JISCmail list.)

So, the aim of this presentation…

To provide some tools to assist with solving this problem

- Really just scratching the surface
- No magic bullet
- We have to plan capacity instead of hoping to *over-provision*
- Fewer AP's if anything, not *more*!

Overview

- Capturing Customer Requirements
- AP Capacity forecasting
- Real world applications
- Some thoughts on how to increase efficiency of the WLAN

The Customer Requirement Capture (CRC)

We need to find out:-

- *Who* the users a*re?*
- *How many* of them are there*?*
- *What* will they be doing?
- *Where* will they be doing it?
- *With* what will they be doing it?

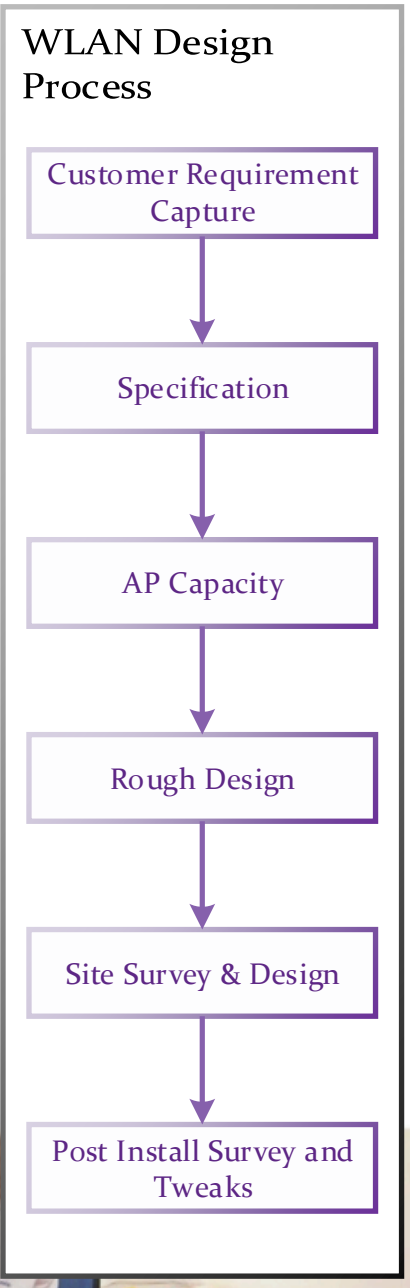
(We don't need to ask why :)

DO

- Talk to them!
- Meet them!
- Visit Site
- Show them Maps!
- Colour them in!

DON'T

- Ask them anything Technical
- Rely on floorplans unless you have to. (Eg, new build)



CRC Examples!

AOS Device Type Summary

iPhone	31.0%
Other	26.8%
Android	17.3%
OS X	13.7%
Win 7	11.2%

AOS Device Type	Count	% of Total
iPhone	9670	30.97%
Android	5394	17.27%
OS X	4289	13.73%
Win 7	3507	11.23%
iPad	2844	9.11%
Windows	2165	6.93%
Unknown	1115	3.57%
iPod	763	2.44%
Win XP	452	1.45%
BlackBerry	306	0.98%
Windows Mo		
Win Vista		
Windows Ph		
Win CE		
Linux		
Chrome OS		
Symbian		
Kindle		
webOS		
Win 2000		
Win Server		
Win 98		
22 AOS Devi		

Clients by Connection Mode

802.11n (2.4 GHz)	63.5%
802.11n (5 GHz)	33.2%
802.11g	3.1%
802.11a	0.3%

1

Compress this into a blurb…

in English…

The Wireless Network should support each user watching a SD movie streamed over the Internet, whilst simultaneously carrying out an IM conversation, reading e-mail and web browsing. Users should be able to do this all simultaneously and no "peak usage bottlenecks" are acceptable. The wireless network needs to support users being able to connect 3 devices at once to the network. No enterprise Voice Over Wi-Fi is officially supported and no location tracking is required.

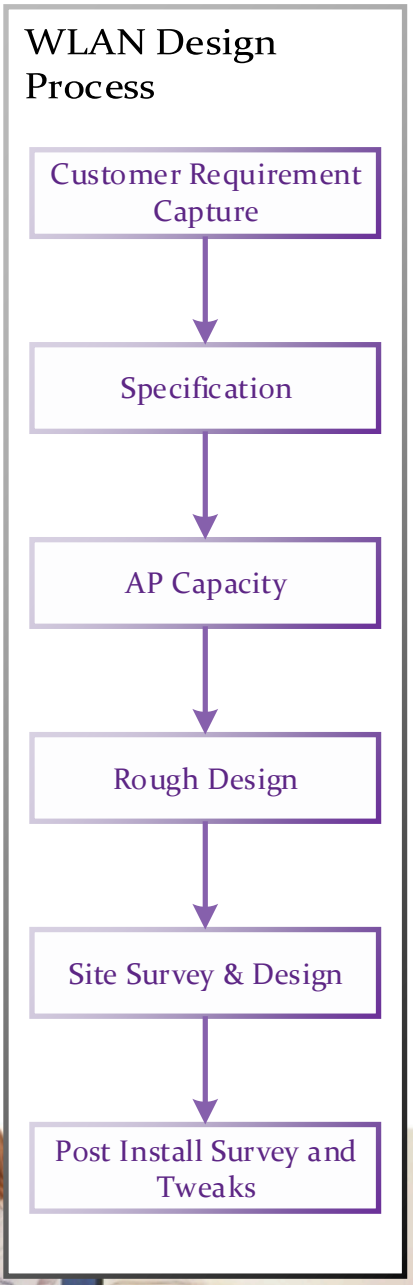
(And get it signed off if you can)

… And translate into a more formal Specification

- *"Bandwidth Contract"* I'd pitch 3Mbps in this example.
- *Zero contention – in this example.*
- Non 'Voice Capable'
- Non RTLS Capable

Notice – no mention of "Signal Strength", "SNR", "dBm"

At this stage, we don't care for this; it could be delivered by WLAN fairy-dust, as long as it's delivered. Especially important if you're outsourcing!



Now, How many AP's do we need?

We know how much 'juice' each user might need.

We can work out how many clients an AP should be able to handle…

Let's start with the AP

- Vendor lock in?
- High capacity – No brainer!
- 802.11n vs 802.11ac – Cost/Benefit

AP	Streams	Throughput
AP 105	2x2:2	300Mbps
AP 135	3x3:3	450Mbps

Spatial streams: Wi-Fi Performance Multiplier

Aruba Example – AP 105 vs AP 135.

Key difference is 3x3:3 vs 2x2:2

Maximum throughput 450Mbps

MCS Table

Modulation and Encoding Scheme

(for 802.11n)

- Vital to understand!
- Is another one for 802.11ac

I'm going to use it to argue that our *actual* available throughput is going to be IRO:-

20 Mbps on a 2.4 GHz Radio
40 Mbps on a 5Ghz Radio

MCS index	Spatial streams	Modulation type	Coding rate	Data rate (Mbit/s)			
				20 MHz channel		40 MHz channel	
				800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	1	BPSK	1/2	6.50	7.20	13.50	15.00
1	1	QPSK	1/2	13.00	14.40	27.00	30.00
2	1	QPSK	3/4	19.50	21.70	40.50	45.00
3	1	16-QAM	1/2	26.00	28.90	54.00	60.00
4	1	16-QAM	3/4	39.00	43.30	81.00	90.00
5	1	64-QAM	2/3	52.00	57.80	108.00	120.00
6	1	64-QAM	3/4	58.50	65.00	121.50	135.00
7	1	64-QAM	5/6	65.00	72.20	135.00	150.00
8	2	BPSK	1/2	13.00	14.40	27.00	30.00
9	2	QPSK	1/2	26.00	28.90	54.00	60.00
10	2	QPSK	3/4	39.00	43.30	81.00	90.00
11	2	16-QAM	1/2	52.00	57.80	108.00	120.00
12	2	16-QAM	3/4	78.00	86.70	162.00	180.00
13	2	64-QAM	2/3	104.00	115.60	216.00	240.00
14	2	64-QAM	3/4	117.00	130.00	243.00	270.00
15	2	64-QAM	5/6	130.00	144.40	270.00	300.00
16	3	BPSK	1/2	19.50	21.70	40.50	45.00
17	3	QPSK	1/2	39.00	43.30	81.00	90.00
18	3	QPSK	3/4	58.50	65.00	121.50	135.00
19	3	16-QAM	1/2	78.00	86.70	162.00	180.00
20	3	16-QAM	3/4	117.00	130.00	243.00	270.00
21	3	64-QAM	2/3	156.00	173.30	324.00	360.00
22	3	64-QAM	3/4	175.50	195.00	364.50	405.00
23	3	64-QAM	5/6	195.00	216.70	405.00	450.00
24	4	BPSK	1/2	26.00	28.80	54.00	60.00
25	4	QPSK	1/2	52.00	57.60	108.00	120.00
26	4	QPSK	3/4	78.00	86.80	162.00	180.00
27	4	16-QAM	1/2	104.00	115.60	216.00	240.00
28	4	16-QAM	3/4	156.00	173.20	324.00	360.00
29	4	64-QAM	2/3	208.00	231.20	432.00	480.00
30	4	64-QAM	3/4	234.00	260.00	486.00	540.00
31	4	64-QAM	5/6	260.00	288.80	540.00	600.00

‘Real World’ Throughput

- Calculations for a single stream device
- Use numbers from our CRC - 2/3 are Single Stream
- Final figure increased to account for 1/3 of devices having 2 or 3 streams

20 Mbps on a 2.4 GHz Radio
40 Mbps on a 5Ghz Radio

Item	Effect	Throughput
Number of Streams	/ 3	150Mbps
20Mhz Channel	/ 2 ish!	72 Mbps
Long GI	*A bit less*	*65 Mbps*
SNR ~ 22	Drop down to 16QAM	39 Mbps
TCP vs Raw	/ 2	20 Mbps
3 SSID, 2 AP on Channel	- 20%	16 Mbps
Max efficiency 90% ?	-10%	**15 Mbps**

Device Capacity

- Number of Streams
- Channel Width
- Guard Interval
- Achievable SNR
- TCP!
- Overheads
- Max efficiency 90% ?

AP-135 user capacity numbers

Radio	Throughput	Contract	Users
2.4GHz	20 Mbps	3 Mbps	7
5Ghz	40 Mbps	3 Mbps	13
			20

How much can you contend this at?

*How much do you **have to** contend it at? Will it work?*

Radio	Capable	Future
2.4GHz	100%	100%
5GHz	35%	100%

How many 5GHz Clients do you have? (Now).

How about in 2 years time? (802.11ac)

Other Helpful Features

- Tweaking supported rates
  - Basic to 6?
  - Kill off 802.11b rates entirely?
  - *Support for g?!*
- Tweaking Management Traffic
  - Beacon rate?
  - Stop AP's responding to **Probe Requests** which are below some threshold?
- Band Steering and 'ClientMatch' and load balancing
  - Ensure best use of airspace
  - Beware unintended consequence!
- **Rate limit** cloud storage?
  - Sync's happen in the background …

  … often with no user input!

The best laid plans…

Arguments include:-

- *I don't want to plan 2000 AP's manually…*
- *What about another network [or rogue device] appearing on channel?*
- *I want my network to be able to be "self healing" – you know, deadspots.*

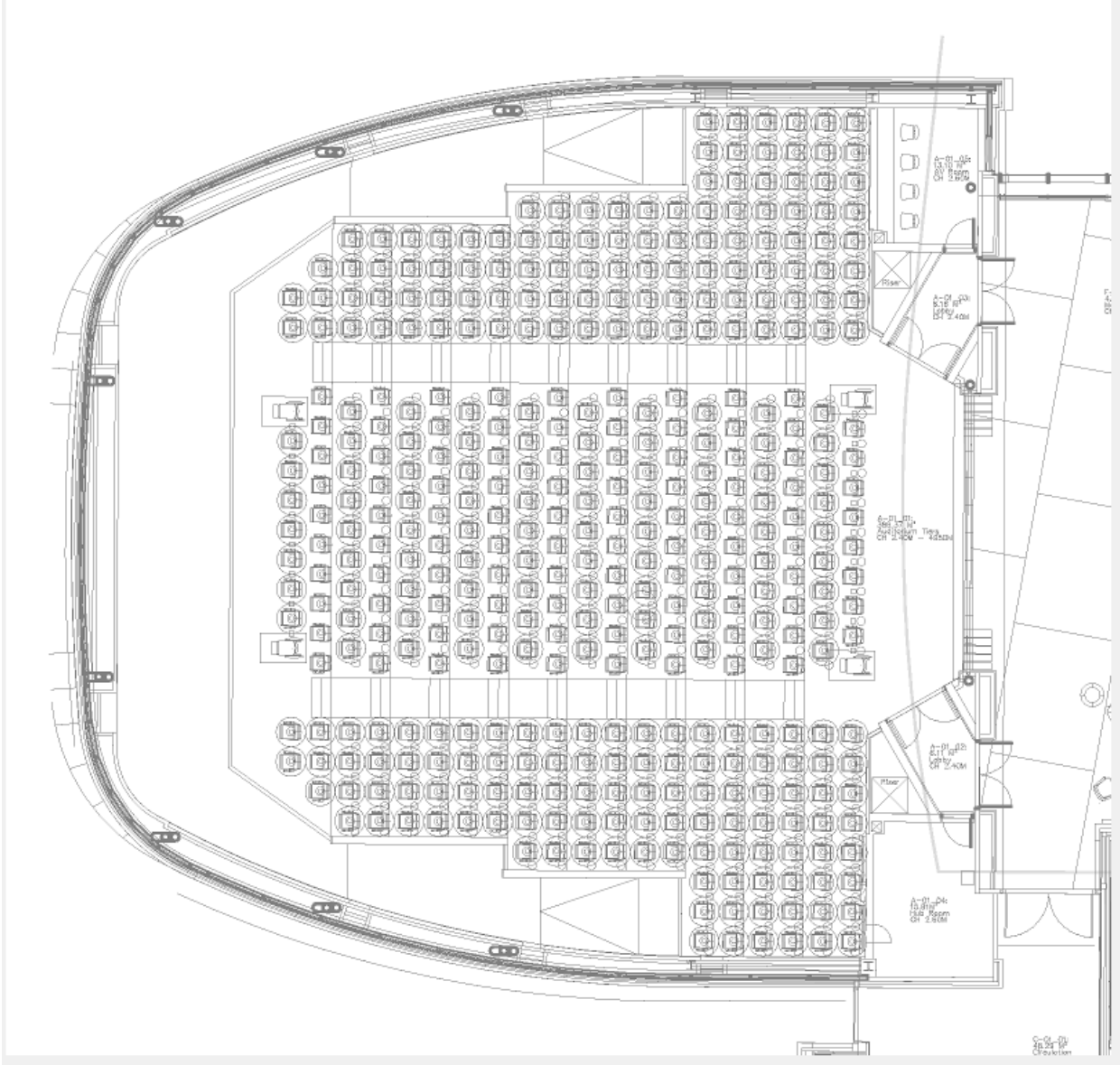
Laid waste by automatic power and channel selection?

Now, Putting this into Practice…

- Choice of 3 examples:-
  - Large auditorium
  - Hall of Residence
  - High density classroom environment

Application I: 400 Seat Auditorium

- 400 Seats
- Absolutely *anyone;* Absolutely *anything.*
- Aesthetics; cable routing issues
- AP's in surrounding Area
- Hard to model with 'off plan' design only
- MUST get some real numbers… With 'bums on seats!'

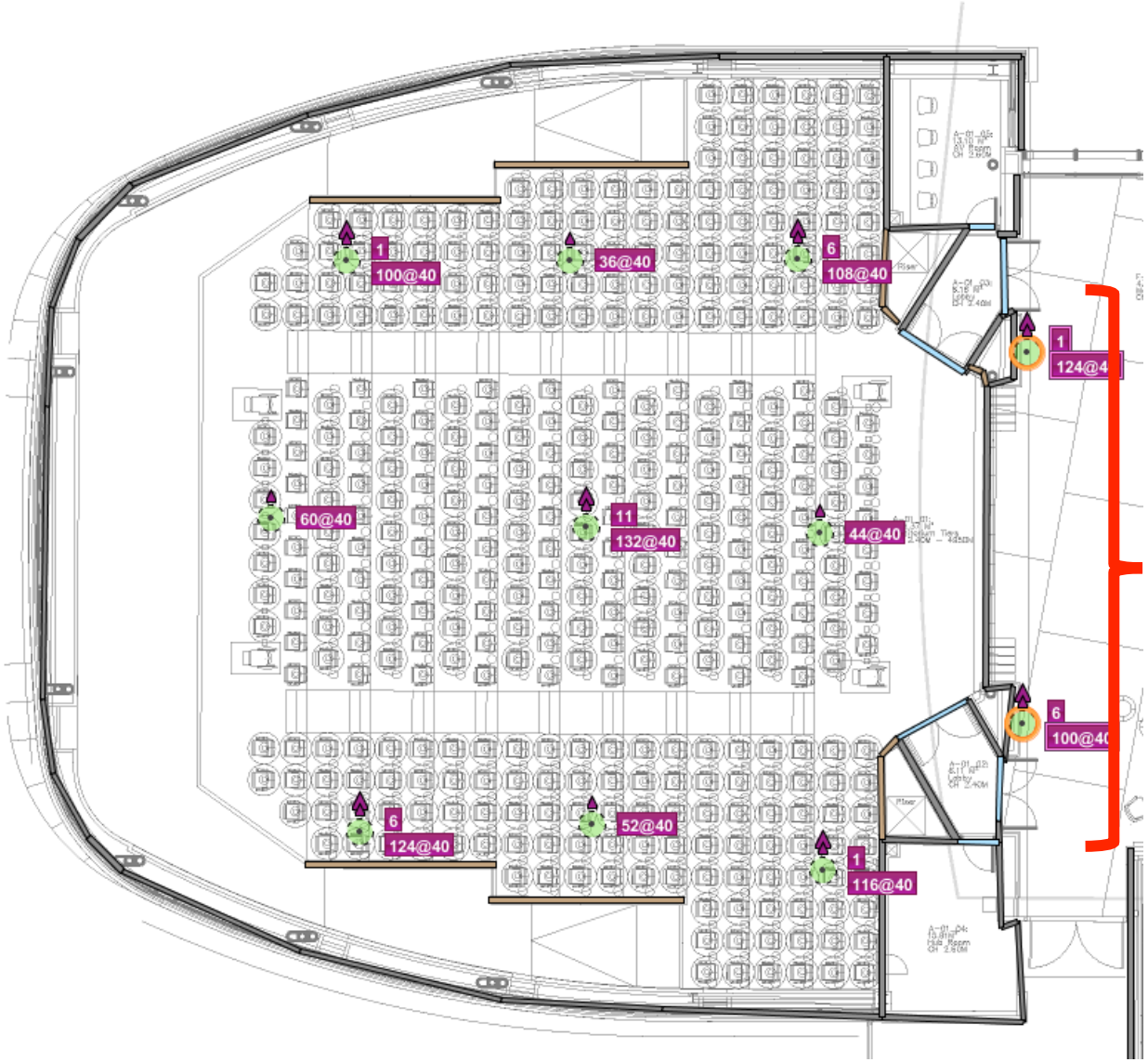


Application I: 400 Seat Auditorium

- 3:1 Contention (33% = 130 Users)
- 3 Mbps Contract?
- 130 Users = 390 Mbps
- 5 x 2.4 Radios = **100 Mbps** of 2.4 Gig
- 9 x 40MHz Channels = **360Mbps** of 5 Gig

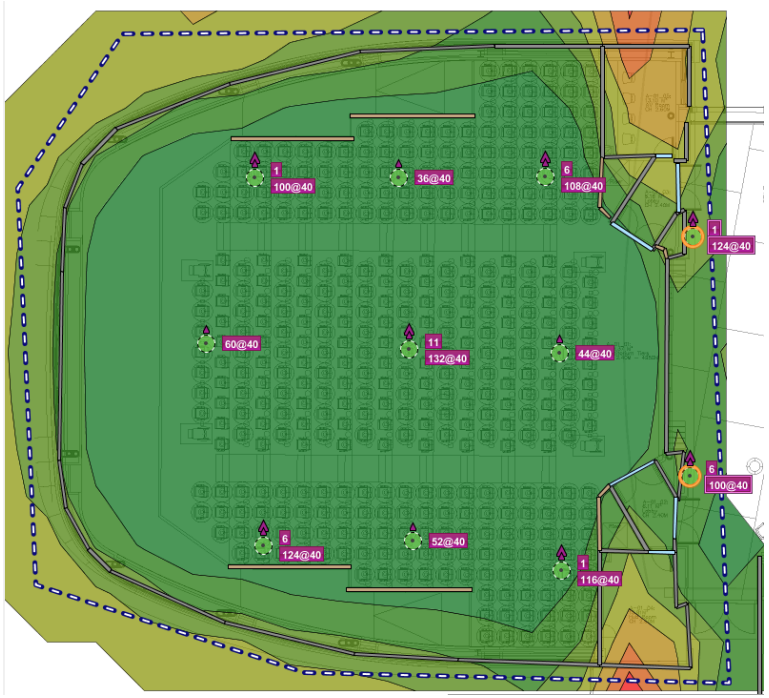
Some channel re-use

AP's Under Seats!

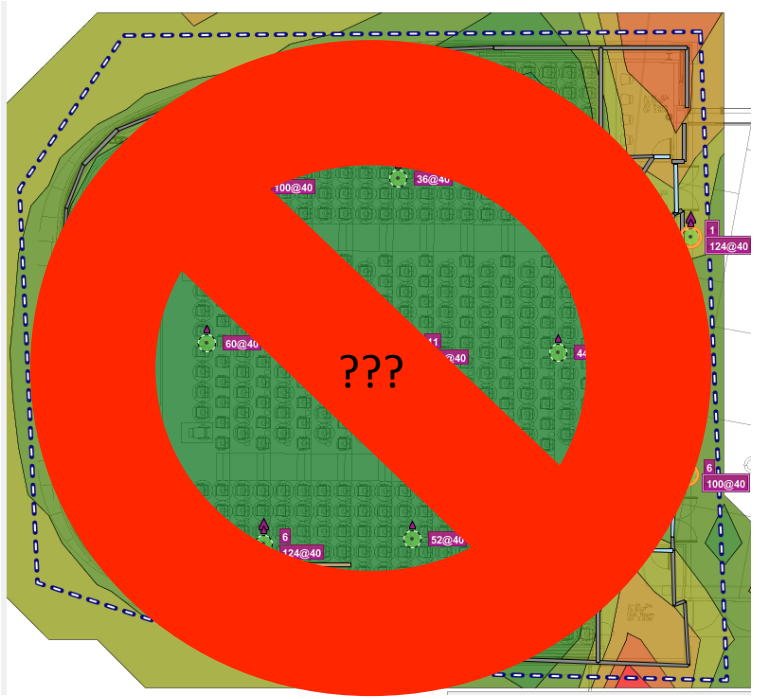


Application I: *Auditorium – ESS Visualizations*

- Off Plan Design of limited use (Hard to model accurately)
- ESS visualisations of ‘limited use’



SNR (20-50)
20% Load

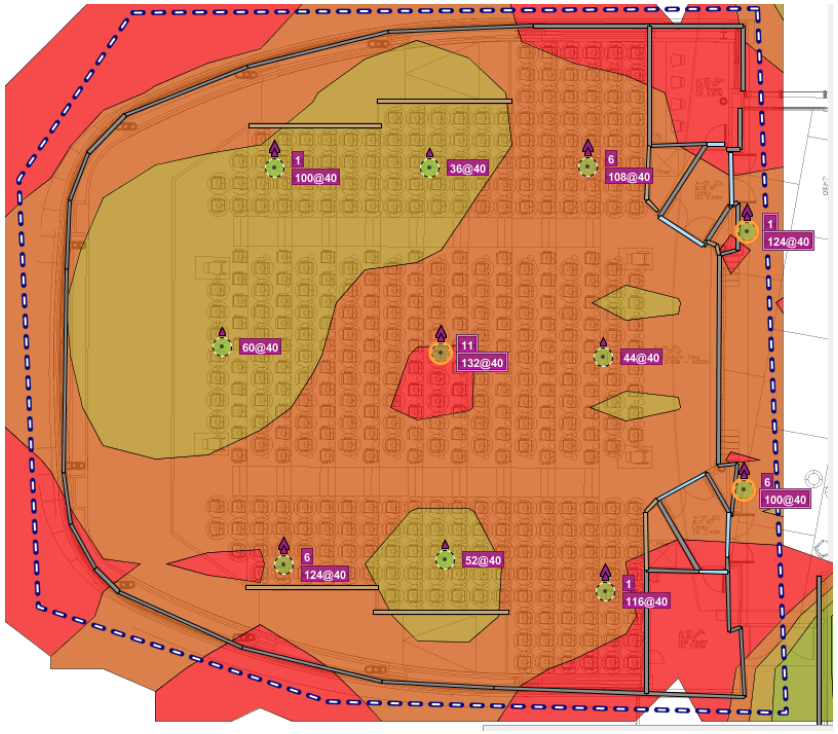


SNR (20-50)
60% Load

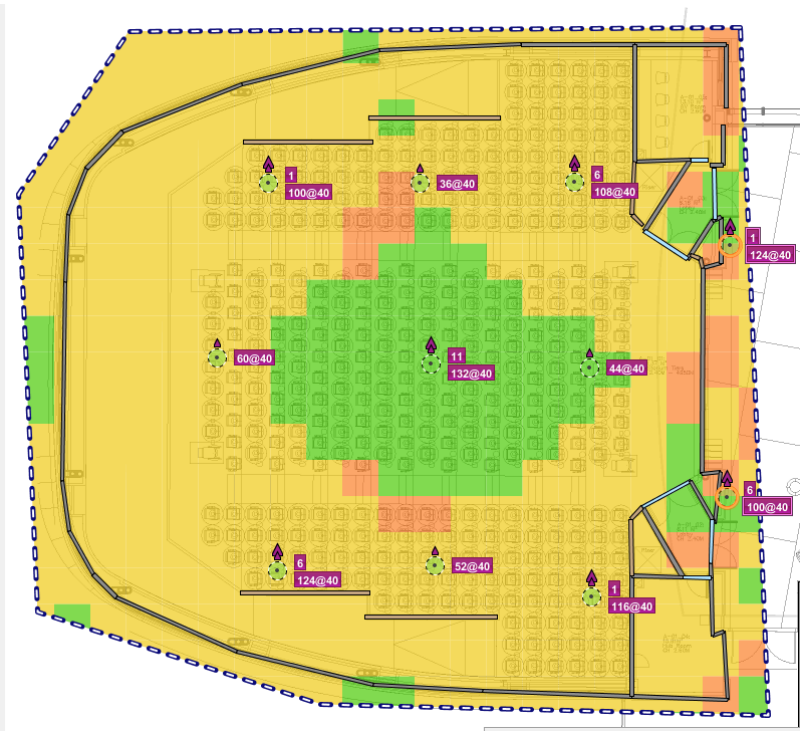
Application I: *Auditorium – ESS Visualizations II*

- SNR – Solved !
- ESS Shows Best Case. Ie 5Gig! ☺
- SNR vs Signal Strength
- Channel Overlap OK

So, will we get enough capacity?



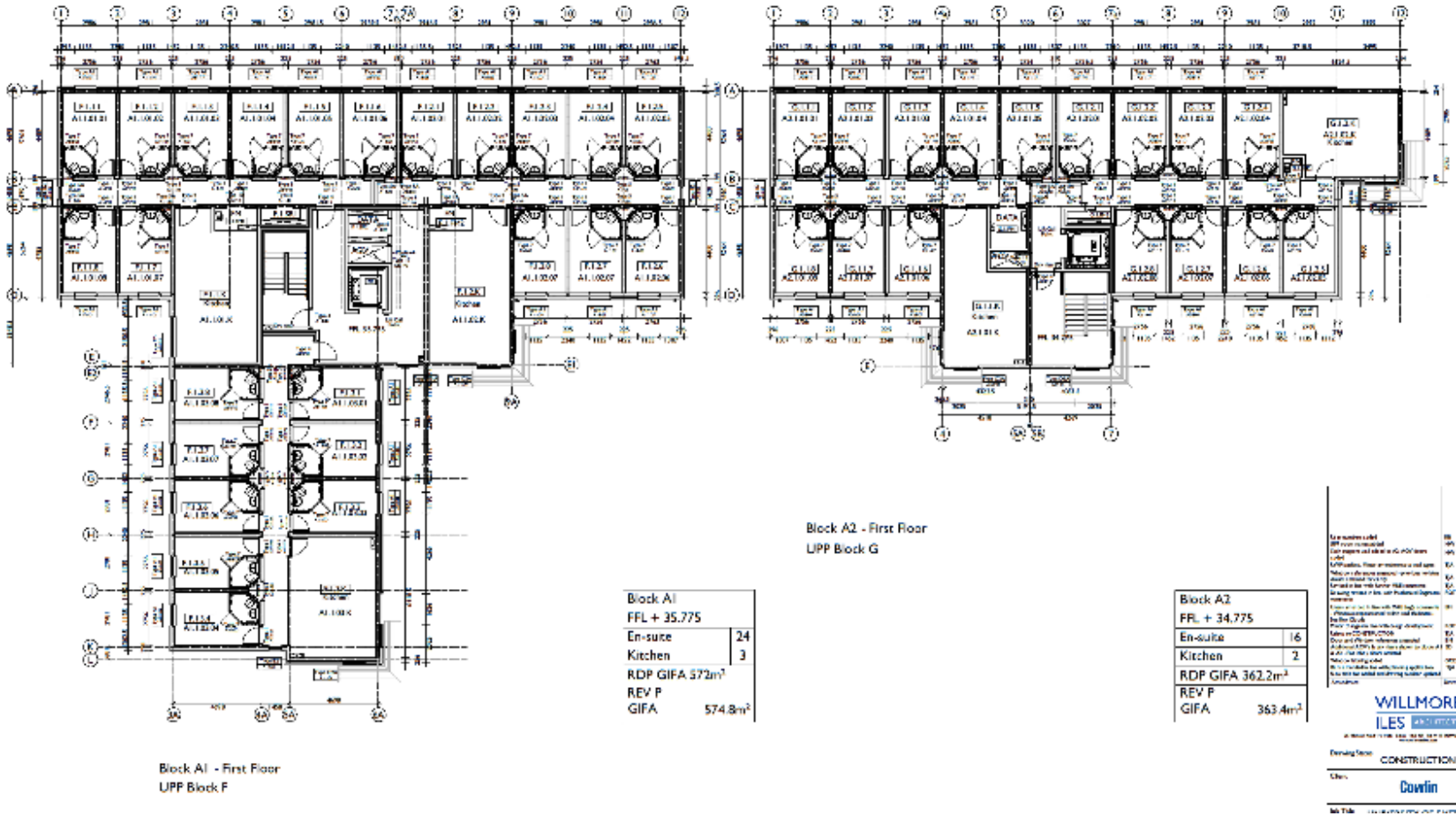
SNR (20-50)
2.4 GHz
60% Load



Channel Overlap

Application II: Halls of Residence

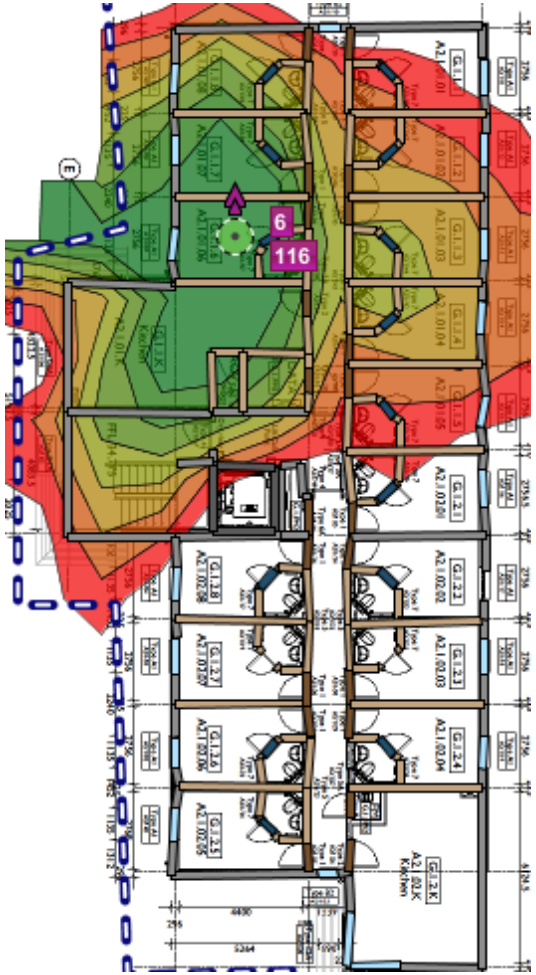
- 3D (Multiple floors)
- ~8 Students per flat.
  - 3+ devices per student
  - Guests
- Anything goes!
- Won’t want to contend the network!



Application II: Halls of Residence

- 5Mbps Bandwidth contract? (if we can!)
- Signal Propagation critical here
- Must get some real numbers
  - Either full survey
  - Or Attenuation through key walls + Floors
- And not forget 5GHz!

SS -70 to -20 dBm

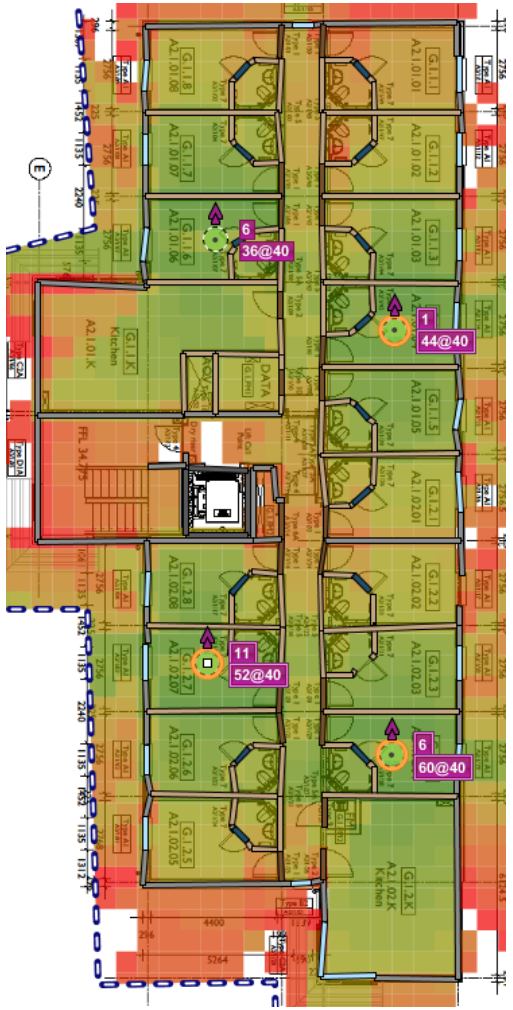


SNR (20-50)
20% Load

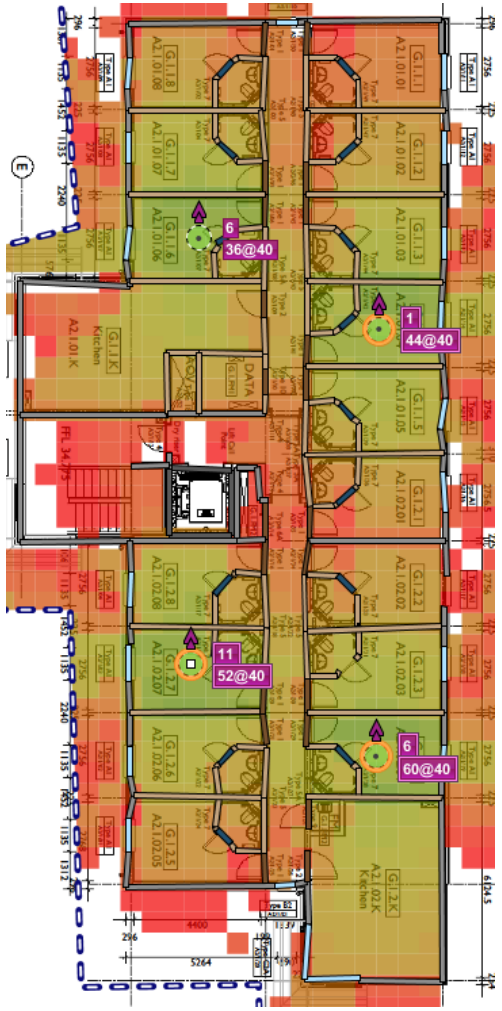
SNR (20-50)
5 Gig!

Application II: H o R

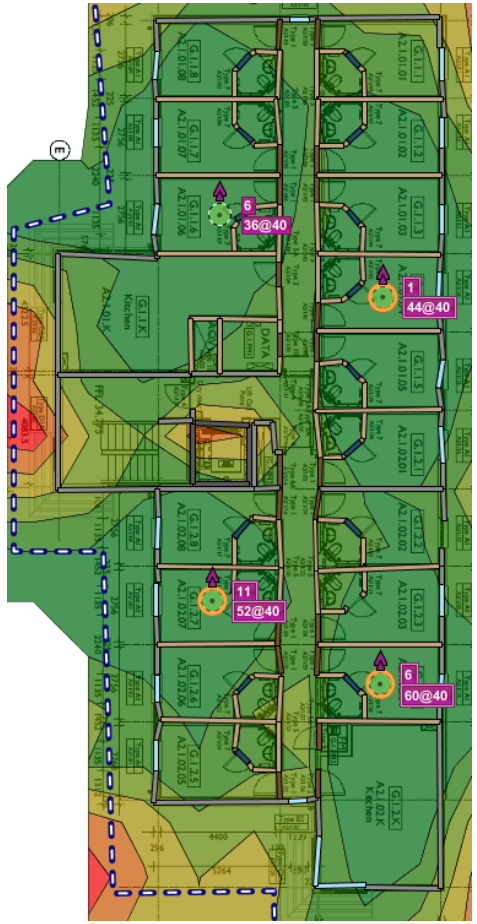
- Showing *Signal Strength* here…
- Scale! Not all green.
- 4 AP's shown , but very little signal overlap (CCI) on 2.4…
- *In one dimension*.



SS -70 to -20 dBm



SS -5 Gig Radio



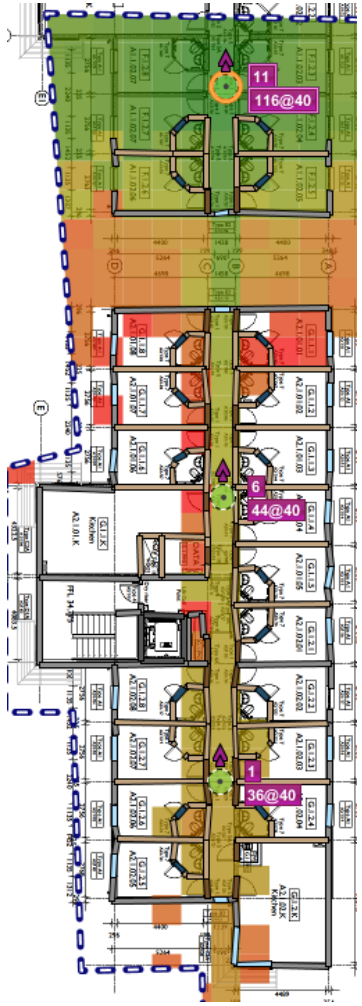
5 GHz SNR
(20-50)
50% Load

Application II: H o R

- Need to hit a budgetary target
- *Can we do it with just 2 APs?*
- *So, 1 per 8 students?*
- Maybe!
- *Need to be very careful if lining up our APs in 3D*

SS 5 Gig

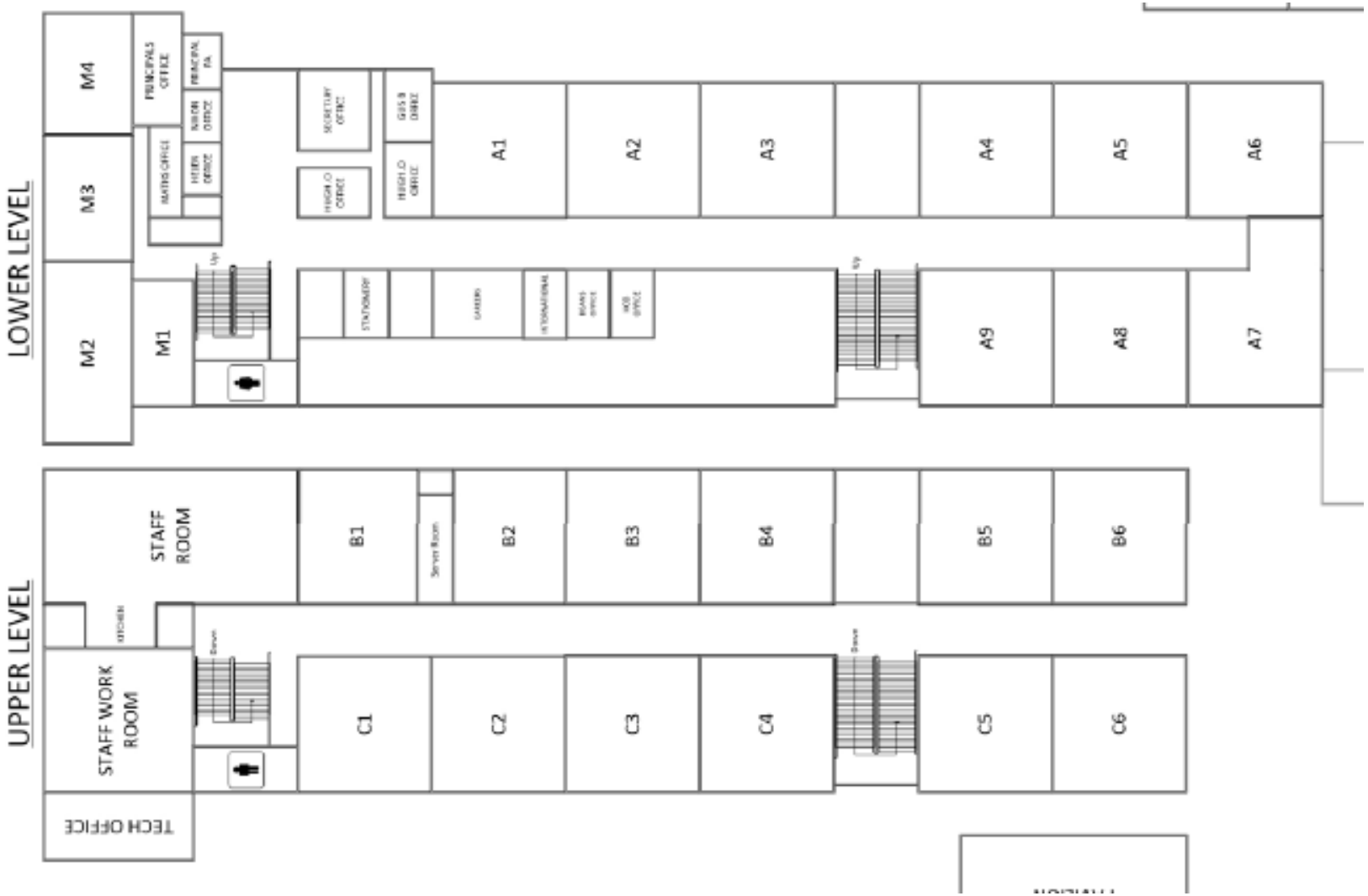
SNR 5 Gig



3D issues!

Application III: *XYZ School*

- *2 Floors; Concrete shell with drywall internally*
- *20 users per room; approx. 300 total*
- *'Normal internet browsing' + RDP*
- *Laptops, iPads, smartphones (various)*
- *AP 105's purchased.*
- *Stairwell = 1.8m wide*



Application III: *XYZ School*

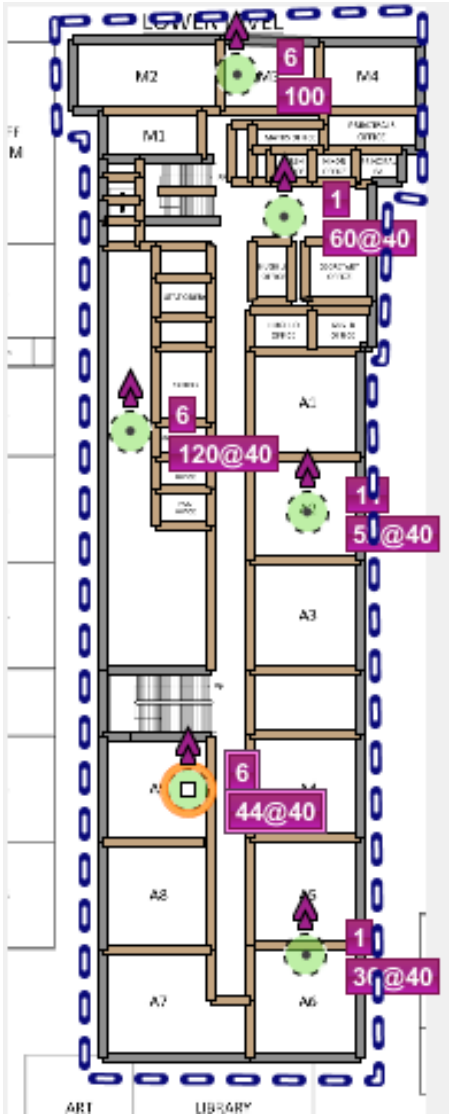
- 1 Mbps Bandwidth Contract

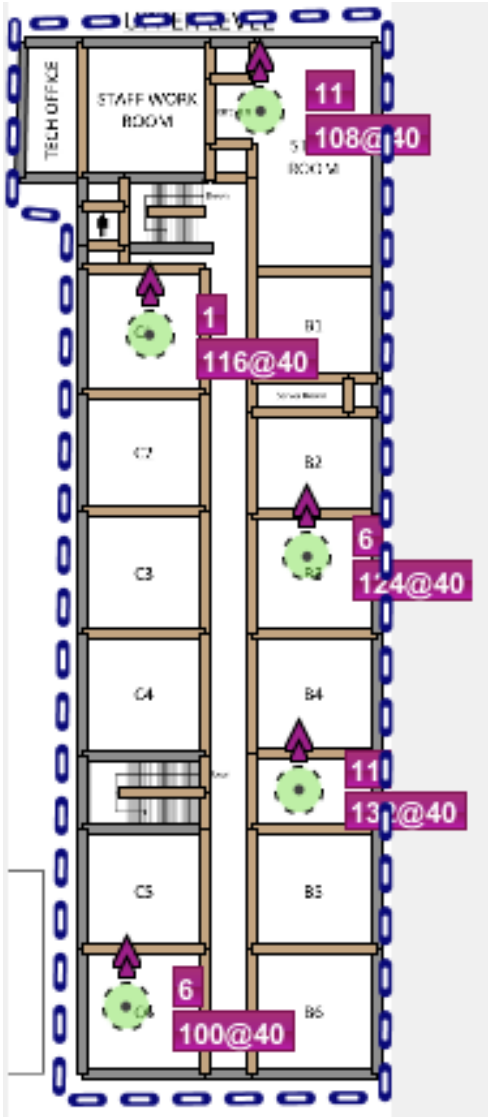
- No information on peak usage, or 2.4/5GHz split

- Similar numbers to our previous example:-

- Guestimate 1 AP per 60 users/3 rooms

- Initial Locations:

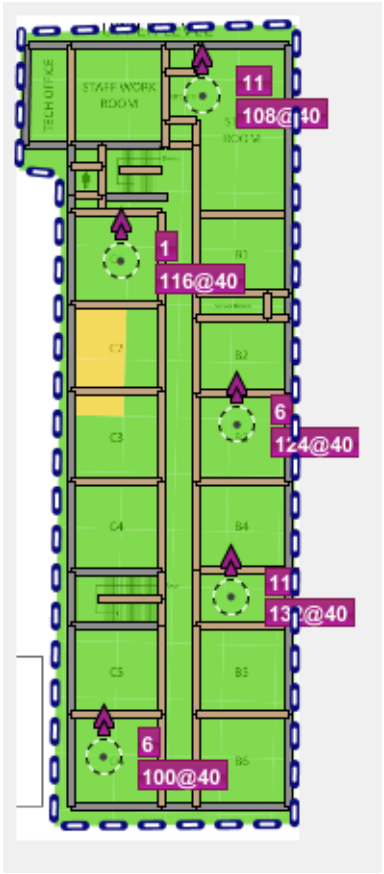




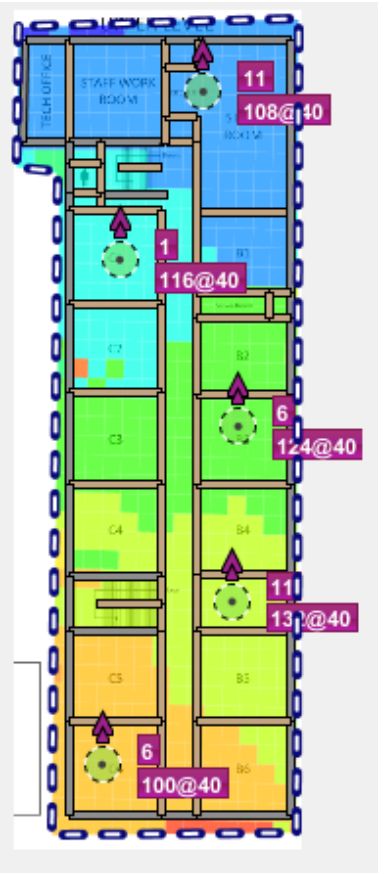
Application III: *XYZ School – ESS Visualizations*

SNR (20-50)
20% Load

SNR (20-50)
60% Load



Channel Overlap

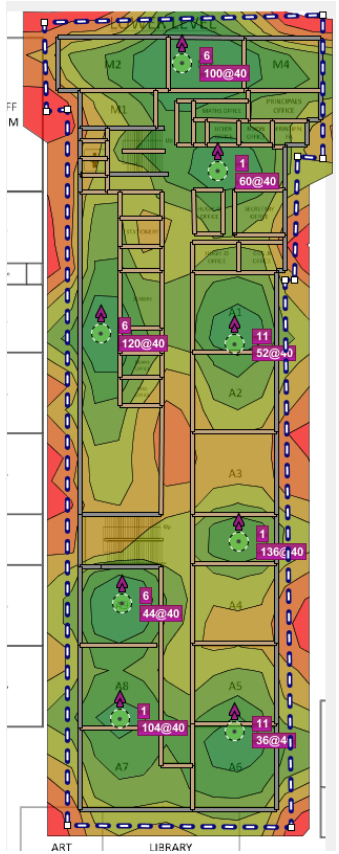


Associated AP

- Just one floor here. (T'other is similar)
- Channel Overlap is ideal! But client CCI?
- Next steps:-
  - Confirm some readings with real life site survey
  - Confirm concurrent usage model. Some concern if events in all rooms. 60 users per AP is heavily subscribed…

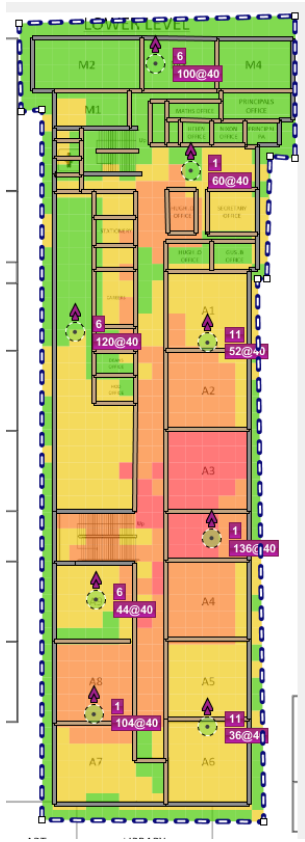
Application III: *XYZ School – Higher Capacity Model*

- Client indicated that 1 AP per 2 rooms would make him more comfortable as they embraced BYOD.
- So, I modelled this… including reduced power
- 4 Extra AP's have massive impact on Channel Overlap (2.4)
- May not realise the benefits of extra capacity
- May need one extra at the top? (Associated AP)
- May want to report back <u>not</u> to increase AP numbers.



SNR (20-50) 20% Load

SNR (20-50) 60% Load



Channel Overlap

Associated AP

A Wrap: Other Resources

- https://community.ja.net/groups/wireless-admin
- http://cwnp.com
- [Aruba] Validated Reference Designs
- Revolutionwifi.net

Questions?