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Ofcom

sky

Wi-Fi and LTE 2.3 GHz co-location field testing, Executive summary

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Final report

Version 1.0

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General

- This is the an Exec summary of the final report of 2.3 GHz LTE – Wi-Fi co-location tests at Victoria station
- Project was a collaborative effort between Ofcom, BSkyB and 7signal
- Purpose of the project was to determine how much 2.3 GHz LTE transmitter impacts to nearby Wi-Fi operation
- Conclusions are presented at the end of the report
  - Co-location conclusions
  - Wi-Fi performance conclusions

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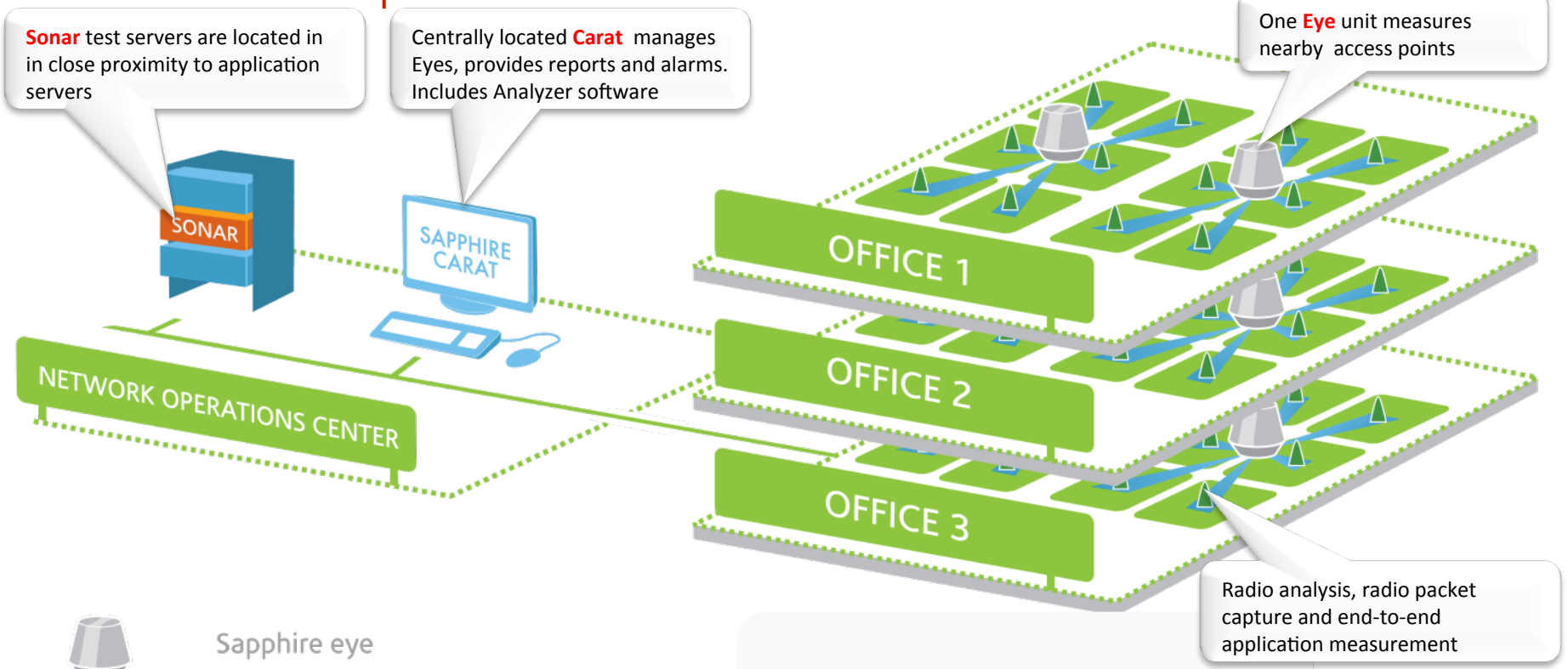
Test setup

Test setup

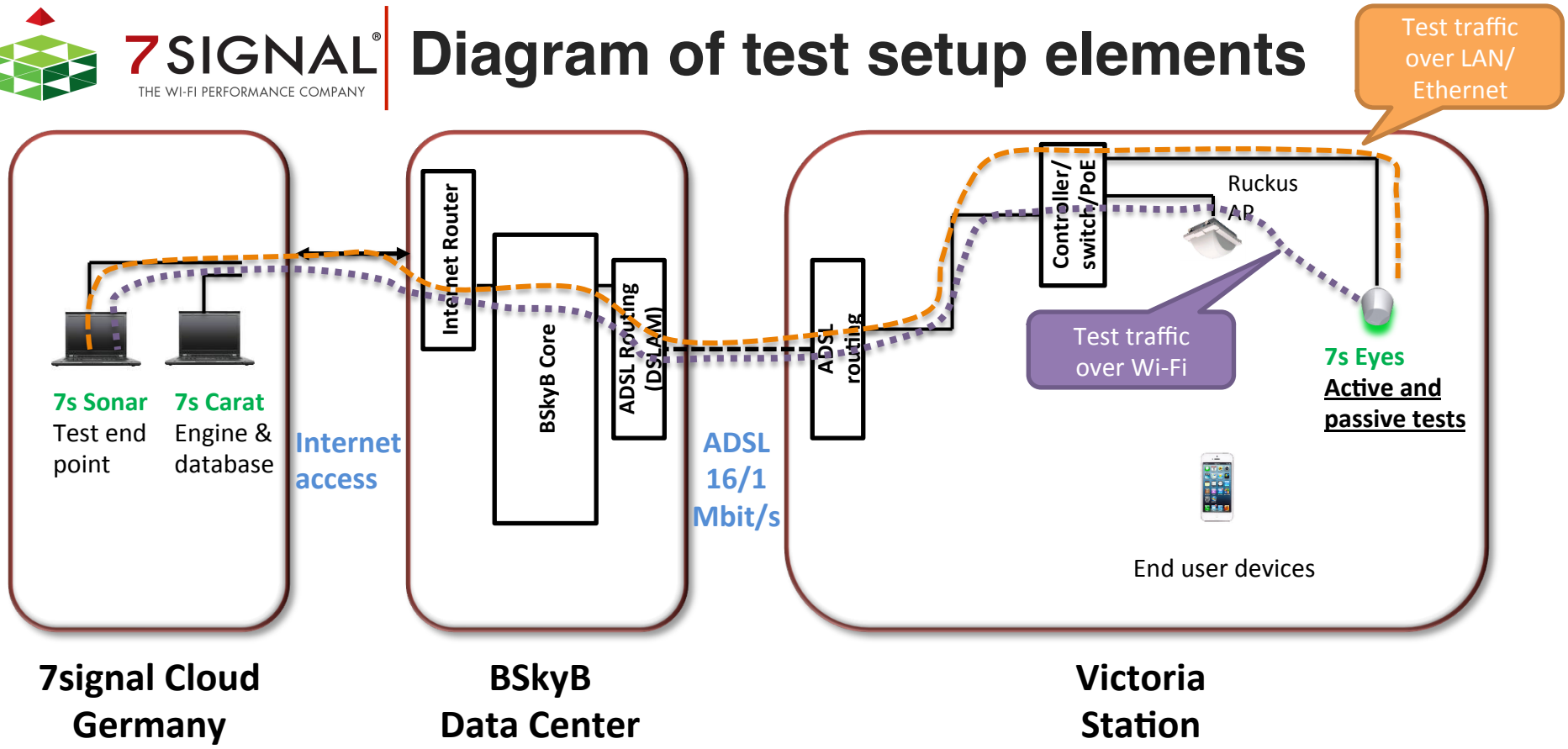
- A LTE test transmitter and Ruckus WLAN access point were co-located
- 7signal Sapphire Wi-Fi service assurance and performance optimization product was used to analyze performance variations during the times when LTE transmitter was on and off
- Two types of 7signal Wi-Fi sensors were used
  - Three 1000 series Eyes with beam steering and one smaller Micro Eye sensor were used
- 7signal measurement engine (Carat) was cloud based. Sensors were connected to cloud server through Ethernet. All collected data was stored to cloud
- During active tests 7signal sensors measure against a test end point. This test end point was also in cloud server
- During the test period, Victoria station Wi-Fi access point were connected to internet through 16/1Mbit/s ADSL connection. Normally a faster multi-ADSL line has been available, but due to failure of aggregating device, only one ADSL line was available for all Wi-Fi traffic in the station

Elements of 7signal Sapphire



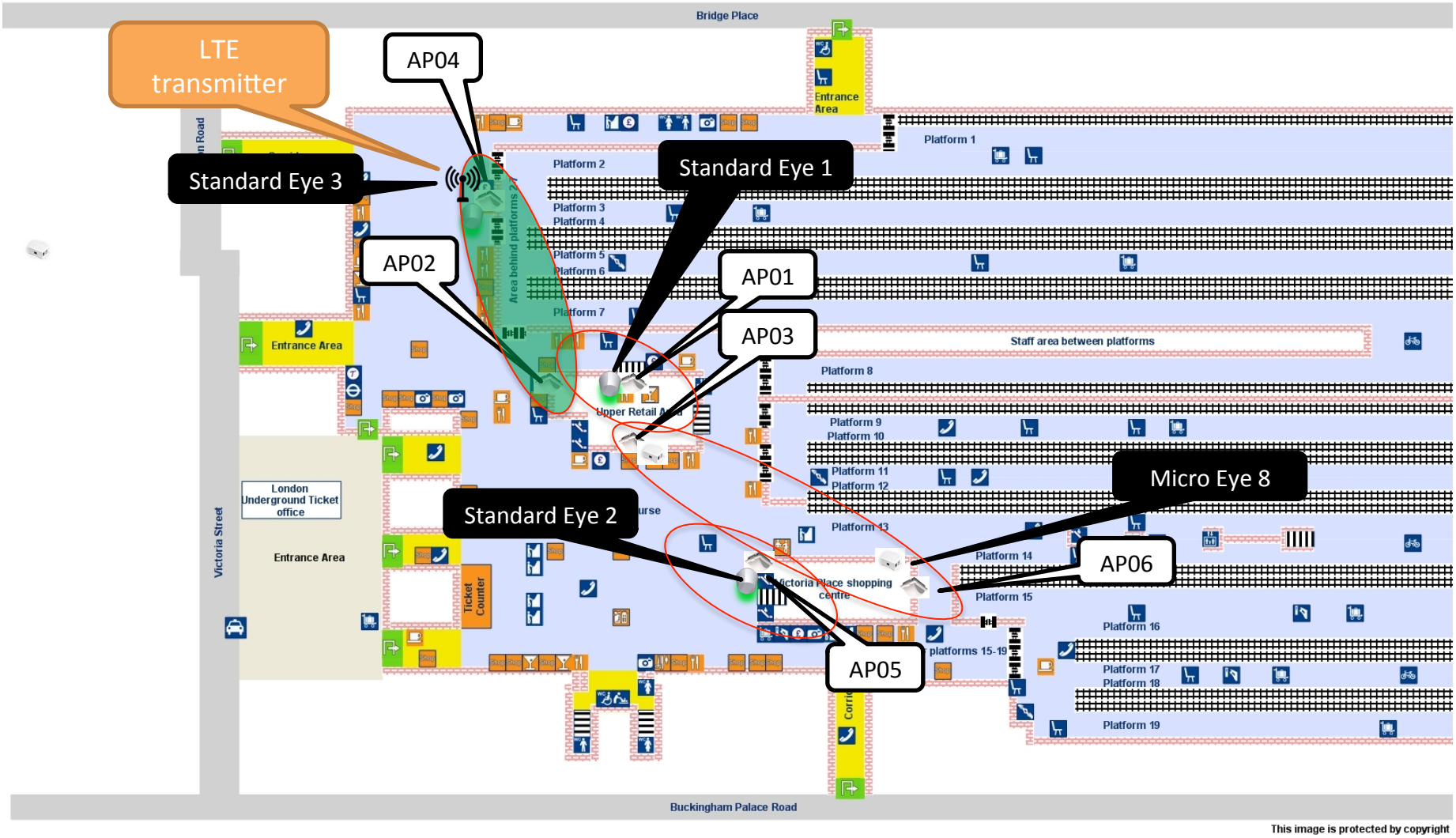
- Monitor
- Measure
- Record
- Report
- Alarm
- Analyze
- Troubleshoot
- Verify

Diagram of test setup elements

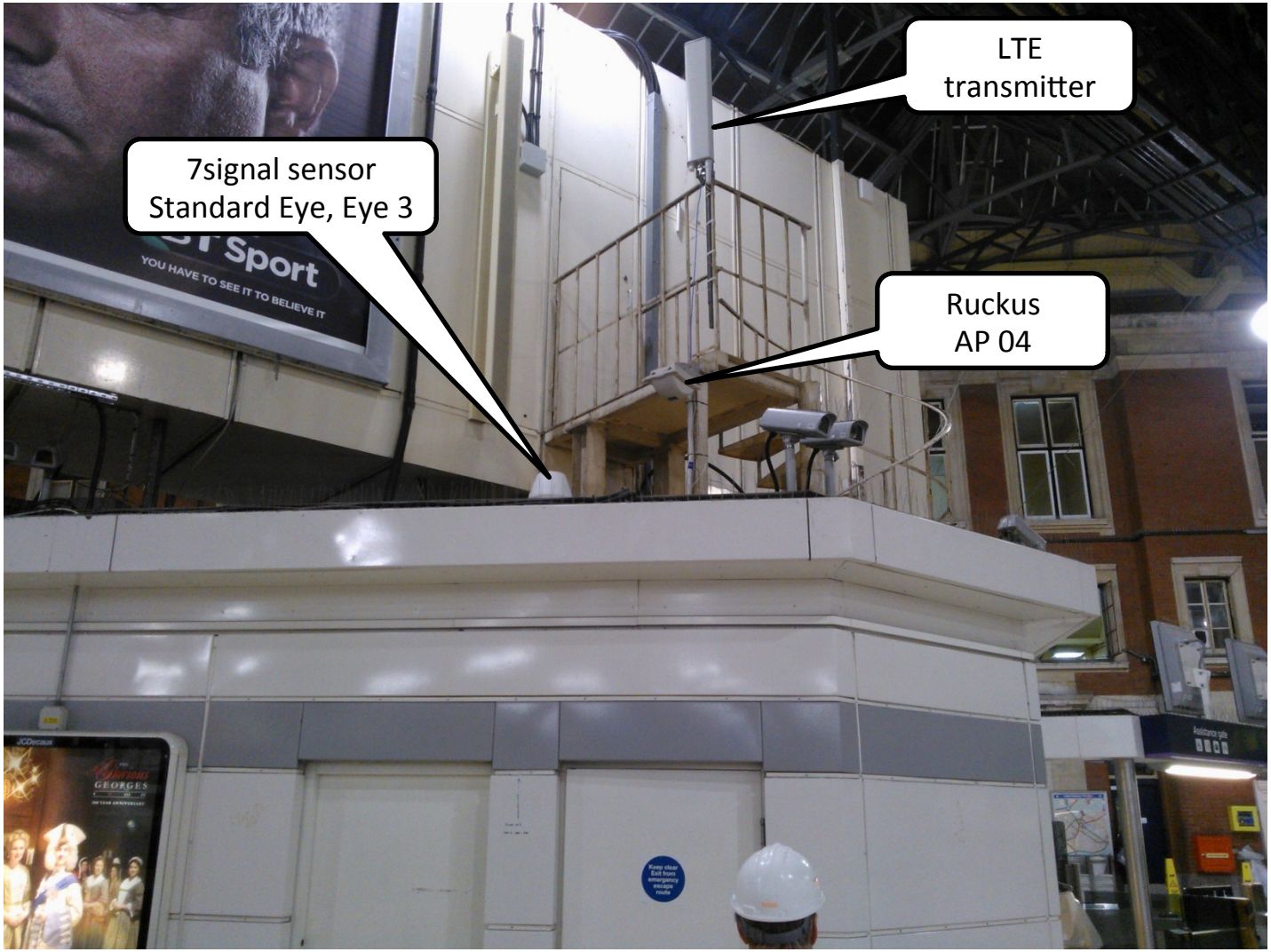


- Eyes performance active and passive tests
- Active tests operate over the LAN and WLAN separately
- Passive tests capture radio packets and calculate metrics from them

AP and Eye locations



Eye 3 and LTE BTS



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Mechanism of possible impact

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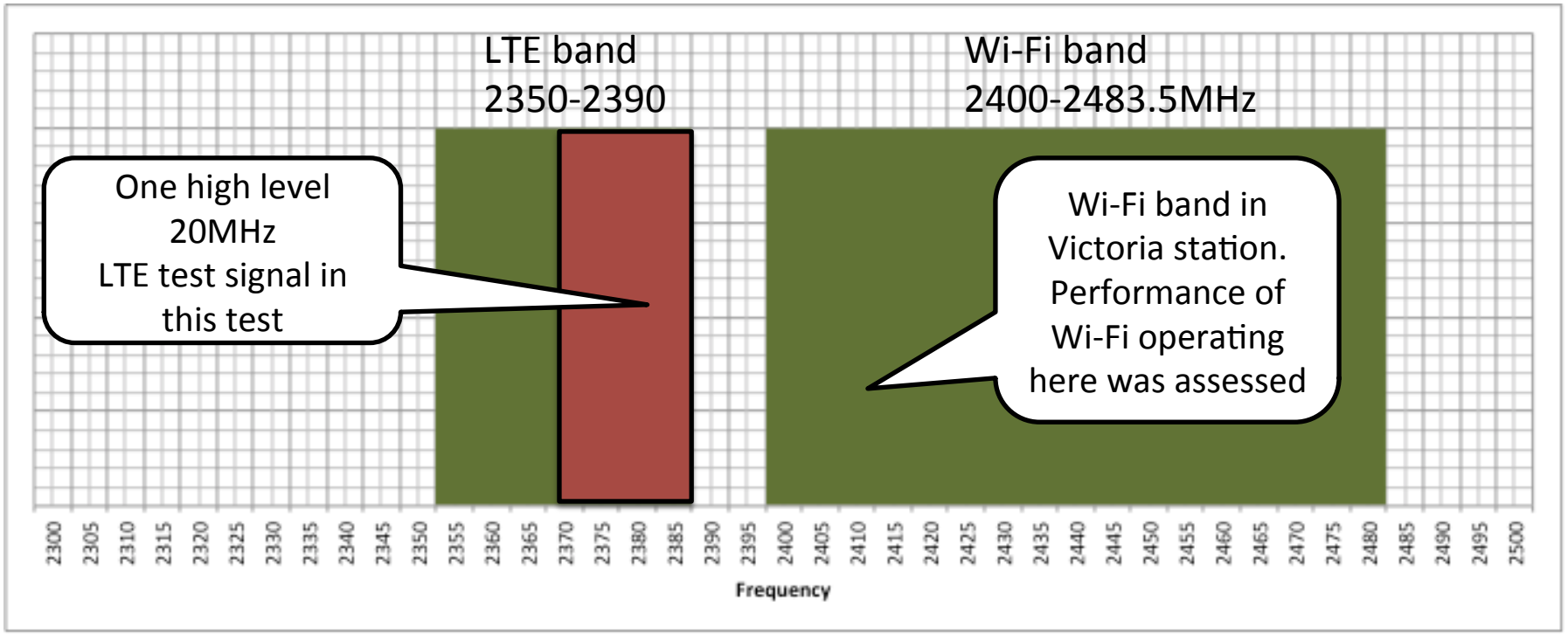
Key aspects

- The key challenge with Wi-Fi and mobile base station co-location is lack of RF filtering in receivers. Wi-Fi access points and end user radios commonly do not have any or only very limited RF filtering preventing out-of-Wi-Fi-band signals entering Wi-Fi receiver RF parts.
- Effective radiated signal levels from mobile network base stations may be very high (1000's RF watts) compared signal levels used in Wi-Fi (typically below 0.1 RF watts)
- Unfiltered RF entering Wi-Fi receivers may degrade Wi-Fi performance in different ways
- Currently studied LTE band in UK is 2350-2390MHz. Likely deployment scenario is one 20 MHz carrier/base station in one site. This is also the test scenario in this study.

Main scenarios

- **Scenario 1:**
  - WLAN receiver is de-senzitized due to high level RF entering the receiver
  - Receiver gain control circuitry may be operating incorrectly under high pout of band RF signal influence
- **Scenario 2:**
  - High level RF signals create intermodulation products within WLAN receiver which lands on the Wi-Fi frequency band. Typically the 3rd order harmonics are most likely causes
  - The main third order intermodulation products are generated between two signal as follows
    - Carrier 1: Frequency 1
    - Carrier 2: Frequency 2
    - Intermodulation products:
      - Frequency 2 + (Frequency 1-Frerquency 2)
      - Frequency 1 – (Frequency 2-Frequency 1)
  - Intermodulation product may be caused of signal at different bands or from two signals in nearby band
- **Scenario 3:**
  - Wide band noise leakage from nearby RF carrier to Wi-Fi band

Test scenario in this study: LTE 2.3 GHz and Wi-Fi 2.4 GHz



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SLA table analysis
LTE on / LTE OFF, 9-13.9

Network performance is compared to pre-defined thresholds

10.9 2.4GHz SLA table, averaged data (All APs)

HOUR	"_The Cloud" (NW-6)/Station, 2.4 GHz									
	Beacon availability in managed AP scan	Radio attach success rate	IP address retrieval success rate	Ping success rate	TCP test success rate	Ping RTT	TCP DL throughput	TCP UL throughput	AP radio retransmission rate	Client radio retransmission rate
2014-09-10 03:00:00	97.8%	38.1%	100.0%	70.2%	100.0%	87.9%	93.3%	80.0%	12.8%	66.7%
2014-09-10 04:00:00	89.1%	44.5%	100.0%	75.9%	98.2%	95.1%	91.7%	71.9%	12.8%	50.0%
2014-09-10 05:00:00	95.8%	41.0%	100.0%	61.5%	97.9%	96.9%	85.0%	59.3%	25.6%	52.6%
2014-09-10 06:00:00	93.6%	43.9%	100.0%	66.0%	100.0%	81.8%	73.9%	44.8%	16.2%	50.0%
2014-09-10 07:00:00	88.4%	36.3%	100.0%	57.5%	100.0%	82.6%	57.1%	66.7%	9.7%	41.6%
2014-09-10 08:00:00	92.7%	55.2%	100.0%	71.4%	100.0%	53.3%	50.0%	34.6%	4.4%	20.9%
2014-09-10 09:00:00	100.0%	26.2%	100.0%	29.8%	72.4%	23.5%	11.1%	8.3%	9.0%	25.8%
2014-09-10 10:00:00	100.0%	32.4%	100.0%	35.1%	67.4%	18.5%	31.2%	13.3%	3.0%	24.6%
2014-09-10 11:00:00	87.5%	47.2%	100.0%	47.5%	89.4%	39.3%	35.0%	13.6%	3.1%	26.7%
2014-09-10 12:00:00	85.4%	69.1%	97.9%	66.1%	84.8%	23.1%	3.7%	3.4%	5.8%	26.8%
2014-09-10 13:00:00	88.9%	71.9%	100.0%	60.3%	80.0%	14.3%	4.2%	7.1%	1.5%	25.7%
2014-09-10 14:00:00	76.2%	54.5%	97.2%	58.8%	78.8%	20.0%	15.0%	4.8%	4.8%	38.1%
2014-09-10 15:00:00	80.0%	54.5%	100.0%	62.3%	84.5%	42.4%	20.8%	0%	6.3%	35.9%
2014-09-10 16:00:00	86.4%	69.8%	100.0%	58.6%	87.5%	29.4%	29.2%	12.0%	2.7%	36.9%
2014-09-10 17:00:00	74.4%	60.3%	100.0%	54.7%	80.8%	24.1%	20.0%	0%	3.0%	35.6%
2014-09-10 18:00:00	82.9%	68.4%	97.4%	24.7%	47.2%	25.0%	21.4%	9.1%	1.6%	24.5%
2014-09-10 19:00:00	75.0%	42.3%	100.0%	33.3%	40.0%	0%	0%	0%	5.2%	34.8%
2014-09-10 20:00:00	73.1%	59.5%	100.0%	69.0%	87.2%	40.0%	10.5%	0%	2.6%	32.1%
2014-09-10 21:00:00	83.9%	56.0%	100.0%	74.2%	92.7%	21.7%	22.2%	0%	5.3%	36.4%

LTE OFF

LTE 36dBm

LTE OFF

LTE 49dBm

LTE OFF

LTE 30dBm

LTE OFF

- => No clear impact from LTE

11.9 2.4G SLA table, averaged data (All APs)

HOUR	"_The Cloud" (NW-6)/Station, 2.4 GHz									
	AV008 Beacon availability in managed AP scan	AC001 Radio attach success rate	AC002 IP address retrieval success rate	QURT007 Ping success rate	RE004 TCP test success rate	QURT004 Ping RTT	QUAP001 TCP DL throughput	QUAP002 TCP UL throughput	QURS004 AP radio retransmission rate	QURS007 Client radio retransmission rate
2014-09-11 03:00:00	47.7%	22.3%	100.0%	38.3%	100.0%	94.4%	83.3%	73.3%	20.3%	66.7%
2014-09-11 04:00:00	68.8%	33.0%	100.0%	55.3%	100.0%	100.0%	100.0%	84.6%	39.6%	44.4%
2014-09-11 05:00:00	56.1%	21.8%	100.0%	40.0%	100.0%	86.4%	82.4%	80.0%	33.8%	23.7%
2014-09-11 06:00:00	53.2%	17.9%	100.0%	30.4%	100.0%	92.9%	72.7%	69.2%	27.1%	25.0%
2014-09-11 07:00:00	91.2%	41.2%	100.0%	63.6%	100.0%	90.5%	100.0%	62.5%	7.7%	38.2%
2014-09-11 08:00:00	82.1%	45.0%	100.0%	52.9%	92.2%	44.4%	36.0%	36.4%	3.4%	33.6%
2014-09-11 09:00:00	84.6%	76.3%	100.0%	86.8%	88.3%	45.5%	39.1%	3.3%	4.2%	26.0%
2014-09-11 10:00:00	92.6%	63.5%	100.0%	64.7%	94.6%	45.5%	21.9%	9.5%	2.8%	32.6%
2014-09-11 11:00:00	88.9%	57.1%	100.0%	66.7%	86.7%	8.3%	11.8%	0%	10.4%	32.6%
2014-09-11 12:00:00	83.8%	68.2%	100.0%	62.2%	83.8%	32.1%	15.4%	4.3%	5.4%	37.9%
2014-09-11 13:00:00	83.3%	75.3%	100.0%	57.9%	88.8%	36.4%	23.5%	14.3%	4.7%	32.2%
2014-09-11 14:00:00	77.4%	57.0%	100.0%	51.1%	71.2%	34.8%	10.0%	11.8%	4.5%	31.3%
2014-09-11 15:00:00	90.0%	43.4%	100.0%	46.8%	88.5%	27.3%	10.3%	0%	2.5%	23.6%
2014-09-11 16:00:00	86.7%	65.1%	100.0%	72.5%	86.8%	13.8%	19.5%	11.1%	4.6%	27.2%
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2014-09-11 18:00:00	85.2%	46.2%	100.0%	39.6%	54.2%	5.3%	5.0%	16.7%	15.6%	18.5%
2014-09-11 19:00:00	73.3%	52.8%	100.0%	18.5%	68.4%	20.0%	0%	0%	21.0%	21.0%
2014-09-11 20:00:00	66.7%	32.4%	100.0%	43.8%	83.3%	0%	0%	0%	8.5%	31.2%
2014-09-11 21:00:00	76.5%	57.8%	100.0%	50.0%	90.3%	53.8%	23.5%	36.4%	7.3%	34.5%

LTE OFF

LTE 36dBm

LTE OFF

LTE 49dBm

LTE OFF

LTE 30dBm

LTE OFF

- => No clear impact from LTE

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Summary of 2.3 GHz LTE and Wi-Fi co-location

Observations and conclusion

- Spectrum analysis measurements did not show noticeable impact from LTE traffic
- Day internal active and passive testing did not show any meaningful correlation with degraded performance and LTE transmitter presence
- **Tested scenario does not show 2.3 GHz LTE transmitter impacting negatively on Wi-Fi performance**

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Summary of General Wi-Fi Performance

Observations 1/2

- Overall Wi-Fi performance and **service quality is modest**. Clients experience connection to Wi-Fi but do not get sufficient throughputs for quality web browsing or other general data usage
- 2.4 GHz access points have **10-20 users** and 5 GHz radios **10-30 users** in peak hours
- **Apple devices** are dominating both bands (75%)
- **Uplink throughput is very low**, in the range of 100kbit/s. Downlink is also low, below 1Mbit/s during day time
- **5 GHz radio works better than 2.4 GHz**, as expected. However, the ADSL connection bottleneck limits better user experience there too
- **The main limitation is the slow ADSL connection** from Victoria station to internet
- **Attach and beacon availability metrics are not accurate**. During the measurements, band steering caused 2.4 GHz attach success rate to degrade. Band steering feature on purpose delays attach process for clients using 2.4 GHz which have been earlier seen using 5 GHz. Current 7signal band steering bypass feature is not optimal for Ruckus. Ruckus APs require 8 authorization requests to bypass and access it. 7signal sensors do not currently make these requests fast enough during each test and access to 2.4 GHz radio is delayed and may fail
- **A lots of personal hotspots** in the area

Observations 2/2

- Active tests have **relatively well balanced rate distribution**
- Passively measured **end user traffic data rates are spread across all the rates** and include also **the lowest rates down to 1 Mbit/s**. This indicates that coverage may not be optimal Wi-Fi service
- **Air utilization is high**, also **surprisingly high at 5 GHz** band in the channels used by measured APs
- **All (overlapping) 2.4 GHz channels are used**. This causes packet loss and increases retries further
- **Retry levels are very high.** This indicates that used data rates are still too high in the given conditions. Rate control should reduce rates further if retries are in this high level. However, this is not uncommon behavior in Wi-Fi but increases rapidly air utilization and reduces overall network capacity
- **APs make a lot of channels changes** when trying to find better spectrum to operate
- There is **significant amount of non-Wi-Fi interference in certain areas (Eye 1)**. This degrades Wi-Fi near to it

Recommendations

- Significantly faster ADSL/interconnection is needed to improve performance. This will have a significant positive impact to end users
- RF operation should be improved as well
  - 2.4 GHz utilization is high during busy hours
    - 802.11b should be disabled or at least the 1-2Mbit/s would need to be removed
    - Less dense beaconing might be helpful (100ms -> 300ms). Optimally also other WLANS should follow this
  - Radio link does not operate properly, uses too high data rates and has very high retry levels
    - Organize and balance channel usage in the area (if possible)
    - Disable the largest MCSs and data rates. Forces clients using lower rates
    - Using A-MPDU aggregation might help lowering retries
    - Review if coverage area is really sufficient with the current APs placements
- Source of interference near to Eye 1 should be located and removed if possible
- Better performance in the available Wi-Fi might reduce use of personal hotspot, which further would help improving the Wi-Fi performance
- **Network performance can be improved significantly with optimization**