



Connectivity on Trains Measurement Study

A study into wireless network performance
and coverage across selected train journeys

June 2026

Prepared for



Prepared by

streetwave

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How to Read This Report

Good Performance: The phone achieved a download speed of at least 5 Mbit/s, an upload speed of at least 1.5 Mbit/s and a response time (latency) of 50 milliseconds or better within the same test cycle. At this level, a passenger should be able to stream video, make video calls, browse the web and send photos without noticeable delay.

Executive Summary

This study, commissioned by Ofcom and delivered by Streetwave, measured mobile and Wi-Fi performance across 50 journeys on 24 rail lines in February and March 2026.

Key Findings

Mobile Networks

- **The best performing network meets the Good Performance threshold less than half the time.** EE delivered Good Performance across 42% of the measurement campaign, with Three, O2 and Vodafone delivering between 17-21%.
- **5G Standalone (SA) transforms the experience where it is deployed.** Good Performance rises on 5G SA, but the technology is deployed sparsely between networks from 0-32%.
- **The core problem is weak mobile signal reaching train passengers.** Most failures are caused by weak signal along rail corridors, which can be further attenuated by certain types of rail carriage.
- **Rural and intercity passengers experience materially worse service than urban ones.** Good Performance pass rates ranged from 82% on short London routes to 4% on cross-country lines.
- **Latency¹ (responsiveness), is the main reason tests fail to meet the Good Performance threshold.** Even when download and upload speeds met the Good Performance threshold, latency was often the bottleneck.
- **Performance was shown to worsen at peak times for commuters.** The Bedford to London case study showed passengers experiencing network congestion during peak travel times.

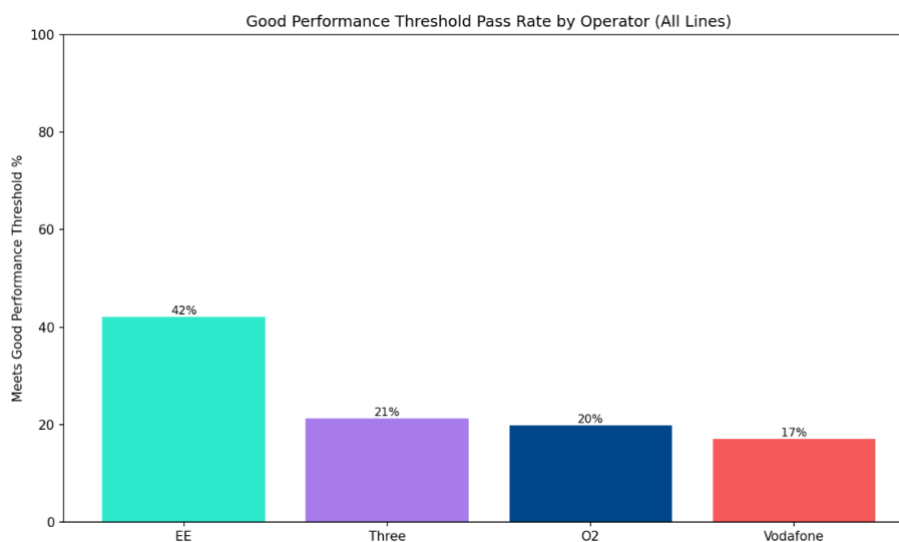


Figure 1: Good Performance threshold pass rate by operator for all lines weighted by time spent on each journey.

¹ Latency in this report is defined as round-trip-time for packets

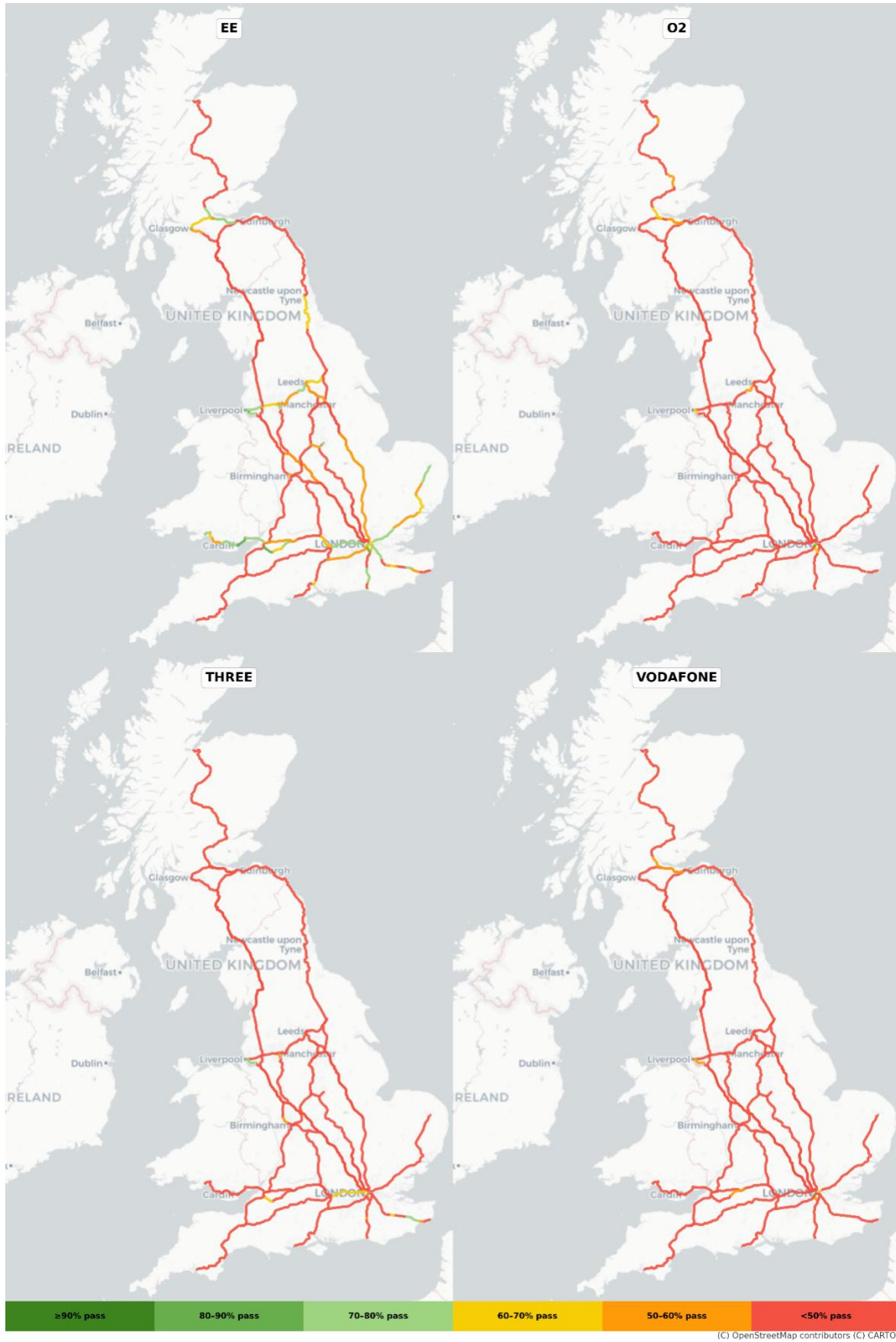


Figure 2: Good Performance threshold pass rate by operator for all rail segments under test.

The table below summarises Good Performance across all 24 measured rail lines for the four mobile network operators and onboard Wi-Fi.

Route	EE	O2	Three	Vodafone	Wi-Fi
Great Western					
London to Bristol (via Swindon, Bath Spa)	70%	18%	47%	38%	0%
London to Plymouth (via Taunton, Exeter, St Davids)	45%	13%	25%	12%	0%
London to Swansea (via Swindon, Bristol, Cardiff)	64%	17%	31%	26%	0%
East Coast Main Line					
London to Leeds (via Doncaster)	52%	19%	38%	17%	0%
London to Edinburgh (via York, Newcastle)	45%	29%	17%	18%	0%
West Coast Main Line					
London to Manchester (via Stoke on Trent)	31%	8%	12%	13%	0%
London to Liverpool (via Nuneaton, Stafford)	59%	25%	36%	25%	N/A
London to Glasgow (via Stafford, Preston)	32%	13%	17%	9%	0%
London to Edinburgh (via Stafford, Preston)	26%	9%	11%	8%	N/A
Midland Main Line					
London to East Midlands Parkway	25%	10%	9%	10%	0%
Nottingham to East Midlands Parkway	66%	18%	22%	7%	0%
Derby to East Midlands Parkway	54%	13%	20%	17%	0%
Cross Country and TransPennine					
Taunton to Leeds	19%	10%	13%	11%	0%
Basingstoke to Coventry (via Reading, Oxford)	9%	4%	5%	6%	0%
Sheffield to Doncaster	20%	12%	7%	10%	N/A
Liverpool to York (via Earlestown, Manchester, Wakefield, Leeds)	65%	41%	22%	32%	0%
Southern and South Eastern					
London Bridge to Brighton	61%	36%	32%	18%	N/A
London Victoria to East Croydon	82%	73%	48%	68%	0%
London to Dover (via Sevenoaks, Tonbridge, Ashford)	54%	31%	47%	26%	0%
London to Bournemouth (via Basingstoke, Southampton)	45%	13%	22%	21%	23%

East Anglia					
London to Norwich (via Colchester, Ipswich)	64%	29%	21%	15%	0%
Scotland					
Edinburgh to Glasgow (via Falkirk)	62%	29%	4%	23%	N/A
Edinburgh to Inverness (via Perth)	39%	45%	14%	19%	N/A
Bedford					
Bedford to London St Pancras Peak	25%	10%	19%	7%	0%

Table 1: Good Performance threshold pass rate by operator. *N/A indicates results could not be reliably captured - affecting latency on Avanti West Coast lines (ICMP ping tests did not run) and Wi-Fi on journeys with no SSID broadcasting (e.g. London Bridge to Brighton) or frequent disconnections.

On-board Wi-Fi

- **On-board Wi-Fi met the Good Performance threshold across 1% of the measurement survey.** Only South Western Railway, who are testing a trackside millimetre-wave technology, delivered a meaningful service as part of their technology trial. It should be noted that Wi-Fi was not available on all rail journeys, and on some rail journeys Wi-Fi disconnected frequently preventing continuous testing (full details available in the report).
- **Wi-Fi speed throttling by Train Operating Companies (TOCs) is too severe and prevents passengers from experiencing Good Performance more often.** The data shows consistent speed caps (around 1 Mbit/s on some routes) and clear evidence of per-user data caps where performance collapses abruptly part-way into a journey.
- **On-board Wi-Fi hardware is generations behind current standards.** All Wi-Fi networks observed used either Wi-Fi 4 or 5, with one train using Wi-Fi 3 (802.11g); no modern Wi-Fi 6 or 7 standards, designed for crowded environments like train carriages, were observed.

Conclusion

This study covered 24 of the busiest passenger rail lines in the UK, representing approximately 33% of the total rail network. The results show that in-train connectivity does not yet consistently meet the expectations of modern passengers, with significant variation by route, operator and time of day. Improving the experience will require continued coordination between mobile operators, train operating companies and rolling stock manufacturers, alongside supportive policy and regulatory frameworks.

Encouragingly, the technologies capable of delivering meaningful improvements to passenger experience already exist and were observed during this study. The opportunity now lies in aligning commercial investment, planning and deployment across the industry to bring these solutions to scale.

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Introduction

About This Report

This study was commissioned by Ofcom to measure mobile and Wi-Fi connectivity on key rail routes across Great Britain. The study assessed the coverage and performance of four mobile network operators, namely EE, O2, Vodafone and Three, alongside on-board Wi-Fi systems across 24 rail lines.

A total of 50 individual journeys were completed between 18 February and 10 March 2026, covering routes in England, Scotland and Wales. The objective of this study is to provide meaningful information to passengers, policymakers and Ofcom regarding the current state of connectivity on trains across Great Britain.

Streetwave was commissioned as the independent network testing and analysis partner to run detailed network experience surveys to support the program. Streetwave was responsible for data collection, processing and analysis of the rail lines, including the production of this report.

Scope

This study sought to assess the coverage and performance of wireless connectivity across 24 rail lines:

Basingstoke to Coventry (via Reading)	London to Edinburgh (via York, Newcastle)
Bedford to London St Pancras	London to Glasgow (via Stafford, Preston)
Derby to East Midlands Parkway	London to Leeds (via Doncaster)
Edinburgh to Glasgow (via Falkirk)	London to Liverpool (via Nuneaton, Stafford)
Edinburgh to Inverness (via Perth)	London to Manchester (via Stoke on Trent)
Liverpool to York (via Manchester)	London to Norwich (via Colchester, Ipswich)
London Bridge to Brighton	London to Plymouth (via Taunton, Exeter)
London to Bournemouth (via Basingstoke)	London to Swansea (via Swindon, Cardiff)
London to Bristol (via Bath Spa)	London Victoria to East Croydon
London to Dover (via Sevenoaks)	Nottingham to East Midlands Parkway
London to East Midlands Parkway	Sheffield to Doncaster
London to Edinburgh (via Stafford)	Taunton to Leeds

Methodology

Equipment & Setup

Four modern chipset smartphones (one per operator: EE, O2, Vodafone, Three) plus a fifth Wi-Fi-only smartphone were mounted in a standardised polylactic acid (PLA) enclosure with 20mm spacing. Standard consumer SIMs with no data caps or speed restrictions were used across all operators.

Fieldwork

50 journeys across 24 rail lines were completed by three operatives between 18 February and 10 March 2026, measured between 08:00-20:00. The Bedford-St Pancras route was measured over four journeys to compare peak vs. off-peak connectivity experience. On all journeys, best attempts were made by operatives to sit in the same middle position of the middle carriage, with the unit on the table at abdominal height. Passenger loading and other observations were noted and can be found in the line-by-line section.

Key Limitations

Each route was measured once per direction on a single day, so results may not reflect seasonal or temporal variation. Passenger loading, rolling stock type, and weather all influence performance but could not be fully controlled. Wi-Fi rate limiting was observed for some train operators, potentially understating network capacity.

The full methodology can be found in the appendix.

Aggregate Network Performance

Across all 50 journeys measured on 24 rail lines, the proportion of tests meeting the Good Performance threshold varied considerably between mobile network operators. Table 2 presents the aggregate results of networks and Wi-Fi meeting the Good Performance threshold.

Operator	Mean	Median	Range	Standard Deviation
EE	42%	45%	9% – 82%	19%
Three	21%	21%	4% – 48%	13%
O2	20%	18%	4% – 73%	15%
Vodafone	17%	16%	6% – 68%	13%
Wi-Fi	1%	0%	0% – 23%	5%

Table 2: Good Performance threshold pass statistics by operator across all 50 journeys (standard deviation calculated from lines being weighted equally).

EE achieved the highest mean Good Performance at 42%, approximately double that of Three (21%) and O2 (20%) and more than double Vodafone (17%). On-board Wi-Fi delivered a mean of 1%, with a median of 0%. On the majority of routes, Wi-Fi returned no tests meeting the threshold. Some rail journeys had challenges with Wi-Fi connectivity during data collection, more information can be found in the On-board Wi-Fi performance section.

The range within each operator is large. EE ranged from 9% on Basingstoke to Coventry (a 117-mile cross-country route through mixed terrain) to 82% on London Victoria to East Croydon (a short, 10-mile urban corridor with dense macro network infrastructure). Similarly, O2 ranged from 4% on the same line - Basingstoke to Coventry - to 73% on the Victoria to East Croydon route. These extremes reflect how profoundly the RF environment varies between rail corridors, route length, terrain profile, proximity to existing macro sites and rolling stock type. All these factors contribute to a performance spread that is wider within each operator than the gap between operators.

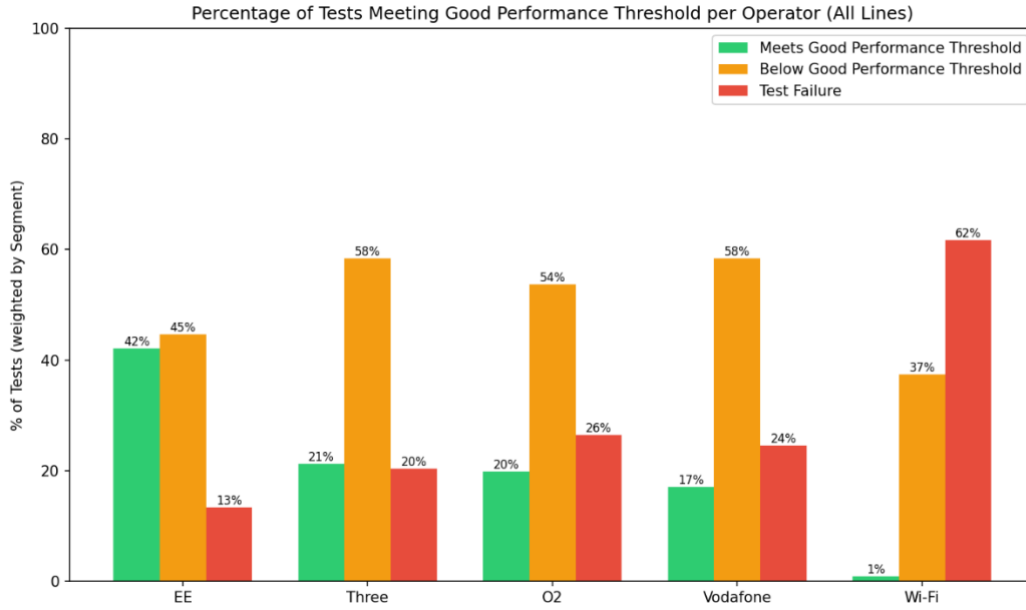


Figure 3: Percentage of tests meeting the Good Performance Threshold, below the Good Performance Threshold and failing per operator for all lines.

Throughput Distribution

This section examines the distribution of Quality-of-Service (QoS) metrics that make up the Good Performance threshold for each Mobile Network Operator (MNO).

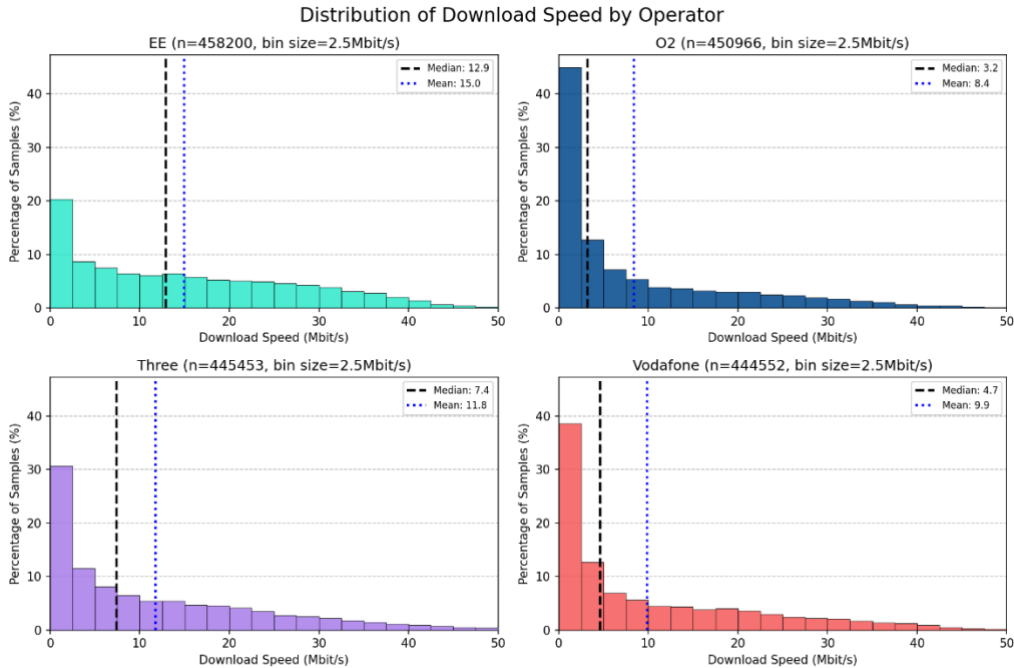


Figure 4: Distribution of download speed (Mbit/s) samples in 2.5Mbit/s intervals for each operator.

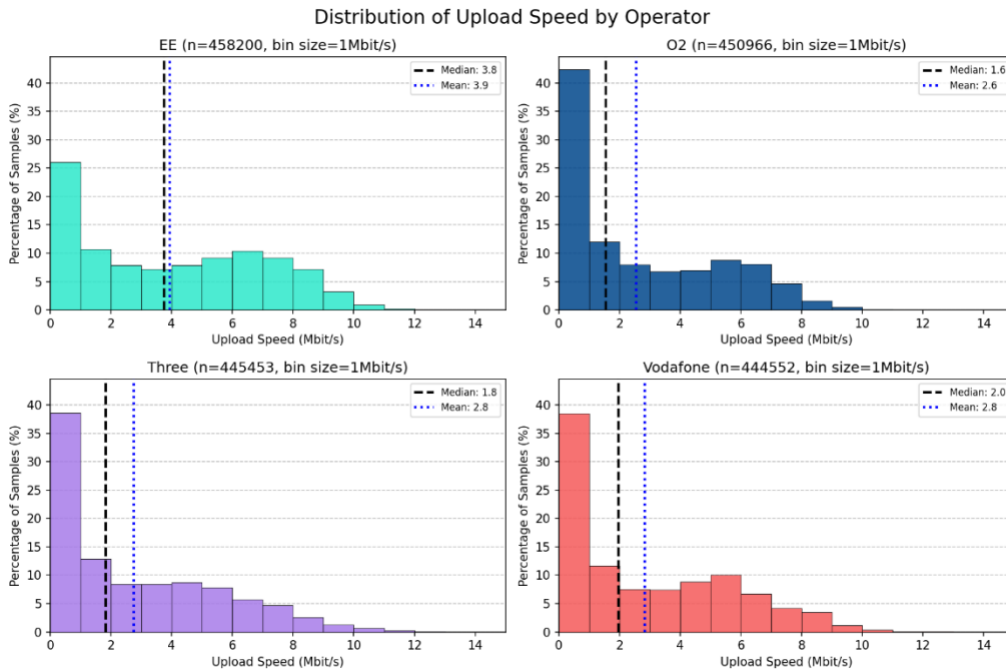


Figure 5: Distribution of upload speed (Mbit/s) samples in 1Mbit/s intervals for each operator.

For the download and upload sample distributions, all operators follow a broadly similar pattern with EE having the fewest samples falling in the lower speed bins. For download speed, the pattern clearly shows all operators having fewer samples in the higher-throughput bins. For upload speed, the pattern is similar, with a large number of samples in the lowest bin, however each operator sees a second local maximum around the 4-6Mbit/s bins. EE consistently leads the other operators in terms of mean and median speeds across both metrics.

Latency Distribution

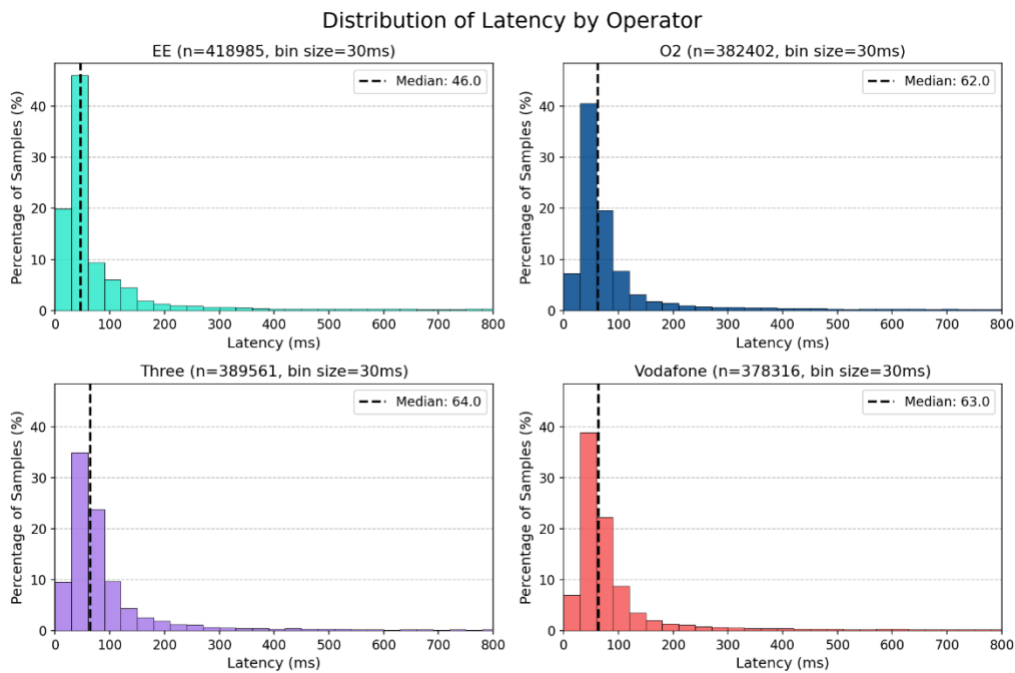


Figure 6: Distribution of latency (milliseconds) samples in 30ms intervals for each operator (discounting test failures).

For latency, EE performs better than the other operators, with 20% of their samples falling in the 0 – 30ms bin; EE are the only operator where the median latency passes the Good Performance threshold. O2, Vodafone and Three all have a median within a few milliseconds of each other, but Three has a more dispersed distribution: its modal 30–60ms bin captures ~35% of samples (against ~39 to ~41% for O2 and Vodafone). Beyond the median, tail behaviour is consistent across all four operators - each has roughly 5.4–5.7% of samples above 300ms, and the shape of the tail past ~200ms is nearly indistinguishable between operators.

Performance Root-Cause Analysis

The Good Performance threshold used throughout this study, defined as ≥ 5 Mbit/s download, ≥ 1.5 Mbit/s upload and ≤ 50 ms latency measured in test cycles, was specified in the Ofcom measurement brief for this project. This threshold was designed to reflect the performance requirements of typical consumer usage, as outlined in the Map Your Mobile methodology [1].

To understand why tests didn't reach the Good Performance threshold, each measurement that fell short of the threshold was classified using an RF (radio frequency) classification framework. The framework applies a hierarchical decision tree based on passive radio measurements reported by the handset.

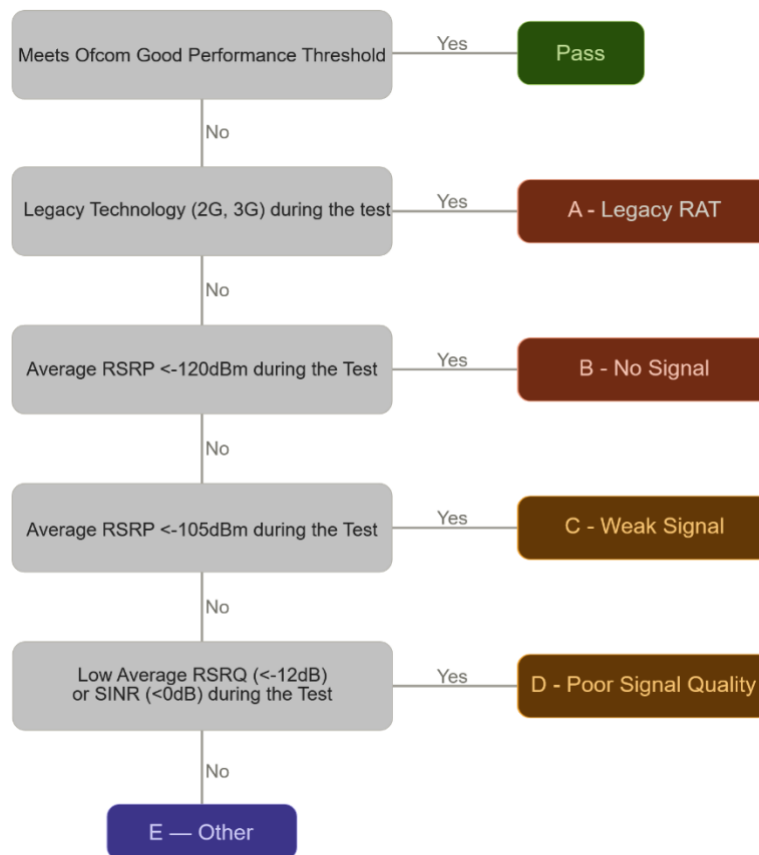


Figure 7: Decision tree for failure classification.

This assessment consists of:

1. First assessing for legacy technology (Category A: 2G/3G RAT)
2. Assessing for signal absence (Category B: RSRP below -120 dBm). This signal strength (or weaker) has been shown to have less than a 50% likelihood of meeting the Good Performance threshold based on analysis of Crowdsense data [1].
3. Assessing for weak signal (Category C: RSRP between -105 and -120 dBm [1])

4. Assessing for poor signal quality (Category D: $RSRQ \leq -12$ dB or $SINR \leq 0$ dB). SINR threshold of 0 dB represents the physical break point at which signal power equals interference-plus-noise power, below which reliable demodulation of higher-order modulation schemes is not possible.
5. Measurements that did not meet the threshold but do not match any of these RF conditions are assigned to Category E.

Table 3 presents the mean classification breakdown by operator across all journeys.

Operator	A: Legacy Technology	B: No Signal	C: Weak Signal	D: Poor Signal Quality	E: Other
EE	1%	9%	47%	25%	18%
Three	0%	17%	55%	13%	15%
O2	0%	8%	50%	27%	15%
Vodafone	6%	8%	41%	26%	19%

Table 3: Mean RF classification of poor and zero-connectivity measurements by operator.

Category C (weak signal, RSRP between -105 and -120 dBm) is the dominant classification across all four MNOs, accounting for ~41% to ~55% of classified measurements. This indicates that the primary constraint on mobile performance across the rail network is inadequate received signal level: the fundamental reach of the macro network into the train environment.

The secondary classifications reveal operator-specific patterns. Three recorded the highest proportion of Category B (no signal, RSRP below -120 dBm) at ~17%, compared with ~8% to ~9% for the other three operators. In contrast, Vodafone recorded the highest Category A (legacy technology) proportion at ~6%. Vodafone's handsets fell back to 2G on a measurable proportion of samples, reaching ~35% of all samples on Sheffield to Doncaster and ~16% on Basingstoke to Coventry (see Table 8). No other operator exceeded 5% legacy technology usage on any route, EE's highest 2G utilisation was just under 5% on London to Manchester (via Stoke on Trent).

Category D (poor signal quality, defined as $RSRQ \leq -12$ dB or $SINR \leq 0$ dB) accounted for ~26% of classified measurements for EE, O2 and Vodafone, but only ~13% for Three. This disparity suggests that where Three has coverage, the signal quality tends to be adequate (reasons for this discussed later in the Signal Quality Analysis section); its performance limitations are more binary in nature (signal present or absent) rather than quality related. For the other three operators, approximately one quarter of poor performance occurs in conditions where signal level is above -105 dBm but signal quality is degraded.

It should be recognised that the RF classification framework is most directly predictive of throughput performance. Latency, which forms one of the three criteria in the Good Performance threshold, has a partially overlapping but distinct set of drivers. Signal quality degradation (Category D) does contribute to elevated latency through increased HARQ (hybrid automatic repeat request) retransmission rates on the air interface: in LTE FDD, a

HARQ round trip takes 8ms [2] [3] and where initial transmissions fail due to poor signal quality, each retransmission adds this delay to the overall latency budget. Multiple retransmissions in succession can push round-trip latency above the 50ms threshold even where throughput remains adequate.

Beyond signal quality, however, latency is also driven by factors that the classification framework does not decompose, for example: handover events during which data transfer briefly stalls (especially with instances of handover failure), RRC state transitions when a connection resumes after a period of inactivity and the radio access technology in use. Backhaul transport latency between the cell site and the core network is a further contributor.

Network capacity constraints due to cell congestion can also degrade latency independently of RF conditions. Where a test does not meet the Good Performance threshold on latency alone, with adequate signal level and quality, the framework assigns it to Category E. This does not indicate an absence of explanation; it indicates that the dominant drivers in these cases lie outside the RF conditions observable through this measurement campaign.

Technology Deployment: The 4G to 5G Transition

The radio access technology (RAT) to which a device connects has a direct bearing on the throughput it can achieve. This section examines how far each operator has progressed through the transition from 4G (LTE) to 5G (NR) along the measured rail corridors, using the RAT recorded for each passive measurement sample. Two distinct 5G deployment modes are relevant: 5G Non-Standalone (NSA), in which a 5G NR radio carrier is added to the existing 4G LTE core network and is anchored to a 4G control plane; and 5G Standalone (SA), in which the device connects to a dedicated 5G core network without any 4G anchor dependency. SA offers architectural advantages including reduced control-plane latency, network slicing capability and optimised uplink scheduling, but requires network-side deployment, device/SIM support and a compatible plan type.

Operator	2G	4G	5G NSA	5G SA
EE	1%	37%	30%	32%
O2	0%	56%	37%	7%
Three	0%	68%	32%	0%
Vodafone	4%	69%	18%	9%

Table 4: RAT distribution by operator (proportion of passive measurement samples). 5G NSA: 5G Non-Standalone (NR carrier anchored to LTE core). 5G SA: 5G Standalone (NR carrier on 5G core).

The technology profiles in Table 4 differ markedly. EE maintains a roughly even three-way distribution, which represents the most advanced 5G deployment observed in the study. By contrast, Three remains predominantly a 4G network along these corridors, with 68% of samples on LTE and 32% on 5G NSA. Vodafone and O2 sit between these findings, with Vodafone notably still carrying 4% of samples on 2G. Despite Vodafone and Three sharing their RAN through MOCN, Three users were not able to use Vodafone 5G SA at the time of this train survey [4].

A breakdown of the RAT share observed per line can be found in the appendix in Table 8.

The performance implications of this technology mix are substantial. Figure 8 presents the Good Performance pass rate by RAT and operator.

RAT Performance

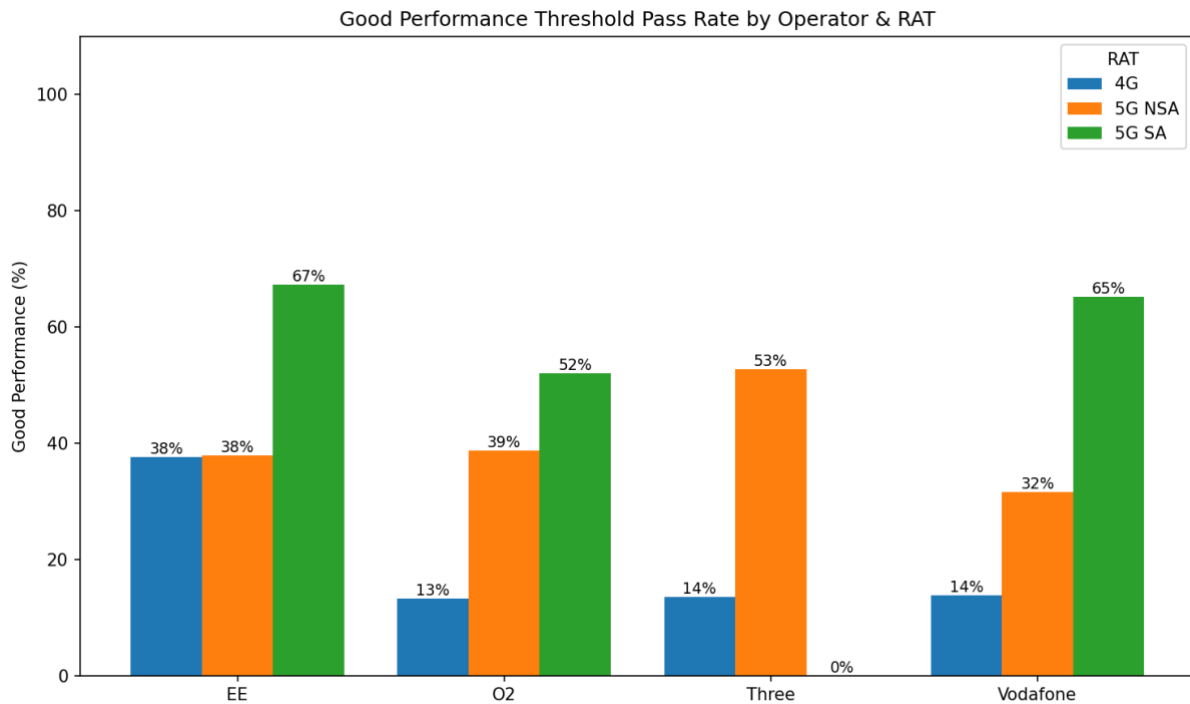


Figure 8: Good Performance threshold pass rate by RAT and operator.

On 4G, EE achieves a Good Performance rate of 38%, nearly three times the 13% - 14% recorded by O2, Three and Vodafone. This disparity on the same technology generation is not explained by RAT alone but can begin to be explained by the spectrum bands deployed by each operator, which is further examined in the next section. On 5G NSA, pass rates range from 32% (Vodafone) to 53% (Three). On 5G SA, EE achieves 67%, O2 52% and Vodafone 65%. Three's 5G SA figure (0%) reflects its absence of a 5G SA network, rather than a measured performance outcome.

EE sees the smallest change between 4G and 5G NSA indicating the other 3 operators were held back more by bandwidth than EE. However, the absolute performance at each technology tier varies considerably, indicating that RAT alone does not determine outcomes. The spectrum band on which each technology is deployed plays a critical role, as discussed in the following section.

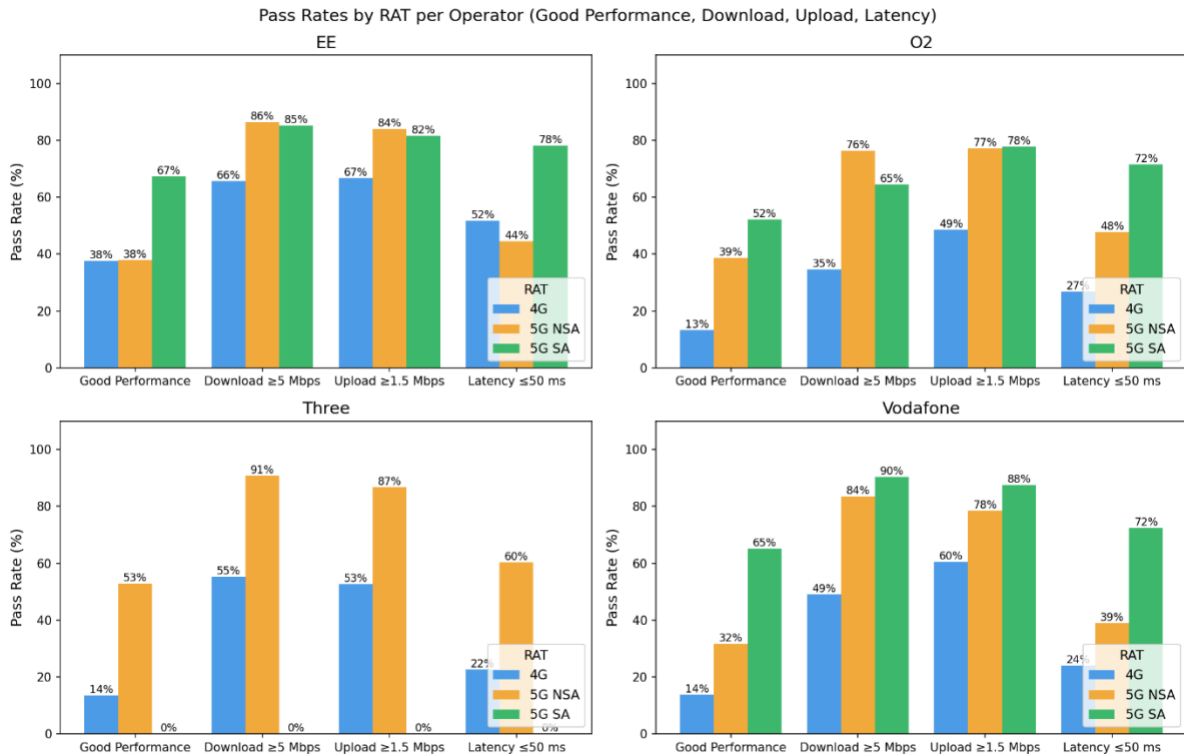


Figure 9: Good Performance threshold, download, upload and latency pass rates by RAT and operator.

Figure 9 shows that all operators who have deployed 5G Standalone see a notable improvement in latency threshold pass rate, which is usually the determining factor for whether a test passes the Good Performance threshold. EE and O2 both see their download pass rates fall on 5G SA which could be explained by the spectrum deployment on this RAT, discussed in the section below.

EE is the only operator to see their latency pass rate fall when 5G NSA is introduced, despite download and upload pass rates improving. This explains their small increase in Good Performance pass rate from 4G to 5G NSA when compared to the other operators.

Spectrum Utilisation and Band Deployment

The frequency band on which a mobile connection operates determines both the available channel bandwidth (and hence peak throughput) and the propagation characteristics of the signal (and hence coverage reach and carriage penetration). This section examines the spectrum bands used by each operator along the measured rail corridors.

Spectrum Holdings Context

This study was conducted shortly after the completion of the VodafoneThree merger, during which the two networks are in the process of integrating their cell site grids. The merged operator has begun deploying MOCN [5], allowing customers of each network to use the other's cell sites, while individual sites are progressively being rebuilt to carry the full combined spectrum portfolio. As a condition of the merger, several spectrum trades were also made between Vodafone, Three and O2 [6], meaning the spectrum holdings of all three operators differ from their pre-merger positions. These changes do not affect EE.

Since the two networks remain structurally distinct, they have been treated as separate operators throughout this report. Detailed information on spectrum usage at the time of measurement is available on the Ofcom website [7], and a full list of NR-ARFCN and EARFCN values observed for each operator can be found in the appendix (Figure 36, Figure 37, Figure 38, Figure 39).

4G Band Distribution

The 4G band distribution below reveals a fundamental structural difference between operators largely reflecting their different spectrum holdings. Figure 10 (Full data in Table 9 in the Appendix) presents the percentage of 4G samples recorded on each primary band (4G or 5G NSA). It is important to note there are additional bands in the secondary cells (in use via carrier aggregation) which are not represented in this data.

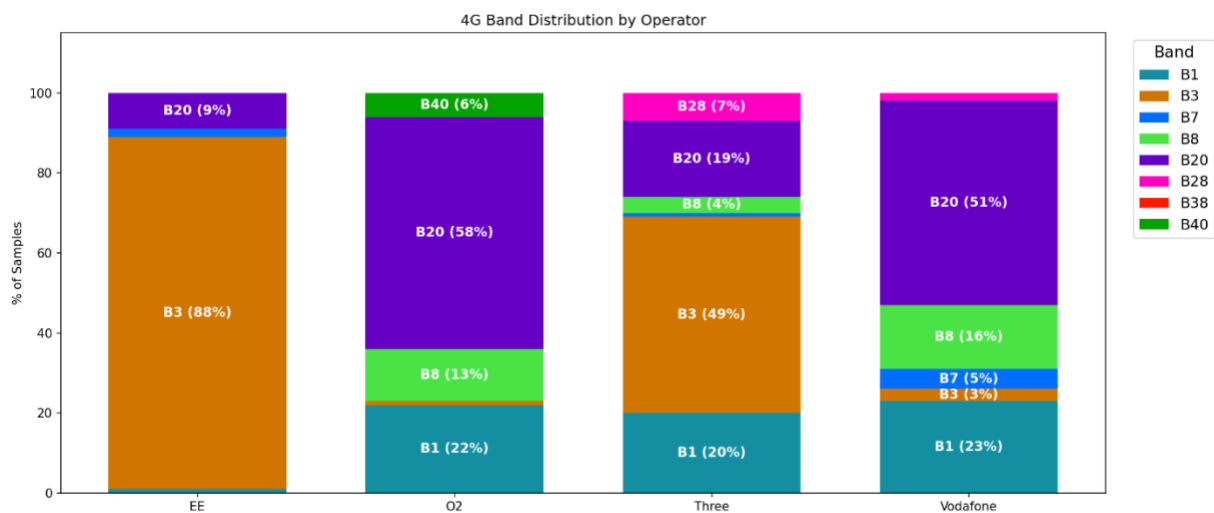


Figure 10: 4G PCell band distribution by operator (only shows bands with more than 1% sample size).

The mapping of 4G Bands is defined in 3GPP TS 36.101 Table 5.5-1. [8]

5G Band Distribution

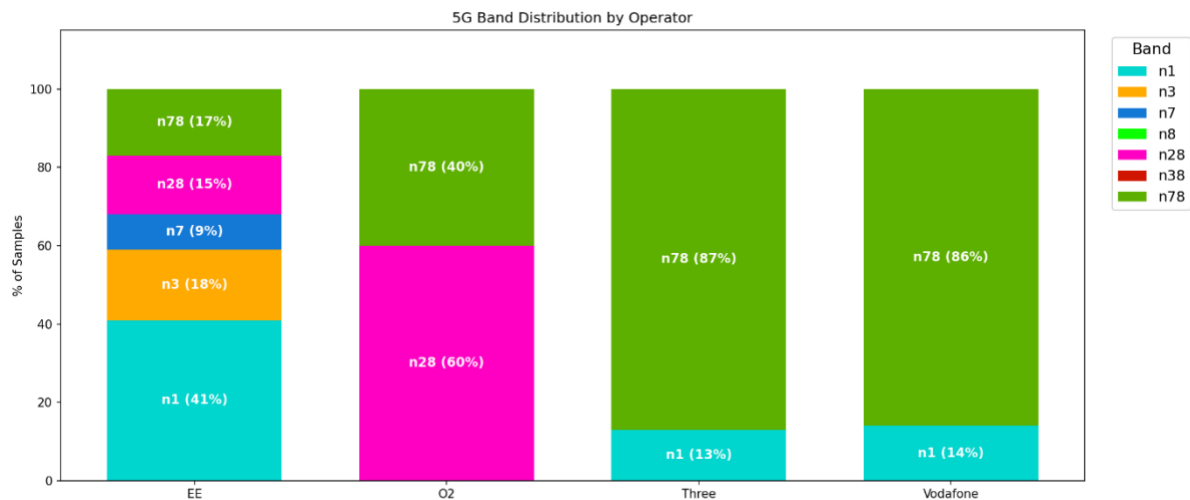


Figure 11: 5G Band (PCell in SA, first SCell in NSA) distribution by operator (only shows bands with more than 1% sample size).

For 5G, the frequency distributions are particularly concentrated – except for EE. This is to be expected as 5G deployments began with the addition of n78 to existing cell sites, with low-band 5G generally being added on n28 following the award of 700MHz licenses in 2021 [9]. The operators can also be seen deploying other 5G bands via the use of spectrum refarming [10] and dynamic spectrum sharing (DSS) [11].

EE has the most diverse frequency deployment on their 5G network, with a commercial deployment across 5 bands: n1 (~41%), n3 (~18%), n7 (~9%), n28 (~15%) and n78 (~17%). This multi-band SA deployment provides both coverage (via lower frequency bands) and capacity (via C-band).

Similar to EE, O2 has 5G deployed on 5 frequency bands: n1, n8, n28, n38 and n78. Their 5G deployment was primarily observed on n28 (700 MHz), a low-band deployment that provides good propagation but only 10MHz of paired bandwidth. Similarly to the other operators, O2 has a substantial deployment in the n78 band, however, diverges from the other 3 operators with n1 observed less frequently (<1% of samples). Very small deployments of n8 were also observed (~0.03%) as well as n38 which O2 recently increased their holding of through the VodafoneThree merger (from 20MHz to 40MHz unpaired [12]) (see Table 10 for more details).

Vodafone and Three observed similar 5G frequency distribution on n78, (~86% and ~87% respectively) and n1 (~14% and ~13% respectively). The operators have different bandwidth holdings in n78 (with Three typically deploying 140MHz unpaired [13] and Vodafone deploying 90MHz unpaired [14]) which can greatly impact performance. Similarly to O2, a small n8 deployment was observed on Vodafone (see Table 10).

The mapping of 5G Bands is defined in 3GPP TS 38.101-1 Table 5.2-1. [15]

Signal to Throughput Efficiency

This section uses linear regression across the combined measurement samples from all rail journeys to test whether, at equivalent received signal levels, operators deliver systematically different throughput.

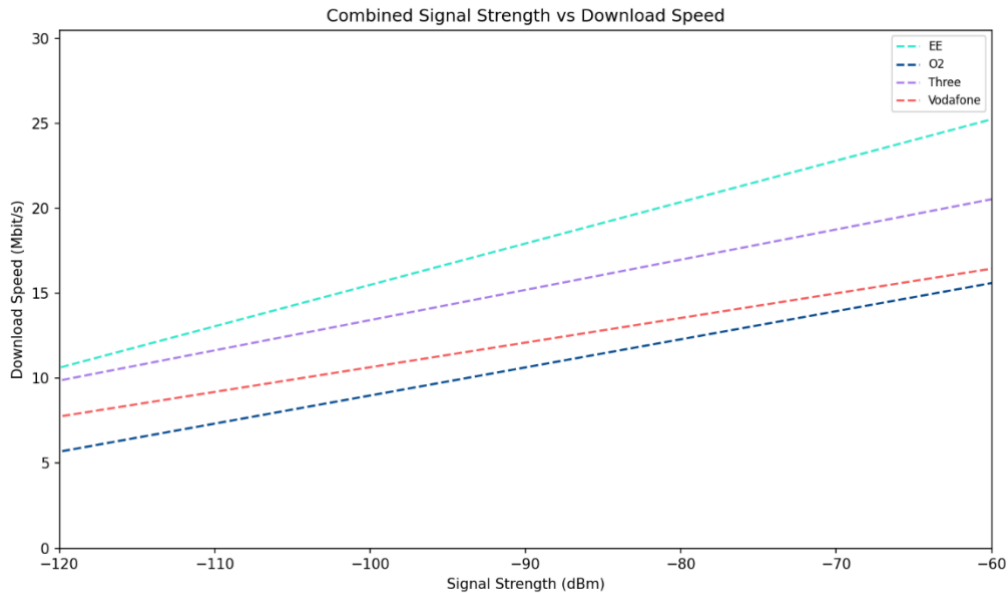


Figure 12: Signal strength (Combined 4G RSRP and 5G SS-RSRP) versus download speed (Mbit/s) by operator.

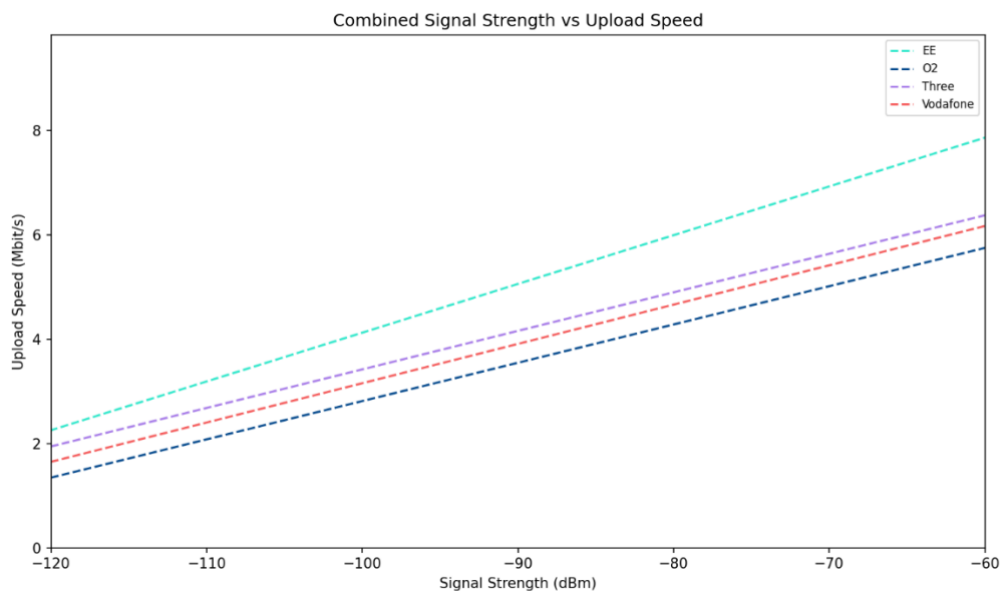


Figure 13: Signal strength (Combined 4G RSRP and 5G SS-RSRP) versus upload speed (Mbit/s) by operator.

Figure 12 and Figure 13 present fitted RSRP-to-throughput relationships across the pooled 4G and 5G SA dataset. At any given RSRP, EE delivers the highest download and upload speeds. At -100 dBm, EE's fitted download speed is approximately 15.5 Mbit/s, compared

with 13.4 (Three), 10.6 (Vodafone) and 9.0 Mbit/s (O2). EE also has the steepest download slope (0.244 Mbit/s per dB versus 0.145–0.178 for the others), so the gap widens at stronger signal levels.

R^2 values for download are low across all operators (0.026–0.071); RSRP alone explains less than 8% of the variance. Upload R^2 values are two to three times higher (0.112–0.170), consistent with the uplink being more power-limited. Downlink throughput depends on scheduler state, carrier aggregation (CA), MIMO rank and cell loading, none of which RSRP captures. Research [16] has found RSRP is the best single uplink predictor but SINR is more relevant for downlink.

Statistics on RSRP values observed can be found in the Appendix in Table 11, Table 12 and Table 13.

The persistent operator separation follows from Shannon-Hartley [17]: at a given SNR, capacity scales linearly with bandwidth and EE's typical wider aggregated bandwidth accounts for its advantage.

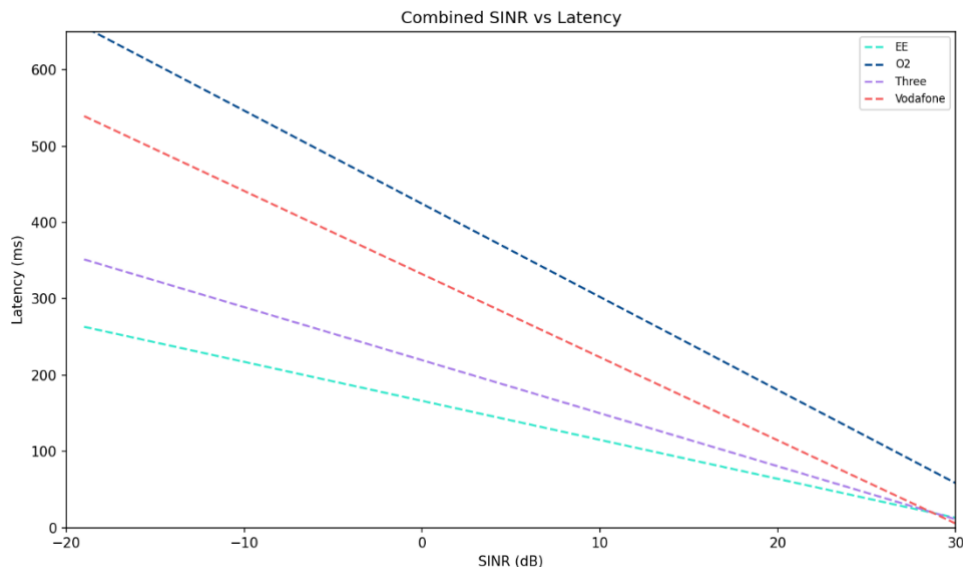


Figure 14: Signal Quality - SINR (Combined 4G SINR and 5G SS-SINR) versus latency (milliseconds) by operator.

Across all four operators, latency exhibits a consistent inverse relationship with SINR, confirming that improvements in signal quality drive measurable reductions in network response time. EE shows the shallowest gradient (-5.1ms/dB) and the lowest baseline latency, followed by Three (-7.0ms/dB), while Vodafone (-10.9ms/dB) and O2 (-12.2ms/dB) exhibit steeper slopes and higher latencies in poor-signal conditions.

At high SINR ($\sim 28\text{--}29\text{ dB}$), the EE, Three, and Vodafone regression lines converge toward a common low-latency floor of roughly 20ms, indicating broadly comparable best-case performance, whereas O2 has a higher floor suggesting other factors beyond SINR (e.g. core-network routing, backhaul, and load).

Signal Quality Analysis

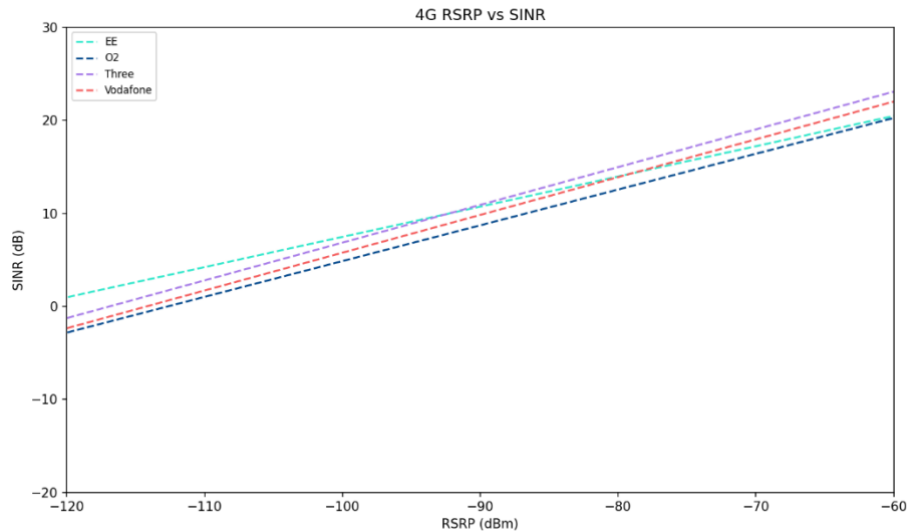


Figure 15: 4G RSRP (dBm) versus SINR (dB) by operator.

Figure 15 shows how SINR tracks to RSRP. All four operators exhibit a positive linear relationship, but slopes differ. EE has the shallowest (0.326 dB SINR per dB RSRP) and Three the steepest (0.462). EE's SINR therefore degrades less per unit of RSRP loss, suggesting a more favourable carrier-to-interference ratio at cell edge, possibly reflecting lower cell loading or more effective inter-cell interference coordination along these routes. R^2 values (0.28–0.42) are higher than the RSRP-to-throughput regressions, confirming that the RSRP-SINR link is a tighter physical relationship.

Three's steeper slope produces the highest fitted SINR at strong signal (≈ 18 dB at -80 dBm RSRP, versus 12.6 dB for EE) but converges with EE at weak signal (-0.4 dB at -120 dBm). Despite favourable SINR at strong signal, Three does not convert this into proportionally higher throughput (Figure 13 and Figure 14), pointing to bandwidth as the binding constraint on Three's downlink capacity.

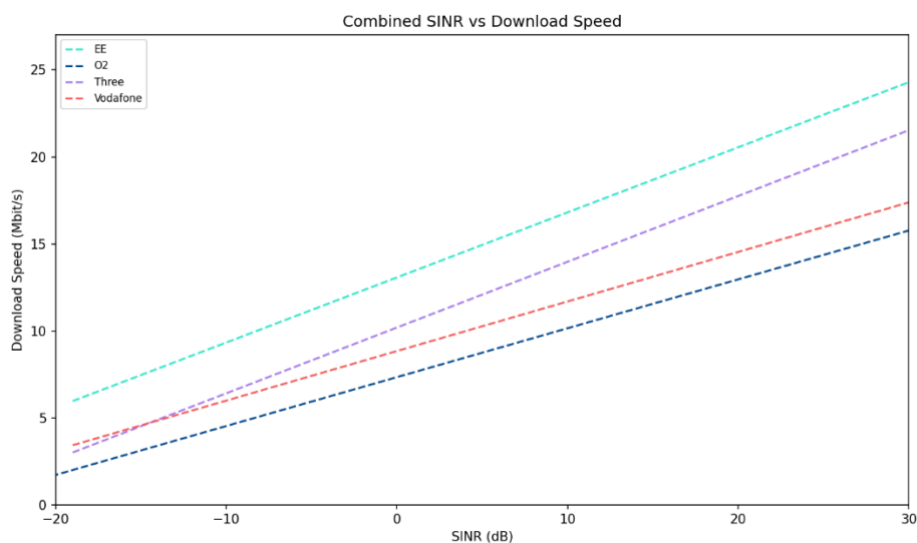


Figure 16: SINR (dB) versus download speed (Mbit/s) by operator. Fitted lines show the throughput response to signal quality for each operator.

Figure 16 presents the direct relationship between SINR and download speed. At equivalent SINR levels, EE consistently delivers higher throughput than the other operators, with the fitted curves maintaining a clear separation across the full SINR range. This pattern is consistent with the Shannon-Hartley relationship: at a given signal-to-noise ratio, the operator with wider aggregated channel bandwidth achieves proportionally higher throughput. The separation between operators in Figure 16 is therefore a visual expression of the structural bandwidth differences described in the earlier section on band distribution, confirming that the throughput advantage persists even when controlling for signal quality rather than signal level.

Technology Layer Analysis

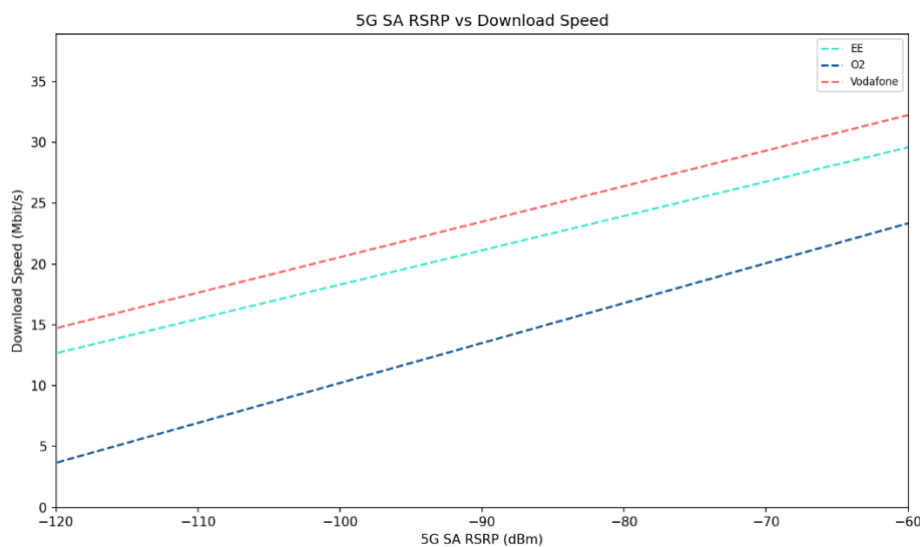


Figure 17: 5G SA SS-RSRP (dBm) versus download speed (Mbit/s) by operator.

Isolating 5G SA (Figure 17) reveals a different competitive picture. Vodafone's fitted download speed exceeds EE across the measured RSRP range: at -100 dBm, Vodafone achieves approximately 20.6 Mbit/s versus 18.3 Mbit/s for EE and 10.2 Mbit/s for O2. Vodafone's higher intercept (49.8 versus 46.6) indicates a per-carrier efficiency advantage, reflecting the fact that their deployment is primarily on the high-bandwidth n78 band which tends to be deployed with higher-order MIMO.

Devices on EE's network spend a higher proportion of their time on SA (see Table 4), which EE has deployed on almost all of their spectrum bands (see section on 5G Band Distribution) with low and mid-band deployments primarily achieved through refarming of spectrum from 3G and 4G and dynamic spectrum sharing on select sites. EE's dominance in the combined charts is therefore a volume effect: more traffic is carried on the higher-throughput 5G SA layer, even though Vodafone's 5G SA cells are individually more efficient where available due to increased bandwidth and higher-order MIMO usage on n78.

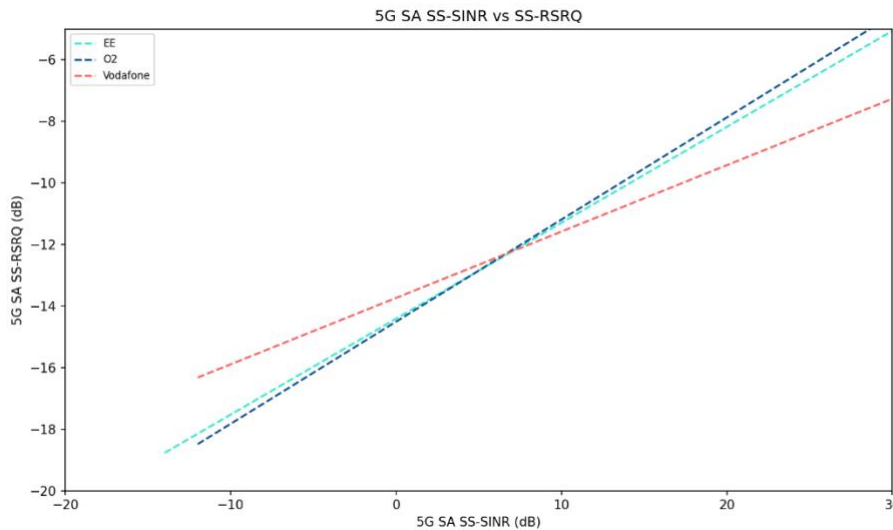


Figure 18: 5G SA SS-SINR (dB) versus SS-RSRQ (dB) by operator.

Figure 18 shows the relationship between SS-RSRQ and signal-to-noise ratio (SINR) on 5G Standalone – two measures of signal quality. The correlation is substantially stronger on 5G than on 4G. R^2 values - a measure of how closely two variables move together, where 1 indicates a perfect relationship - reached 0.80 for EE, 0.81 for O2 and 0.74 for Vodafone on 5G Standalone. The equivalent 4G figures, which cover all four operators, were 0.50 for EE, 0.48 for O2, 0.55 for Three and 0.49 for Vodafone.

This tighter correlation indicates that interference is more predictable on 5G. Three factors likely contribute. First, 5G cells may be carrying less traffic than 4G cells. Second, 5G's wider channel bandwidths reduce the impact of narrowband interference. Third, 5G beam management directs signals more precisely, lowering interference between neighbouring cells.

5G Standalone therefore provides a more consistent link between radio conditions and signal quality. However, signal quality is only one stage in the chain that determines download speed. The correlation between signal strength (RSRP) and throughput remains weak on both 4G and 5G, indicating that bandwidth and how the network allocates capacity between users have a greater effect on throughput than radio conditions alone.

Vehicle Penetration Loss

The signal measured inside a train carriage is attenuated relative to the external signal by the vehicle penetration loss (VPL) of the rolling stock. VPL varies with train construction: modern sealed-body designs with metallic window coatings, used for thermal insulation and infrared reflection, can impose considerably greater attenuation than older rolling stock with openable windows and less RF-reflective materials. Some newer rolling stock may incorporate window treatments designed to improve RF transmission, although this has not been confirmed. [18] [19]

Whilst this study was not setup to measure VPL, it is still a variable that impacts the results of the study. The Department for Transport [20] documented RF attenuation characteristics

across UK rolling stock classes, confirming that VPL is a material constraint on in-train connectivity. VPL also varies with frequency: higher-frequency signals experience greater attenuation through the same vehicle structure (see section 3GPP TR 38.901 7.4.3 [21]).

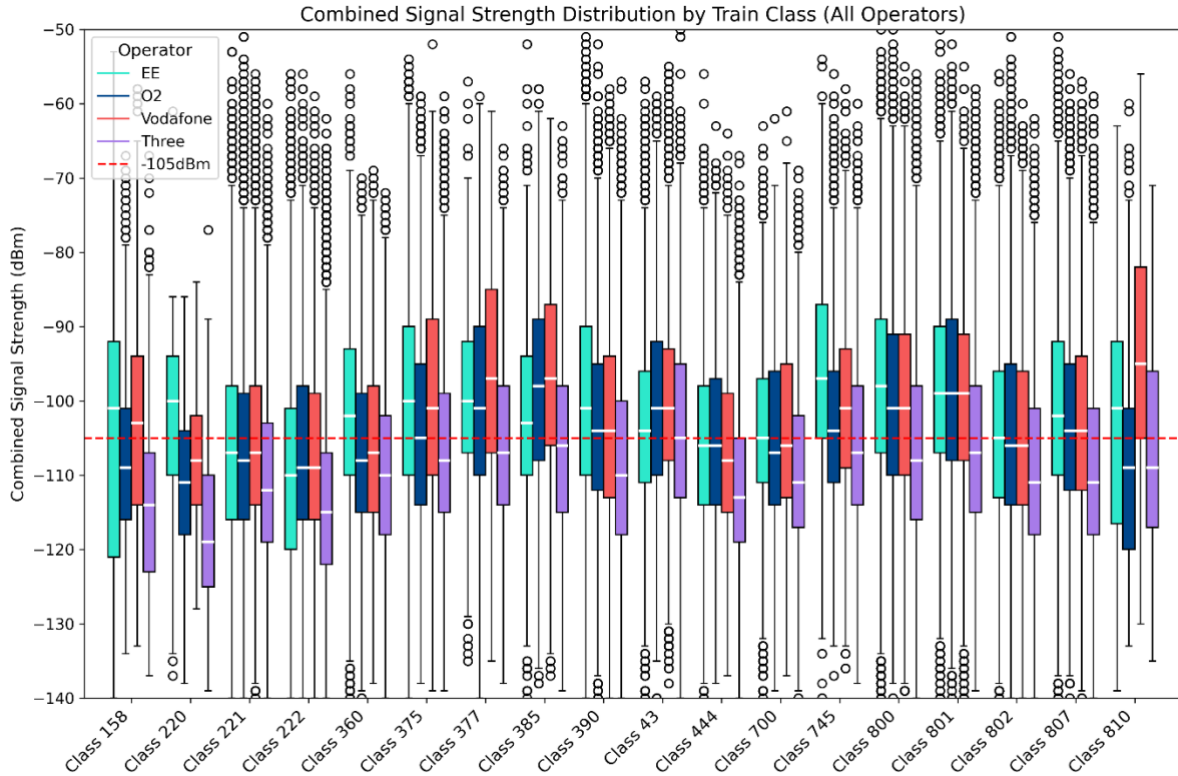


Figure 19: Signal strength (RSRP measured in dBm) distribution by train class and operator, with a line at -105dBm.

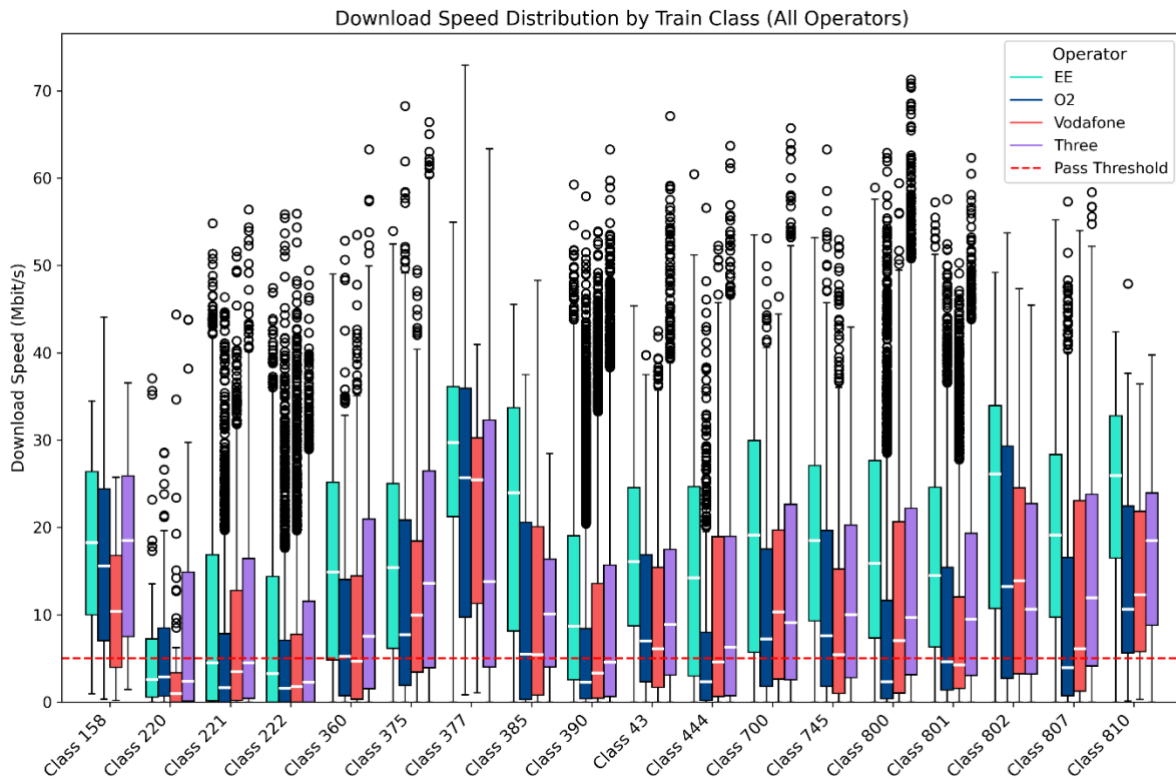


Figure 20: Download speed distribution by train class and operator, with a line showing the good performance pass threshold of 5Mbit/s.

Figure 19 and Figure 20 present the distribution of measured signal strength (RSRP) and download speed by rolling stock class. All measurements were taken inside the carriage; this study did not include external reference measurements, so absolute VPL values cannot be derived. The variation in median RSRP between train classes provides some indication of relative penetration loss differences, but this comparison carries important caveats. First, the rail lines served by different rolling stock classes are not comparable: route length, terrain, proximity to macro sites and the urban-rural balance all vary materially between them, as do the operators' frequency band deployments (discussed in an earlier section). Since higher-frequency bands experience greater vehicle attenuation and have shorter propagation range, differences in median RSRP between classes may reflect the band mix in use on that route as much as any genuine difference in the rolling stock's RF characteristics. The per-class RSRP figures should therefore be treated as indicative rather than as a controlled comparison.

With that caveat stated, median RSRP varies by approximately 5 to 10 dB across the train classes observed. In a predominantly coverage-margin environment such as the rail network, where median signal levels already sit between -101 and -108 dBm, an additional 10 dB of vehicle attenuation has a material impact: it shifts a proportion of measurements from the weak-but-usable range (Category C) into the no-signal range (Category B), effectively converting marginal-coverage segments into no-service segments.

This finding is relevant because vehicle penetration loss is the one factor in the connectivity chain that cannot be addressed through network investment alone. Improving VPL requires

coordination between train operating companies, rolling stock manufacturers and potentially the deployment of on-train solutions such as mobile repeaters or distributed antenna systems. Where newer rolling stock is introduced on a route, the effective coverage footprint for passengers inside the carriage can contract even if the external macro network remains unchanged.

The per-class comparisons in Figure 19 and Figure 20 should be read as indicative of the issues observed on well-sampled fleets – primarily the Class 220-series (Class 220, 221, 222; 10 journeys, ~16 hours combined), Class 800/801 (10 journeys, ~30 hours) and Class 390 Pendolino (6 journeys, ~28 hours) – rather than as a like-for-like comparison table across all rolling stock. Coverage of the wider fleet is uneven: of the 18 classes appearing in the charts, 10 are represented by two journeys or fewer and three classes (Class 158, Class 220 and Class 810) have only a single journey each. The Class 810 contributes just one ~12-minute run, which is not a sufficient basis on which to characterise its RF performance or compare it meaningfully against better-sampled classes. Any apparent differences in median RSRP or download speed for these low-sample classes are as likely to reflect the specific route, time of day and network conditions encountered on that one trip as any genuine attribute of the rolling stock.

Case Study: Peak vs Off-Peak Commuting Times - Bedford to London St Pancras

This service was operated by EMR, all four journeys were conducted on the same day with the operative taking a seat in the middle carriage of the train.

Journey	Date & Time	Carriage	Passenger Load
Off-Peak Outbound	2026-03-05 11:10 – 11:52	Class 360	0-25%
Off-Peak Return	2026-03-05 10:15 – 10:55	Class 360	0-25%
Peak Outbound	2026-03-05 08:10 – 09:05	Class 360	75-100%
Peak Return	2026-03-05 17:17 – 17:57	Class 360	75-100%

Table 5: Contextual information for Bedford to London off-peak and peak rail journeys from Streetwave measurement data.

As part of this study, the Bedford to London St Pancras line was surveyed twice – once at peak times (8am – 9am inbound and 5pm – 6pm outbound) and again at off-peak times (10am – 11am outbound and 11am – 12pm inbound). This was done on the same day using a Class 360 service operated by East Midlands Railway. The results revealed that for 3 of the 4 operators, performance was noticeably reduced at peak-times – with Three seeing reduced download performance but slightly improved latency and upload performance which could be due to a number of reasons, such as run-to-run variance or differing passenger behaviour.

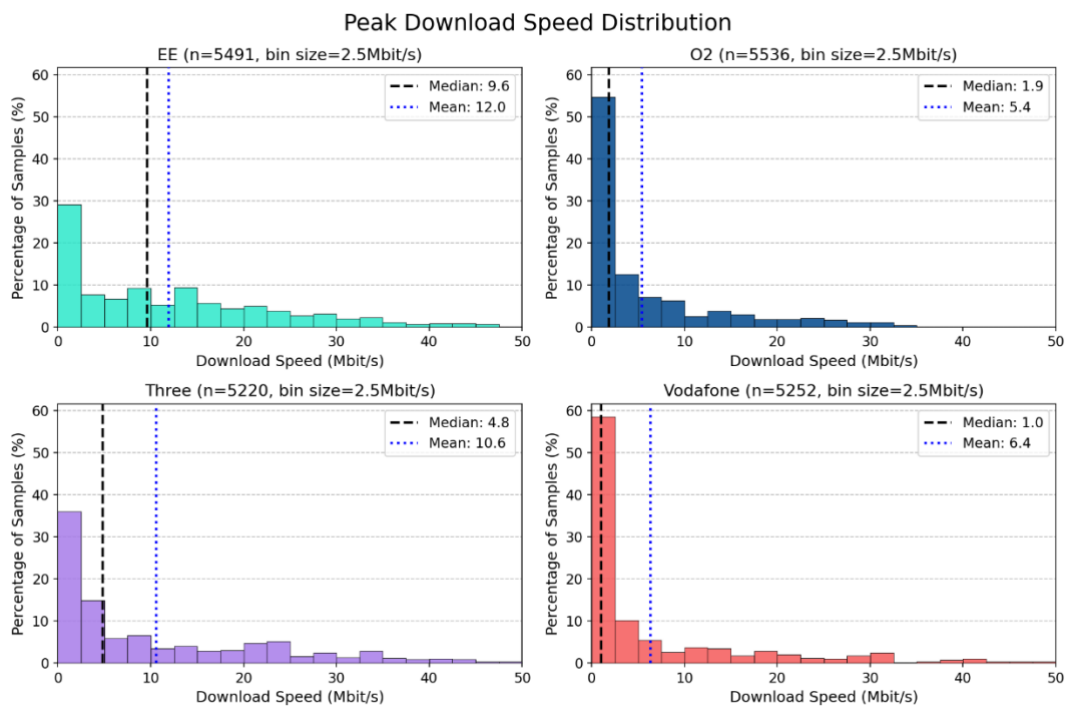


Figure 21: Distribution of download speed samples in 2.5Mbit/s size bins at peak time for each operator.

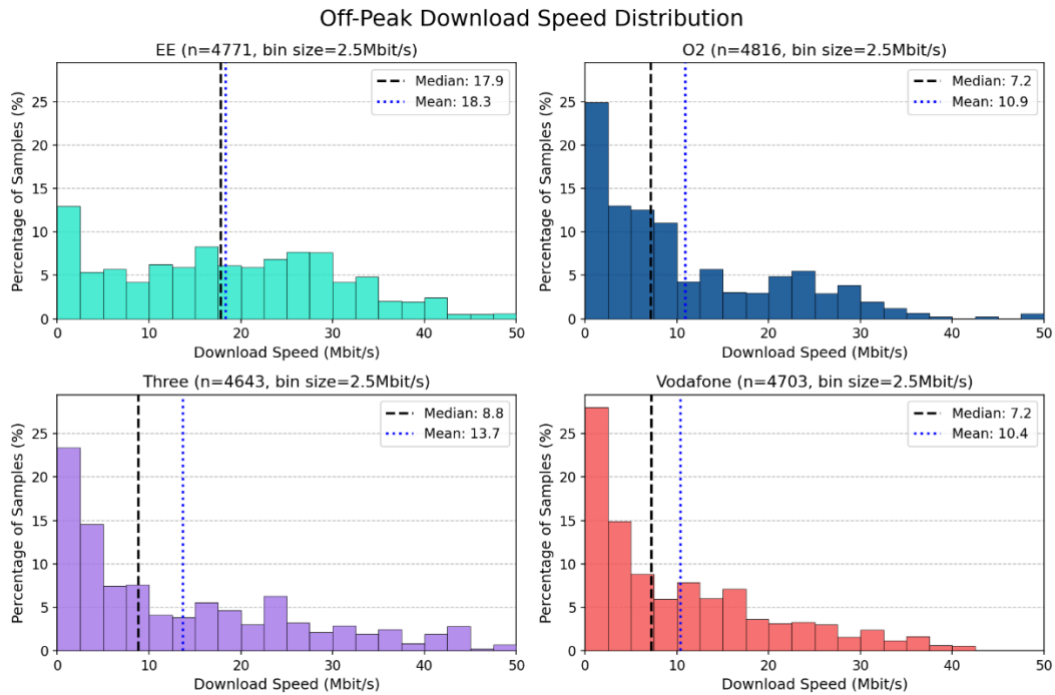


Figure 22: Distribution of download speed samples in 2.5Mbit/s size bins at off-peak time for each operator.

Comparing Figure 21 and Figure 22, downlink performance across all operators was observed to be lower at peak times than at off-peak times with EE providing the best experience overall on both the peak and off-peak journeys. The median downlink performance of all networks at off-peak time is well above the 5Mbit/s Good Performance threshold. At peak times EE is the only network whose median downlink performance passes this threshold.

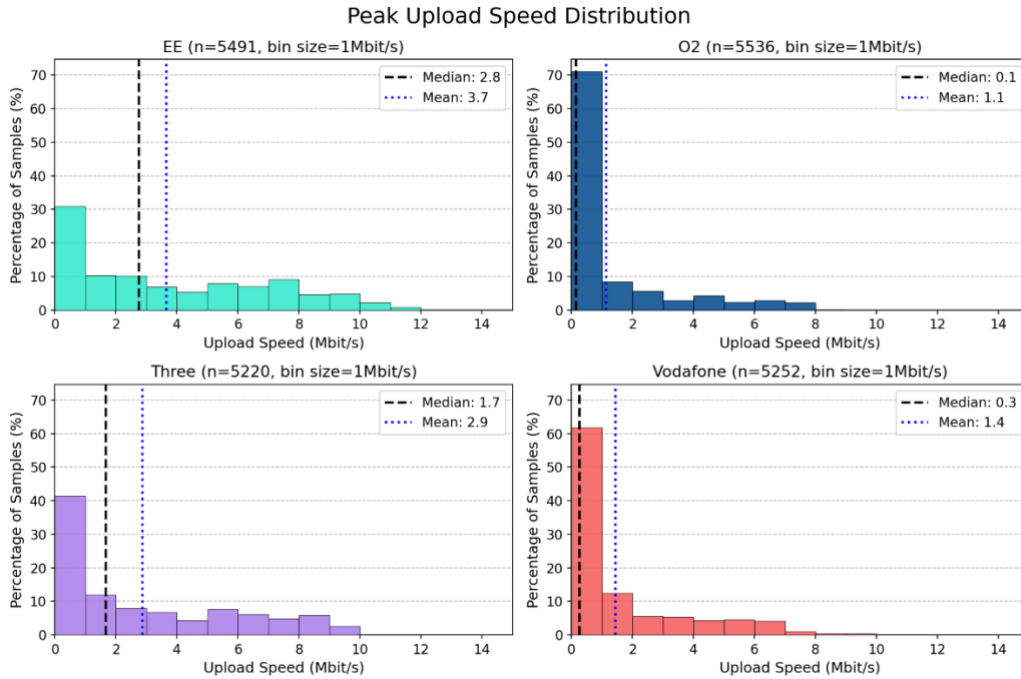


Figure 23: Distribution of upload speed samples in 1Mbit/s size bins at peak time for each operator.

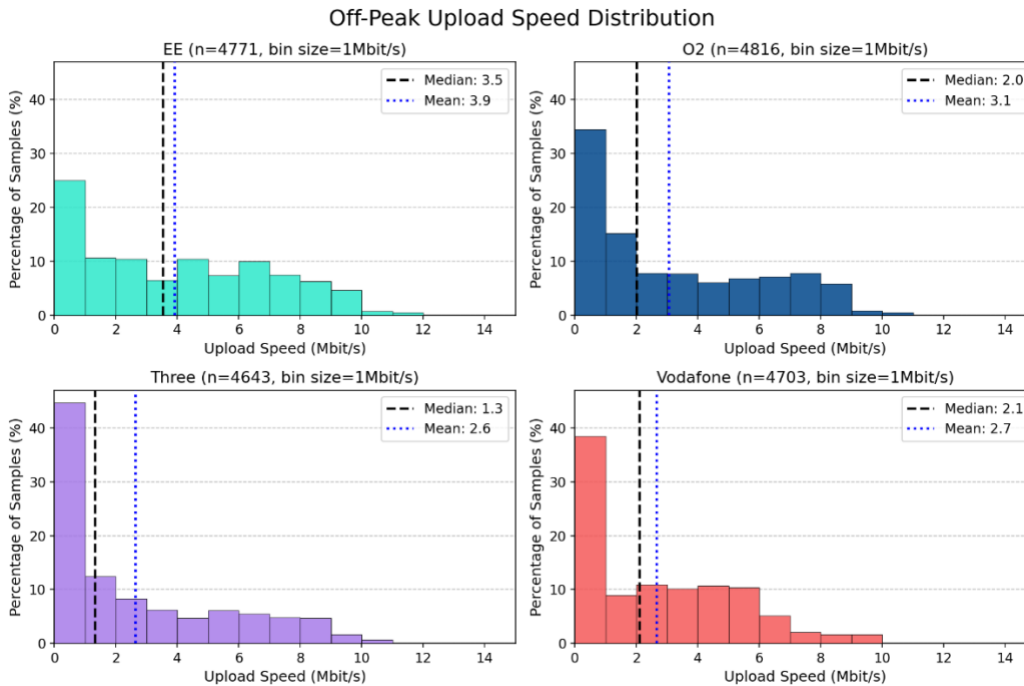


Figure 24: Distribution of upload speed samples in 1Mbit/s size bins at off-peak time for each operator.

Uplink performance illustrates a similar trend, where at peak times, O2 and Vodafone have median speeds of 0.1Mbit/s and 0.3Mbit/s respectively, this improves to 2.0Mbit/s and 2.1Mbit/s respectively during off-peak times. EE follows a similar trend – however Three’s uplink performance degrades slightly during off-peak times – albeit not by a significant

amount – with both networks retaining a usable median speed at peak time that passes the Good Performance uplink threshold of 1.5Mbit/s.

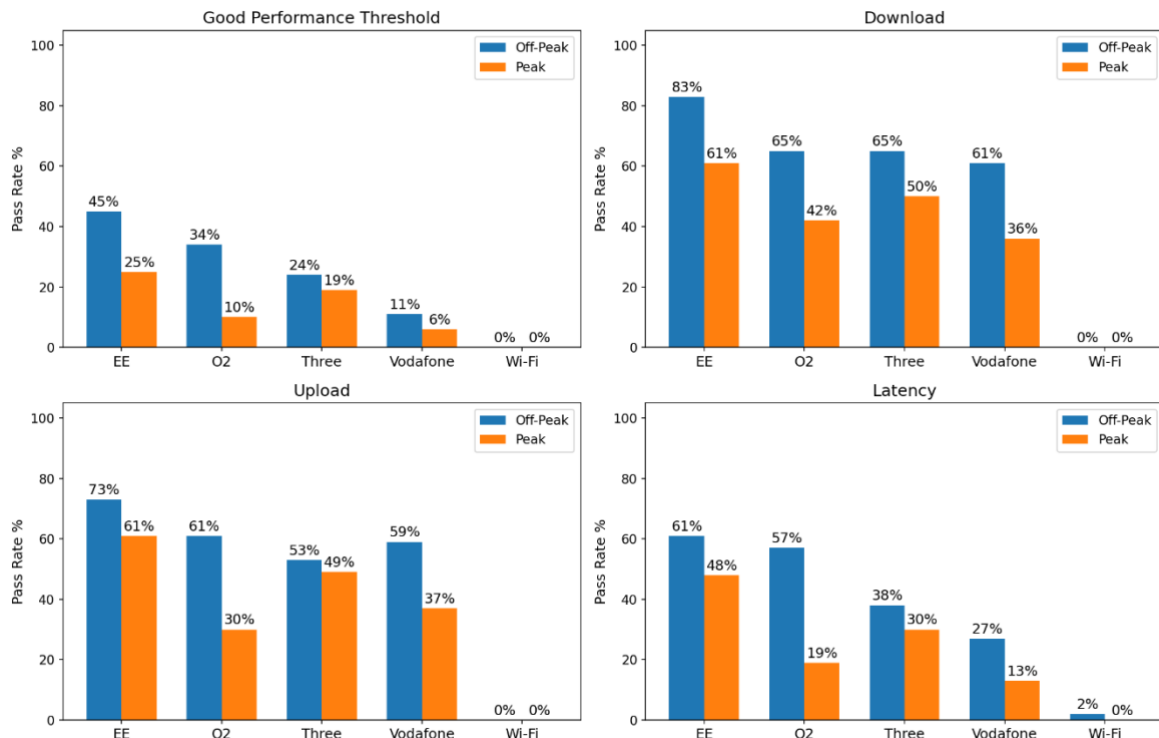


Figure 25: Threshold pass rate percentages for Good Performance Threshold, Download, Upload and Latency Pass Rates for each operator (including Wi-Fi) at peak vs off-peak times (blended both directions).

Figure 25 shows a reduction in performance across all metrics for all operators (including on Wi-Fi, which is covered in more detail in a section later in the report), with some operators impacted by passenger load more than others. A common trend amongst all networks is that latency is the largest factor contributing to tests not meeting the Good Performance threshold.

Operator	Good Threshold %	Download Pass %	Upload Pass %	Latency Pass %
EE	-20	-22	-12	-13
O2	-24	-23	-31	-38
Three	-5	-15	-4	-8
Vodafone	-5	-25	-22	-14
Wi-Fi	N/A	N/A	N/A	-2

Table 6: Negative values indicate degraded performance during peak hours relative to off-peak. N/A signifies no change due to 0% on both journeys.

All operators experience measurable performance degradation during peak hours compared to off-peak, with every metric showing negative percentage changes. O2 sees the largest drop in pass rates, with upload and latency pass rates dropping by over 30%; Vodafone

sees the largest download pass rate drop with O2 and EE seeing a similar degradation. Overall, Three is not as impacted by the change in passenger load as the other operators with them seeing the smallest drops on download, upload and latency (excluding Wi-Fi).

Mobility and Handover Performance

Mobile devices on trains frequently change serving cell as they move through the network, driven by high average train speeds in rural areas and dense cell deployments in urban ones. Each handover introduces a brief service interruption during which data transfer may stall; rapid successive handovers can compound this effect, degrading throughput and elevating latency. Additionally, densely occupied carriages concentrating many network users onto the same serving cell increases contention for radio resources, potentially amplifying the throughput and latency impacts of each handover event.

Handovers are measured as a change of Cell ID, this can occur as the device moves between sectors of the same cell site, to a different cell site, to a different RAT or to a different frequency.

Operator	Mean	Median	Maximum
EE	4.50	4	18
Three	4.60	4	18
Vodafone	4.29	4	18
O2	4.12	4	18

Table 7: Handover rates by operator across all segments. The table refers to the number of Cell ID changes over a 1 minute period.

Handover rates are broadly consistent across all four operators, ranging from a mean of 4.12 (O2) to 4.60 (Three) cell ID changes per minute. At a median rate of 4 changes per minute, a device is executing a handover roughly every 15 seconds.

Peak handover rates reached 18 changes per minute on certain segments, equating to a cell change every 3.3 seconds. At this rate, a material proportion of the measurement interval may be consumed by handover procedures, contributing to elevated latency and reduced throughput. The latency component of the Good Performance threshold (50ms) may be particularly sensitive to handover-induced delays, as each cell change can introduce a transient latency spike during RRC reconfiguration.

The similarity of handover rates across operators suggests that the physical cell layout along rail corridors is broadly comparable.

On-Board Wi-Fi Performance

On-board Wi-Fi was measured alongside the four mobile operators on each journey. Wi-Fi performance was assessed using the same Good Performance threshold as the mobile networks, though the RF classification framework does not apply to Wi-Fi as it operates on a different technology stack.

Across all 50 journeys, Wi-Fi achieved a mean Good Performance rate of 1%, with a median of 0.0%. On the majority of routes surveyed, Wi-Fi returned no tests meeting the Good Performance threshold which represents a substantially lower level of performance than any of the four mobile networks. This section of the report details the reasons for the performance difference.

Wi-Fi Throttling & Data Usage Caps

One of the main reasons that train operating companies make use of Wi-Fi throttling and data caps is to ensure that the limited backhaul capacity available to the train is shared fairly among all passengers, preventing a few users from slowing down the service for everyone else². A throttle can be implemented as either a throughput restriction, a data cap or a combination of both techniques; this can vary by TOC and train unit.

Additionally, some TOCs restrict which services you can access (e.g. video streaming) to artificially reduce the data demand from passengers [23]. Since TOCs often do not publish the limits they impose on their Wi-Fi service, conclusions as to the presence of a throttle must be drawn from the results of the testing in context of the passenger load and other variables that impact performance.

It was not possible on some of the shorter lines surveyed to deduce if the TOC was throttling the speed of the Wi-Fi connection, specifically: East Midlands Parkway to Nottingham, East Midlands Parkway to Derby and Sheffield to Doncaster.

Latency Testing Issues

The study observed that on all Avanti West Coast operated rail lines, no ICMP ping tests were able to run, resulting in no latency measurement results. This is due to ICMP traffic being blocked at the train's Wi-Fi gateway. Throughput (download and upload speeds) measurements were still captured. This impacted the measurements on the following journeys:

- London to Liverpool (via Nuneaton, Stafford)
- London to Edinburgh (via Stafford, Preston)
- London to Manchester (via Stoke on Trent)
- London to Glasgow (via Stafford, Preston)

² For example, an eight-car Class 700 Thameslink service has a maximum passenger capacity of 1146 (including standing passengers) [22]. Assuming a download speed cap of 0.5Mbit/s the service would need 573Mbit/s of backhaul capacity to maintain this level of service for all passengers.

On the London to Manchester and London to Glasgow journeys, each measurement survey did not record any download speeds above 1.81Mbit/s and 1.45Mbit/s respectively; meaning that even if latency had passed on these journeys for every test, the Wi-Fi performance would have still failed to meet the Good Performance threshold.

On the Liverpool to London journey, the measurement survey recorded many tests with speeds above the required levels to pass the Good Performance threshold - Figure 26 shows the download and upload test results for one journey on the line binned into 2-minute intervals.

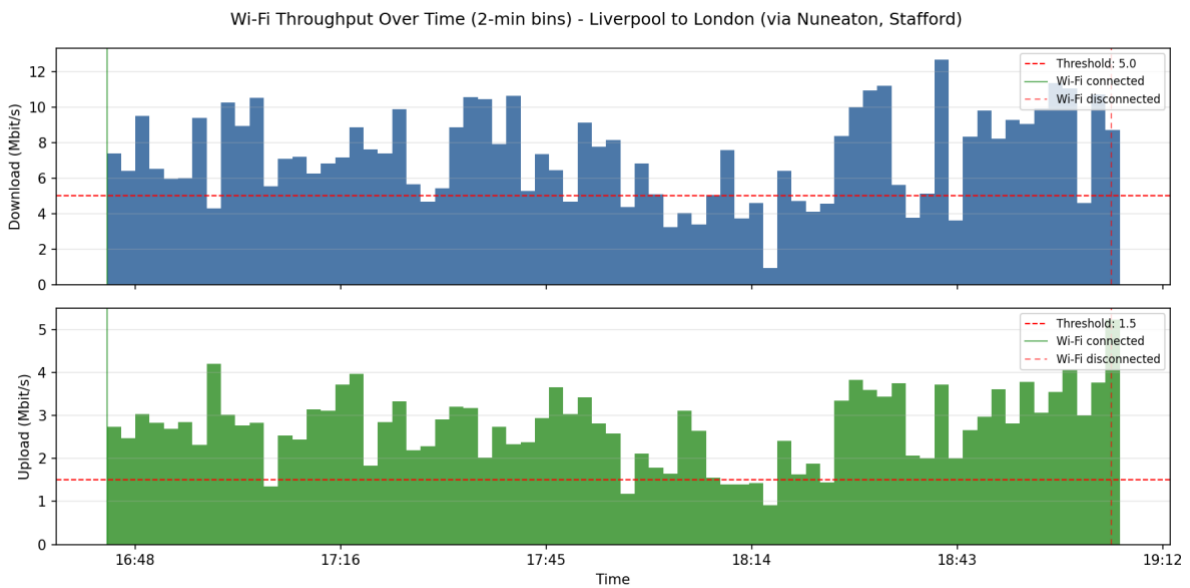


Figure 26: Liverpool to London Wi-Fi throughput including connection events (results binned into 2-minute intervals).

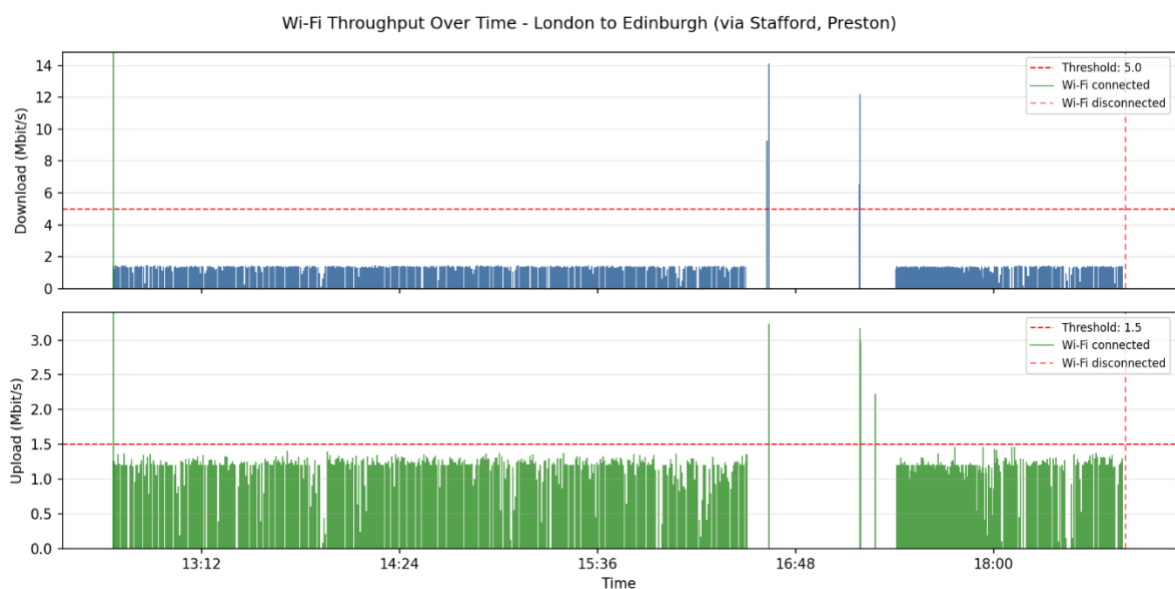


Figure 27: London to Edinburgh Wi-Fi throughput including connection events (individual tests).

On the London to Edinburgh line, only a small number of download tests were fast enough to pass the Good Performance threshold - Figure 27 shows the individual download and upload test results as well as the Good Performance threshold.

Wi-Fi Availability

There was one line where it was not possible to connect to Wi-Fi at all: Brighton to London Bridge. At time of measurement, there was no SSID broadcasting in the train carriage.

Several journeys experienced frequent disconnections which meant it was not possible to test the Wi-Fi performance consistently, these were:

- East Midlands Parkway to London
- Edinburgh to Inverness (via Perth)
- Glasgow to Edinburgh (via Falkirk)
- Nottingham to East Midlands Parkway

For example, Edinburgh to Inverness’s connection chart is shown below.

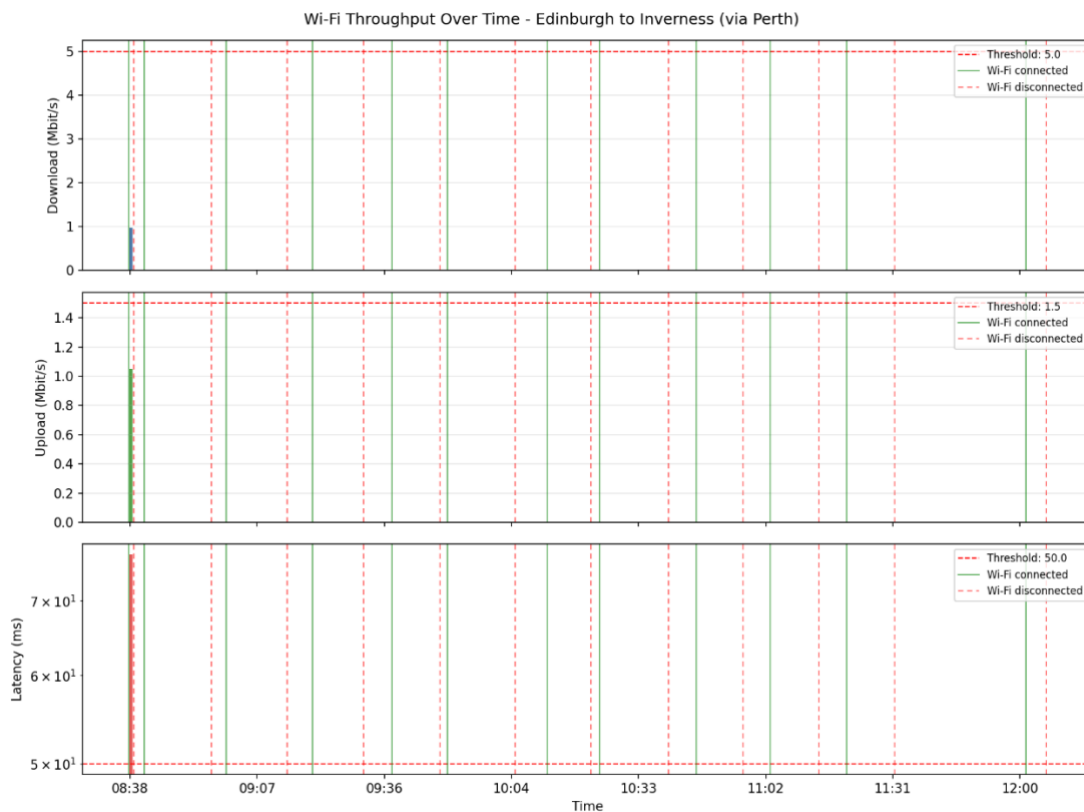


Figure 28: Edinburgh to Inverness (via Perth) Wi-Fi throughput including connection events.

Wi-Fi Throttling

The following analysis infers TOC Wi-Fi throttling behaviour from the throughput characteristics observed during the measurement campaign. As the throttling policies applied by the train gateways were not available to us, the conclusions below are necessarily inferential.

Two distinct throttling patterns were identified in the data. The first pattern, characterised by stable throughput for an initial portion of the journey followed by an abrupt and sustained collapse to near-zero speeds, was observed on the following routes:

- Glasgow to London (via Preston, Stafford)
- London to Glasgow (via Stafford, Preston)
- Inverness to Edinburgh (via Perth)
- London to Edinburgh (via Stafford, Preston)
- Edinburgh to London (via Preston, Stafford)
- London to Manchester (via Stoke on Trent)

This first pattern can be observed in the throughput charts for the London to Edinburgh (via Stafford, Preston) line – see both Figure 27 (outbound journey) and Figure 29 (return journey).

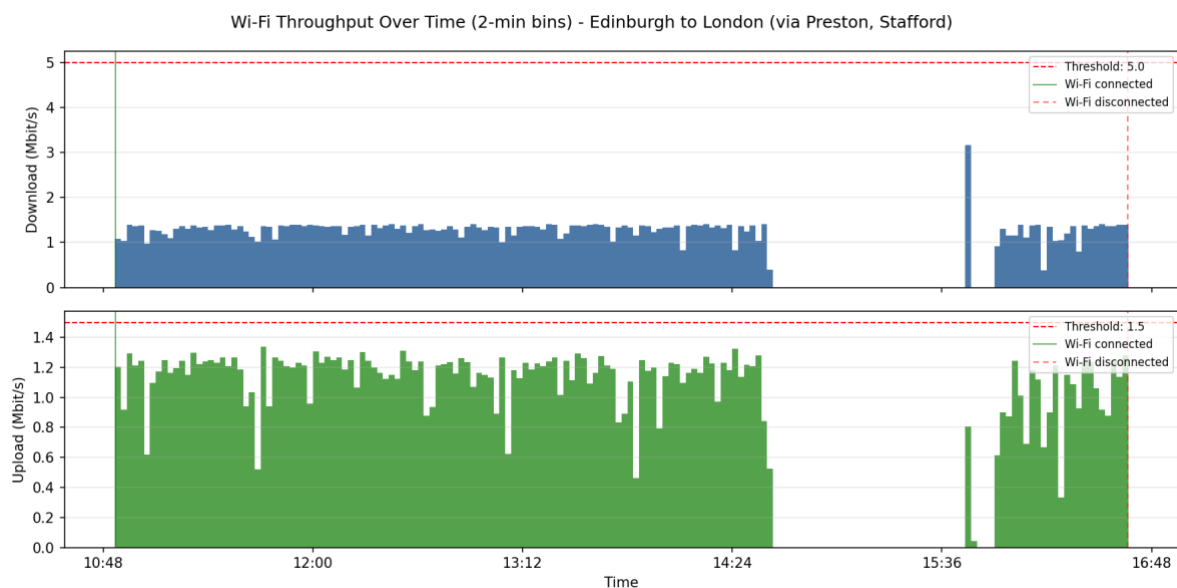


Figure 29: Edinburgh to London Wi-Fi throughput including connection events.

The second pattern is consistent with the imposition of a per-MAC or per-session data allowance, after which the connection is hard-throttled or de-prioritised. This behaviour was observed on:

- Basingstoke to Coventry (via Reading, Oxford)

- Dover to London (via Sevenoaks, Tonbridge, Ashford)
- London to Dover (via Sevenoaks, Tonbridge, Ashford)
- London to Norwich (via Colchester, Ipswich)
- Norwich to London (via Ipswich, Colchester)

The London to Norwich throughput chart (Figure 30) illustrates this effect: the throughput cap appears to have been reached early in the journey, with all subsequent measurements constrained to materially lower speeds.

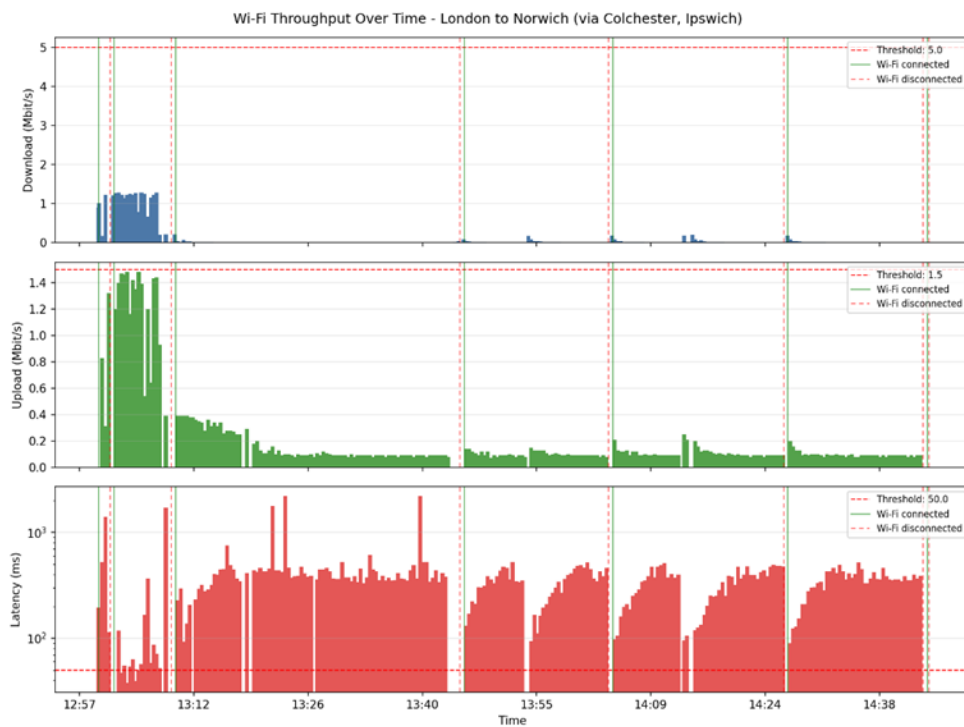


Figure 30: London to Norwich Wi-Fi throughput including connection events.

All journeys appear to be subject to throughput caps. This is illustrated by the Liverpool to York route (see Figure 31), where the cap was observed at approximately 1 Mbit/s on the downlink and 1.2 Mbit/s on the uplink. The throughput profile on this route is consistent with a fixed speed cap rather than a cumulative data allowance as discussed earlier.

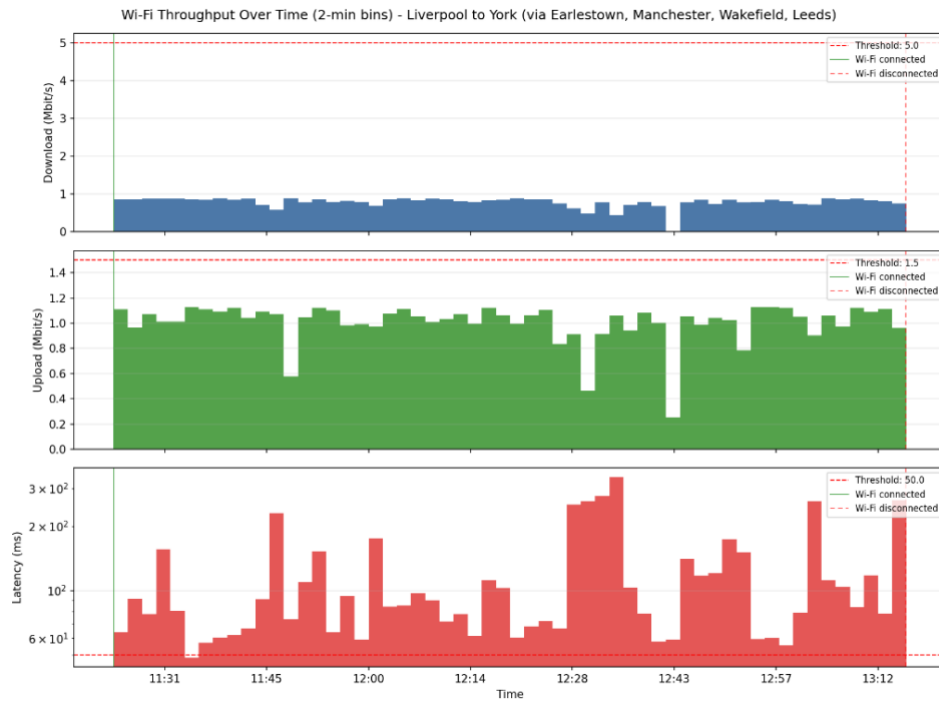


Figure 31: Liverpool to York Wi-Fi throughput over time (results binned into 2-minute intervals).

Performance Analysis

The measurement results for Wi-Fi across the lines rarely met the Good Performance threshold on any of the three metrics; download speed, upload speed and latency. Only 5 lines recorded any speeds over the Good Performance threshold for download speed, 15 lines for upload speed and 12 lines for latency.

It is worth noting that certain operators such as GWR offer “enhanced Wi-Fi” in first class [24], so performance may differ in these carriages – data collection for this report was conducted in standard class and therefore the data reflects the experience of passengers travelling in standard class.

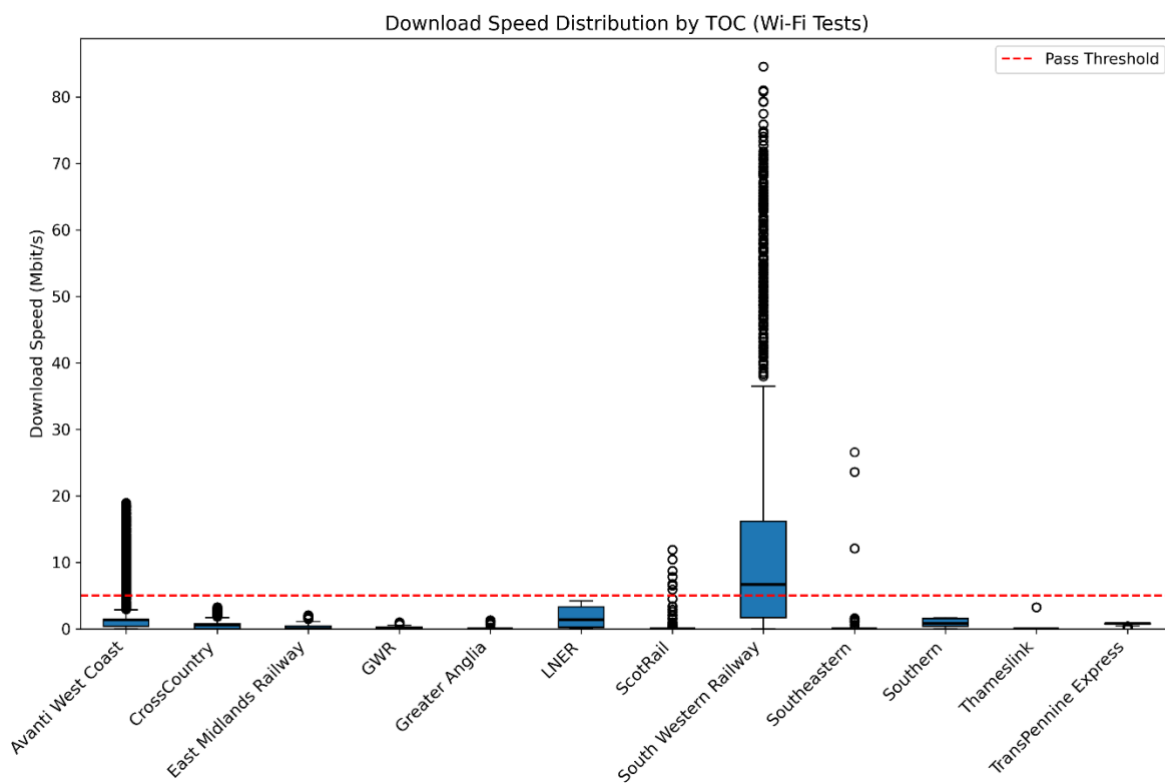


Figure 32: Wi-Fi download speed distribution by train operating company (TOC).

Figure 32 presents the distribution of Wi-Fi download speeds by train operating company (TOC). All TOCs except from South Western Railway (SWR) recorded median Wi-Fi download speeds below the Good Performance threshold required 5Mbit/s, in many cases, performance was below 1Mbit/s.

SWR stands out as the clear outlier, with measurably higher download throughput than any other TOC in the dataset. SWR has deployed a next-generation Wi-Fi system based on trackside 5G millimetre-wave technology along part of the South West Mainline [25]. This provides dedicated bandwidth for the train’s Wi-Fi gateway, with the added benefit of taking load off the cellular grid serving the railway line.

The effect on the data is pronounced: between Earlsfield and Basingstoke the Good Performance threshold is met 83.2% of the time, falling to get above 1% across the remainder of the journey. SWR routes measured in this study (London to Bournemouth via Basingstoke and Southampton) therefore show a fundamentally different Wi-Fi performance profile to other TOCs.

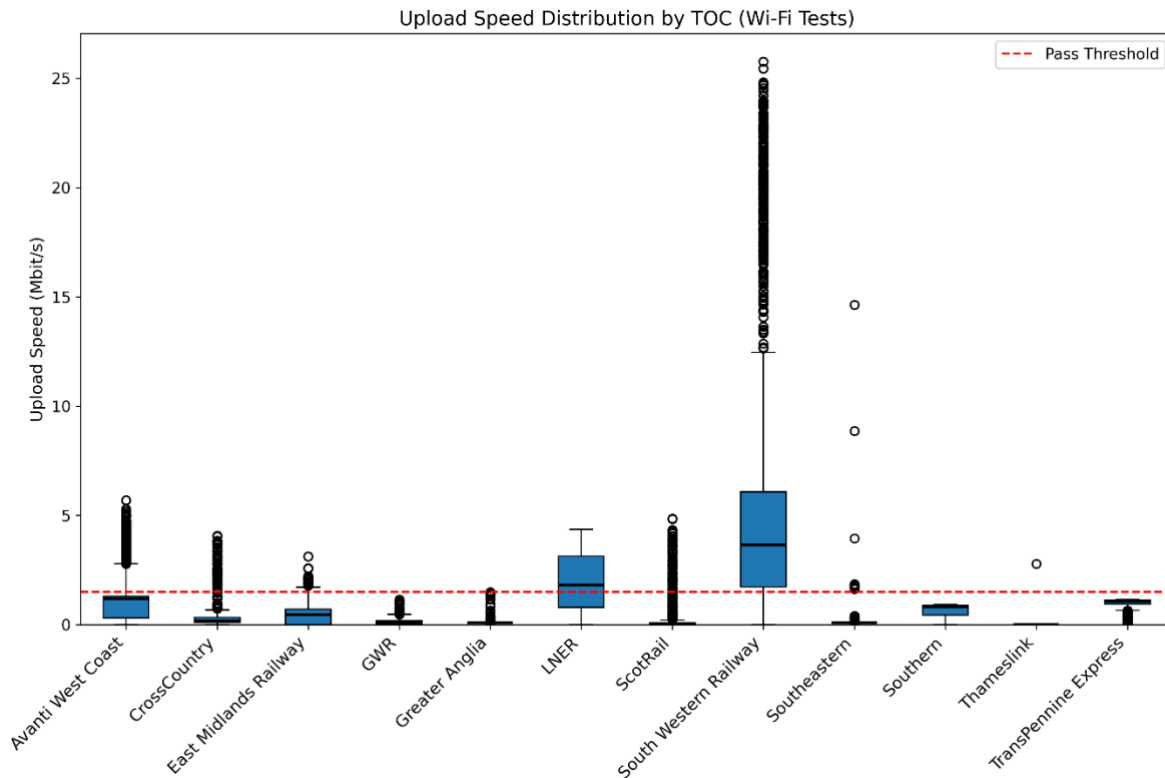


Figure 33: Wi-Fi upload speed distribution by train operating company.

Figure 33 presents the corresponding Wi-Fi upload speed distribution by TOC. The pattern mirrors the download results: SWR is the only operator delivering measurable upload throughput through its Wi-Fi system, confirming that the trackside millimetre-wave backhaul provides an improvement over conventional bonded cellular approach. For all other TOCs, Wi-Fi upload speeds were at or near zero, consistent with the backhaul being a binding constraint.

Wi-Fi Backhaul

The majority of UK train operating companies use bonded cellular backhaul for their on-board Wi-Fi systems [26]. The train's Wi-Fi gateway aggregates data connections from one or more mobile networks via a roof-mounted external antenna, then distributes this connection to passengers over multiple Wi-Fi access points (APs) distributed throughout the carriages³.

³ Internal train Wi-Fi networks are difficult to upgrade and quickly become obsolete especially when compared to the lifespan of the train itself [27]

A key distinction from the cellular measurements is that the device under test is stationary relative to the Wi-Fi APs. The local Wi-Fi link between the measurement device and the nearest in-carriage AP remains stable regardless of train speed, as a result. However, on carriages equipped with legacy Wi-Fi APs, available bandwidth is more limited, meaning passenger load becomes a more significant variable – carriage where passengers are predominantly streaming video presents a materially different contention environment than one where usage is limited to light web-browsing. On modern AP hardware this distinction is less pronounced, but it should be noted as a caveat when interpreting results collected in mixed or high-load conditions. The primary performance bottleneck is the backhaul connection between the train's roof-mounted antenna and the macro network. The performance of this architecture is therefore fundamentally constrained by the same cellular coverage that passengers experience directly on their own devices, with the addition of contention from other Wi-Fi users sharing the backhaul connection. In areas where cellular coverage is weak or absent, the Wi-Fi system has little to no backhaul capacity to distribute.

The train's external cellular modem and internal distribution system also significantly influence Wi-Fi performance. These components are difficult to upgrade but can substantially affect the quality of service delivered over Wi-Fi. Outdated APs lack support for newer Wi-Fi standards that are better optimised for multi-user environments (i.e. Wi-Fi 6 & Wi-Fi 7 [28]), whilst outdated train routers may fail to support the latest cellular technologies - for example the first 5G enabled train router was introduced in 2020 by Icomera [29].

Several TOCs have worked with the mobile operators to improve coverage along rail routes, by building new masts [30] or upgrading the existing macro network with additional capacity [31] which has led to improvements to on-train Wi-Fi.

Where specific TOCs showed better Wi-Fi performance, this may reflect differences in backhaul technology. TOCs such as ScotRail [32], GWR [33] and SWR [34] have begun exploring satellite-based backhaul using Starlink low-earth-orbit connectivity as a complement to bonded cellular, though these deployments were not operational on the routes measured during this study. These emerging backhaul technologies have the potential to decouple train Wi-Fi performance from the terrestrial cellular coverage environment.

Wi-Fi Standards

Figure 34 shows the number of unique SSIDs observed during our testing, 63% were Wi-Fi 5 (adopted 2013), 32% were Wi-Fi 4 (adopted 2009), and the remaining unique SSID was using legacy Wi-Fi standards (Wi-Fi 3) - no trains were observed to be using Wi-Fi 6 or 7.

Share of Wi-Fi Networks by Standard (unique SSID x standard)

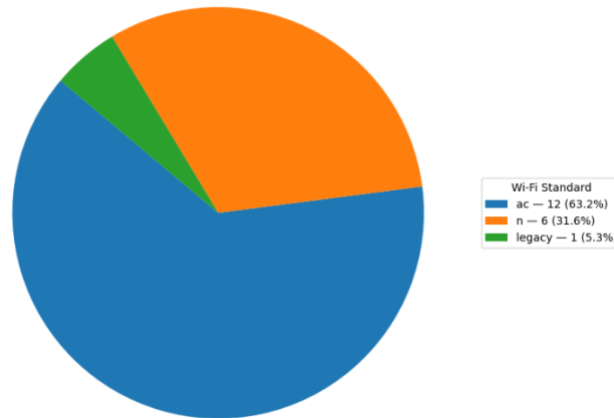


Figure 34: Number of unique SSIDs observed by Wi-Fi standard (note: train operators sometimes vary the name of the train’s SSID).

The two legacy SSID were observed on a single train used across two journeys⁴. Wi-Fi networks classed as legacy have a maximum physical link rate of 54Mbit/s [35], which will quickly become a bottleneck with multiple passengers using the service. Newer standards have much higher link rates which vary depending on AP support, device support and signal conditions, and Wi-Fi 6 and 7 introduce features such as OFDMA [36] and enhanced MU-MIMO that could materially improve per-user performance in busy carriages where high passenger density causes contention at the access point.

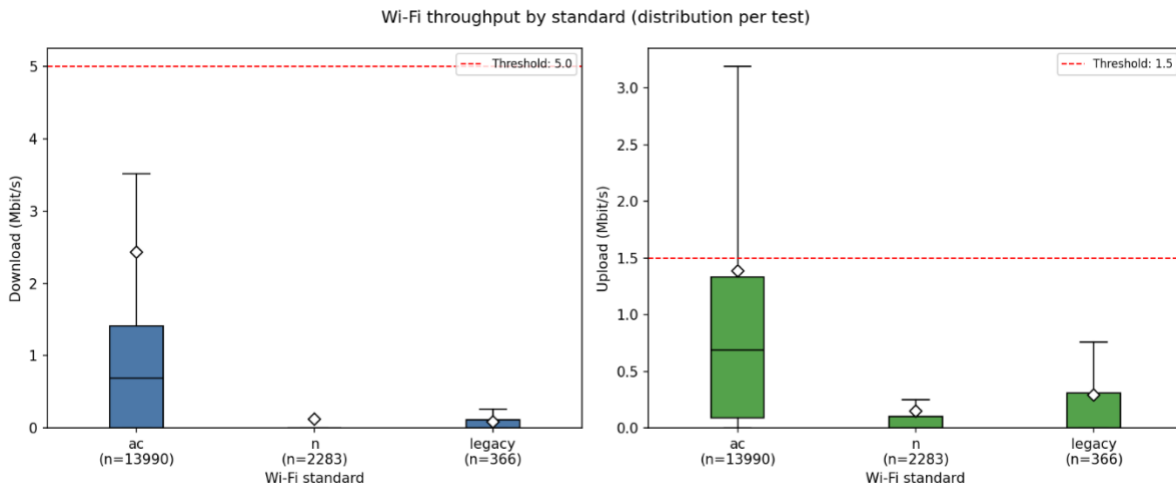


Figure 35: Wi-Fi performance throughput by standard for all journeys.

⁴ The two journeys that recorded legacy Wi-Fi standards were Derby to East Midlands Parkway and London to East Midlands Parkway, travelling on a Class 222 operated by East Midlands Railway.

Wi-Fi 5 shows a significant performance improvement over Wi-Fi 4 which is to be expected. Further conclusions cannot be made as this study was not designed to measure the differences between Wi-Fi standards. The observed difference should therefore be treated as indicative rather than definitive.

Wi-Fi Conclusion

The overall finding from this measurement campaign demonstrates that backhaul connectivity and throttling are the dominant factors constraining end-user Wi-Fi performance, with conventional bonded cellular backhaul fundamentally limiting throughput regardless of the quality of in-carriage distribution hardware. Newer backhaul technologies such as trackside millimetre wave and LEO satellite could both improve passenger experience and allow TOCs to improve or even remove the throttling limits they impose on passenger connections, although these could be limited by commercial constraints.

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Glossary

Term	Definition
2G (GSM)	Second-generation mobile communications standard.
3G (UMTS/HSPA)	Third-generation mobile communications standard.
4G (LTE)	Fourth-generation mobile communications standard.
5G NR	Fifth-generation New Radio mobile communications standard.
5G NSA	5G Non-Standalone, where 5G operates alongside a 4G anchor connection.
5G SA	5G Standalone, operating independently without a 4G anchor.
ARFCN	Absolute Radio Frequency Channel Number.
Backhaul	The network link connecting a mobile cell site to the operator's core network
BSSID	Basic Service Set Identifier (Wi-Fi access point MAC address).
CA	Carrier Aggregation combines two or more frequency bands into a single connection to increase the total available bandwidth and throughput for a device.
Cell ID	Unique identifier for a mobile network cell.
DL	Download, data transmission from network to device.
DSS	Dynamic Spectrum Sharing allows 4G and 5G to share the same frequency band simultaneously, enabling 5G deployment without requiring dedicated new spectrum.
EARFCN	E-UTRA Absolute Radio Frequency Channel Number (4G channel identifier).
eNodeB	4G base station.
ESSID	Extended Service Set Identifier (Wi-Fi network name).
gNodeB	5G base station.
GPS	Global Positioning System.
ICMP	Internet Control Message Protocol, used for latency (ping) testing.
HTTP	Hyper Text Transfer Protocol.
KPI	Key Performance Indicator.
Latency	The time taken for data to travel from the device to a server and back, measured in milliseconds.
Linear regression	A statistical method that models the relationship between a dependent variable and one or more independent variables
Mbit/s	Megabits per second, a measure of data throughput.
MIMO	Multiple-Input Multiple-Output is an antenna technique that uses multiple transmit and receive antennas simultaneously to increase throughput and reliability without requiring additional spectrum.
MNO	Mobile Network Operator.
MOCN	Multi-Operator Core Network, allows multiple operators to share the same RAN equipment

NRARFCN	NR Absolute Radio Frequency Channel Number (5G channel identifier).
PCell	Primary cell that the device uses for control plane traffic.
PLMN	Public Land Mobile Network.
QoS	Quality of Service: Objective network performance indicators like signal strength, throughput, and packet loss.
R ²	A statistical measure (ranging from 0 to 1) that represents the proportion of variance in the dependent variable that is explained by the independent variable(s) in a model.
RAT	Radio Access Technology (e.g. 2G, 3G, 4G, 5G).
RAN	Radio Access Network: Antennas and towers that make up the network
RRC	Radio Resource Control is a protocol that manages the connection state between a device and the network,
RSRP	Reference Signal Received Power, a measure of signal strength in dBm.
RSRQ	Reference Signal Received Quality, a measure of signal quality in dB.
RSSI	Received Signal Strength Indicator.
SCell	A secondary cell that is aggregated to a PCell to provide better user-plane throughput
SINR	Signal-to-Interference-plus-Noise Ratio, measured in dB.
Spectrum Refarming	The reallocation of spectrum previously used for an older technology (e.g. 3G) to a newer one (e.g. 5G)
TOC	Train Operating Company.
TTFB	Time to First Byte.
UE	User Equipment (mobile device).
UL	Upload, data transmission from device to network.

Appendix

Methodology

Equipment and Configuration

Samsung Galaxy S24 smartphones were used as measurement devices (User Equipment (UEs)). Four UEs were deployed simultaneously during each measurement journey, with one device allocated to each of the four mobile network operators (EE, O2, Vodafone, Three)⁵. A fifth device was dedicated to Wi-Fi measurement.

Background activity was disabled, where feasible and not related to the measurement activities, to prevent additional performance degradation that might result from background applications or system processes. This approach ensures that the measured performance reflects network conditions rather than device resource constraints.

The five devices were mounted in a custom polylactic acid (PLA) enclosure with identical polarisation and 20-millimetre spacing between devices. This configuration was designed following electromagnetic compatibility principles that were validated through EMC laboratory testing conducted by the German Federal Network Agency (Bundesnetzagentur) [37]. The standardised mounting ensures consistent measurement conditions across all journeys and allows fair comparison between operators.

Each UE was powered via a 5-volt USB-C connection. The overall measurement unit required a 12-volt direct current supply with integrated cooling fans to manage thermal load during continuous operation.

The measurement application (Streetwave's in-house Data Collection Native Android App) controlled all measurement activities and logging throughout each journey. This application automates the test cycle execution and recording of all network measurements.

SIM Card Configuration

Standard consumer SIM cards from each Mobile Network Operator (MNO) were deployed, providing access to all available network technologies without restrictions. The SIM cards were not obtained from Mobile Virtual Network Operators (MVNOs), ensuring direct access to each operator's infrastructure. All SIM cards were configured with no data volume restrictions, no traffic prioritisation and no speed caps. Consumer experience may differ with SIM plans, including but not limited to speed and data caps.

Each SIM card was compatible with all available technologies offered by the respective operator, including 5G Standalone where available. This ensures that the measurement devices could connect to the highest performing technology available at each location.

Periodic verification measurements were conducted using randomly procured SIM cards obtained through standard retail channels. These verification measurements were designed to detect any unintended prioritisation or rate limiting that might have been applied to the primary measurement SIM cards. No evidence of such prioritisation was detected.

⁵ Following the merger of Vodafone and Three UK in mid-2025, these can now be considered as one MNO. For the purpose of this report, they will be considered separately to reflect the performance differences that a consumer on each network would experience.

Measurement Approach

All measurements were conducted as attended surveys. A data collection operative carried the measurement unit onto scheduled passenger services and collected data continuously for the full duration of each journey.

The measurement unit was positioned on the table in front of the operative's seat at approximately abdominal height of a seated adult, simulating a typical passenger position. Where table placement was not available, the unit was held at waist height. The operative was instructed to sit in the middle carriage of the train where possible, ensuring measurements were taken from a representative location within the train.

No additional objects were placed on the table that could influence radio signal propagation. The operative did not use a personal mobile device during data collection to avoid potential interference or additional network load.

Data collection equipment was activated approximately 10 minutes before departure where early boarding was possible. However, only data collected while the train was in motion between departure and arrival was included in the final analysis. Data recorded before departure and after arrival was discarded to ensure measurements reflected in-journey conditions only.

Test Cycle

An automated test cycle was executed continuously throughout each journey. Each cycle comprised: HTTP download throughput test (2-megabyte file, 7-second timeout), HTTP upload throughput test (1-megabyte file, 7-second timeout) and an ICMP ping test (10 pings sent 200ms apart each with a 2-second timeout).

Where a timeout occurred before the requested amount of data could be transferred, the total bytes actually transferred were recorded and used to calculate the effective speed. This approach ensures that slow network connections are not discarded but rather recorded with accurate speed metrics reflecting what the user experienced.

All test cycles were directed to common internet endpoints including Content Delivery Networks (CDN), matching the connections that would be made when users access typical websites. This approach provides a representative end-to-end view of network performance as experienced by real passengers.

All four mobile networks were tested using identical endpoints to maintain consistency and ensure fair comparison. This eliminates the possibility that differences in performance between operators could be attributed to different destination servers or network paths.

Active tests were designed to reflect nominal usage and capture real-world performance. Network steering including Spectrum Band and RAT selection were not artificially locked.

In addition to active throughput testing, passive coverage measurements were recorded continuously. Signal strength (RSRP), signal quality (RSRQ), Signal-to-Interference-plus-Noise Ratio (SINR), cell identity, frequency band and radio access technology (RAT) were recorded approximately every second, providing detailed insight into RF conditions throughout each journey.

Wi-Fi Measurement

Wi-Fi was measured using a dedicated Samsung Galaxy S24 with no SIM card installed. This configuration ensures that all data transmission occurred exclusively over the train operator's Wi-Fi network and not via mobile networks.

At the start of each journey, the operative manually connected the Wi-Fi device to the train's publicly available Wi-Fi network and completed any captive portal authentication that was required. The same automated test cycle used for mobile networks was then executed, enabling direct like-for-like comparison of performance between Wi-Fi and mobile technologies. Where Wi-Fi disconnection occurred during the journey, up to three reconnection attempts were made. If reconnection was unsuccessful after the third attempt, a five-minute waiting period was observed before repeating the reconnection cycle. This cycle continued for the remainder of the journey. All disconnection events and reconnection attempts were recorded in the data.

Additional Wi-Fi-specific metrics were recorded throughout each journey including: Extended Service Set Identifier (ESSID), Basic Service Set Identifier (BSSID), channel number, Received Signal Strength Indicator (RSSI) and security protocol type. These metrics provide detailed characterisation of the Wi-Fi network encountered on each route.

Routes and Fieldwork Schedule

A total of 50 journeys were completed across 24 rail lines between 18 February and 10 March 2026. Each rail line was measured in both directions of travel. All measurements were taken between 08:00 and 20:00 to capture typical passenger usage patterns.

The Bedford to London St Pancras route received additional measurement attention to support peak versus off-peak analysis. This route was measured four times, comprising two journeys during peak hours (morning commute departing 08:10 and evening commute departing 17:17) and two journeys during off-peak hours (departing 10:15 and 11:24), allowing investigation of passenger loading effects on connectivity.

Three data collection operatives conducted the fieldwork activities across the 3-week measurement period. Measurements were not taken during extreme weather events or major passenger events that could generate atypical passenger loading patterns.

Qualitative observations were recorded for each journey including weather conditions, estimated passenger loading (to the nearest quartile), train operator name, rolling stock class and type. These observations provide context for interpreting variations in measured connectivity.

A full schedule of routes measured, including dates, train operators and rolling stock types, is provided in the journey context section for each line.

Calibration and Quality Assurance

All measurement devices were calibrated prior to commencing fieldwork. The reported Received Signal Strength Indicator (RSSI) was verified to be within plus or minus 2 decibels of a reference level through static testing at a fixed outdoor location. Device polarisation, frequency band and serving cell were locked during calibration testing. Each device was

tested across all four mobile network operators to ensure consistent calibration across the measurement platform.

Data Cleaning

Stage 1: Metric-Level Cleaning

All metrics were validated against known acceptable ranges. Values representing errors or unavailable metrics, commonly maximum integer values such as 256 or 65535 used as placeholders in raw data, were replaced with null values.

Channel number (ARFCN) readings were validated against known UK frequency allocations for each operator. Invalid values were flagged, including misreads of Band 20 (values 9565 and 9615) and bands B41 and B66 which are not authorised for use in the UK.

Cell identity and ARFCN values of zero were treated as indicating no active connection and the corresponding rows were removed from the dataset. Cell identities were decomposed into eNodeB and gNodeB identifiers based on UK network formats.

Stage 2: Row-Level Cleaning

Duplicate rows were identified and removed through uniqueness constraints on timestamp and device identifier combinations.

Rows with null or corrupt values in required fields such as latitude or longitude were discarded.

Roaming data was cleaned by identifying instances where a device registered on another operator's network via emergency calling protocols, in which case only data from the home operator was retained. Non-UK Public Land Mobile Network (PLMN) identifiers (detected near Dover in southern England) were filtered out to ensure analysis focused on UK network performance.

Stage 3: GPS Cleaning

Global Positioning System (GPS) accuracy on rail is affected by train speed and carriage construction materials. Certain rolling stock types, notably Class 220 (Voyager), 221 (Super Voyager) trains commonly used on Cross Country services and Class 222 (Meridian) trains commonly used by East Midlands Railway, were observed to attenuate GPS signals more severely than other carriage types.

Several mitigation steps were applied at the point of data collection: modern dual-band capable smartphones were deployed; independent GPS data was collected across all five devices to enable cross-referencing; and GPS accuracy metrics were recorded to support post-processing optimisation.

Post-processing GPS cleaning comprised three steps. First, GPS readings with reported accuracy values outside the acceptable range were removed. Second, a speed-based forward-chain filter was applied to remove positions that were unreachable from the previous known-good GPS fix given the time elapsed and maximum possible train speed. Third, Hampel identification was applied to detect and remove rogue GPS points using a rolling median algorithm across the trace.

After individual device GPS traces were cleaned, a single consensus trace was created by taking the median coordinate across all active devices at each timestamp. This consensus approach is effective in removing single-device drift and produces a single best-estimate position trace.

For tunnel sections where GPS readings cluster at the entry and exit points without intermediate fixes, linear interpolation was applied to approximate device position based on timestamps and known tunnel endpoints.

Where GPS quality remained insufficient after cleaning, predominantly on services using the aforementioned rolling stock, an external railway geographic dataset was used to reconstruct the route. Publicly available railway line geometry data (sourced under a Creative Commons Attribution-ShareAlike 4.0 International License) was used to generate an accurate representation of each rail line. A commercial dataset (<https://www.realtimetrains.co.uk/>) of station pass-through times was cross-referenced to pin measurements to known station and junction locations. In these cases, precise location resolution between stations was lost and data was assigned to the relevant section of rail line based on timestamps.

Segmentation

For this report, measurements were aggregated into segments defined by the stations at which the train passed through. Where applicable, data from both directions of travel was blended within each segment to present a single representative picture per route section. Sections of this report also report data by direction of travel to allow identification of directional asymmetries in network performance. This approach was chosen because station names provide a natural and intuitive frame of reference for passengers.

For this segmentation, an external dataset, purchased for Commercial use, from Realtime Trains [38] was used to provide the accurate Station timings.

The station-to-station approach was adopted following analysis of GPS accuracy across all 50 journeys. Fixed-distance segmentation (for example, 2-kilometre bins) was considered but not adopted because GPS accuracy varied significantly between journeys. Only 65 percent of journeys achieved greater than 90 percent of GPS samples meeting a 200-metre accuracy threshold at the 2-kilometre level. Station-to-station segmentation provides a consistent and defensible methodology across all routes regardless of GPS quality, ensuring valid comparison between routes.

When providing statistics at segment level, active measurements that were conducted whilst the train was within that segment are isolated and binned into 2-minute windows (segments shorter than 2 minutes degenerate to a single bin). For line-level statistics, individual segments are weighted by the duration (travel time within the segment) to reflect the proportion of time that a passenger spends in each segment along a route.

Limitations and Caveats

Measurements presented in this report reflect conditions on the specific day and at the specific time they were taken. Each rail route was measured once in each direction of travel, with the exception of the Bedford to London St Pancras route which was measured twice in each direction to enable peak versus off-peak comparison. Measurements taken on a single

day may not be fully representative of connectivity patterns across different seasons, weather conditions or times of year.

Passenger loading, rolling stock type, time of day and weather conditions all influence measured connectivity but could not be fully controlled in this study. While qualitative observations of passenger loading were recorded, this was a visual estimate and provides only approximate information. Rolling stock type was recorded for each journey, allowing post-hoc analysis of train type effects, but measurements on different train types cannot be directly compared if other variables also differed.

The test methodology itself (repeated active measurements) does not reflect typical passenger usage patterns, which are more sporadic.

Wi-Fi fair usage policies may limit throughput for heavy users. Where possible, train operating companies (TOCs) were asked to remove data limits for the measurement device. This was only confirmed for South Western Railway services but no other TOCs. Where Wi-Fi rate limiting was in effect, measured performance may underestimate network capacity. GPS accuracy limitations on certain rolling stock types mean that location precision varies between routes. Where GPS cleaning could not achieve sufficient accuracy, measurements were assigned to station-to-station segments rather than precise geographic coordinates. This approach ensures consistency across routes but reduces spatial resolution of analysis for affected services.

Appendix for Technology Deployment: The 4G to 5G Transition

Line	Operator	2G (%)	4G (%)	5G NSA (%)	5G SA (%)
Basingstoke to Coventry (via Reading, Oxford)	EE	0.5	77.4	11.7	10.4
	Vodafone	15.6	69.6	12.1	2.7
	Three	0.0	88.4	11.2	0.4
	O2	0.4	76.4	22.8	0.4
Bedford to London St Pancras Off-Peak	EE	0.0	42.8	35.9	21.3
	Vodafone	5.0	61.7	21.5	11.8
	Three	0.0	67.8	32.2	0.0
	O2	0.0	40.4	56.6	3.0
Bedford to London St Pancras Peak	EE	0.0	51.8	29.3	18.9
	Vodafone	8.5	59.4	23.2	8.9
	Three	0.0	67.5	32.5	0.0
	O2	0.0	40.4	57.3	2.3
Derby to East Midlands Parkway	EE	1.5	19.1	24.2	55.2
	Vodafone	4.7	72.5	18.7	4.1
	Three	0.0	64.6	35.4	0.0
	O2	0.0	36.3	54.9	8.8
Edinburgh to Glasgow (via Falkirk)	EE	0.0	23.6	19.0	57.4
	Vodafone	2.3	68.3	24.5	4.9
	Three	0.0	63.9	36.1	0.0
	O2	0.0	41.6	48.3	10.1
Edinburgh to Inverness (via Perth)	EE	0.0	53.2	34.2	12.6
	Vodafone	5.5	84.7	8.4	1.4
	Three	0.0	78.2	21.8	0.0
	O2	0.0	59.6	26.2	14.2
Liverpool to York (via Earlestown, Manchester, Wakefield, Leeds)	EE	0.0	35.1	15.1	49.8
	Vodafone	0.6	55.2	27.4	16.8
	Three	0.0	57.2	42.8	0.0
	O2	0.1	26.5	47.1	26.3
London Bridge to Brighton	EE	0.6	43.0	21.9	34.5

Line	Operator	2G (%)	4G (%)	5G NSA (%)	5G SA (%)
	Vodafone	3.6	61.2	23.4	11.8
	Three	0.0	66.9	33.1	0.0
	O2	0.0	53.5	45.0	1.5
London Victoria to East Croydon	EE	0.0	6.1	4.8	89.1
	Vodafone	0.0	13.5	22.2	64.3
	Three	0.0	46.7	53.3	0.0
	O2	0.0	9.3	84.2	6.5
London to Bournemouth (via Basingstoke, Southampton)	EE	0.8	51.1	23.4	24.7
	Vodafone	2.0	63.1	22.6	12.3
	Three	0.0	75.8	24.2	0.0
	O2	0.9	61.2	25.5	12.4
London to Bristol (via Swindon, Bath Spa)	EE	0.0	19.8	28.3	51.9
	Vodafone	0.5	55.4	16.1	28.0
	Three	0.0	49.2	50.8	0.0
	O2	0.2	56.5	34.6	8.7
London to Dover (via Sevenoaks, Tonbridge, Ashford)	EE	0.6	41.1	47.2	11.1
	Vodafone	2.5	81.0	10.6	5.9
	Three	0.0	64.4	35.6	0.0
	O2	0.6	41.6	53.6	4.2
London to East Midlands Parkway	EE	0.0	37.0	21.5	41.5
	Vodafone	10.2	71.2	15.3	3.3
	Three	0.0	78.0	22.0	0.0
	O2	0.7	56.2	42.9	0.2
London to Edinburgh (via Stafford, Preston)	EE	0.0	35.5	38.9	25.6
	Vodafone	7.0	67.7	17.3	8.0
	Three	0.0	75.5	24.5	0.0
	O2	0.7	66.0	30.3	3.0
London to Edinburgh (via York, Newcastle)	EE	1.7	30.3	36.9	31.1
	Vodafone	1.8	82.1	14.6	1.5
	Three	0.0	67.8	32.2	0.0
	O2	0.0	43.5	41.8	14.7

Line	Operator	2G (%)	4G (%)	5G NSA (%)	5G SA (%)
London to Glasgow (via Stafford, Preston)	EE	0.0	32.7	41.0	26.3
	Vodafone	1.8	68.2	23.6	6.4
	Three	0.0	67.7	32.3	0.0
	O2	0.1	67.3	27.9	4.7
London to Leeds (via Doncaster)	EE	0.0	32.1	27.5	40.4
	Vodafone	3.3	81.1	13.1	2.5
	Three	0.0	57.9	42.1	0.0
	O2	0.0	38.5	56.3	5.2
London to Liverpool (via Nuneaton, Stafford)	EE	0.0	24.2	38.8	37.0
	Vodafone	0.5	66.6	19.4	13.5
	Three	0.0	57.5	42.5	0.0
	O2	0.1	47.1	51.1	1.7
London to Manchester (via Stoke on Trent)	EE	4.6	33.3	29.3	32.8
	Vodafone	3.3	70.0	20.4	6.3
	Three	0.0	78.1	21.9	0.0
	O2	0.1	60.5	33.6	5.8
London to Norwich (via Colchester, Ipswich)	EE	0.2	25.8	28.4	45.6
	Vodafone	5.4	74.4	12.5	7.7
	Three	0.0	67.9	32.1	0.0
	O2	0.0	32.4	67.1	0.5
London to Plymouth (via Taunton, Exeter, St Davids)	EE	0.0	25.9	43.5	30.6
	Vodafone	0.3	83.6	8.4	7.7
	Three	0.0	66.7	33.3	0.0
	O2	0.0	80.0	17.1	2.9
London to Swansea (via Swindon, Bristol, Cardiff)	EE	0.0	18.4	20.5	61.1
	Vodafone	0.6	58.4	14.9	26.1
	Three	0.0	56.8	43.2	0.0
	O2	0.0	56.2	34.5	9.3
Nottingham to East Midlands Parkway	EE	0.0	2.8	16.4	80.8
	Vodafone	1.5	73.1	19.6	5.8
	Three	0.0	58.5	41.5	0.0

Line	Operator	2G (%)	4G (%)	5G NSA (%)	5G SA (%)
	O2	0.0	30.5	66.8	2.7
Sheffield to Doncaster	EE	0.0	41.1	12.2	46.7
	Vodafone	35.0	55.4	7.0	2.6
	Three	0.0	84.4	15.6	0.0
	O2	0.0	68.6	19.5	11.9
Taunton to Leeds	EE	0.3	57.6	24.7	17.4
	Vodafone	7.6	68.0	22.4	2.0
	Three	0.0	77.1	22.9	0.0
	O2	0.3	66.7	29.2	3.8

Table 8: RAT percentage per operator, per line for both journeys combined, dominant RAT highlighted in bold.

Appendix for Spectrum Utilisation and Band Deployment

Frequency Distribution: EE

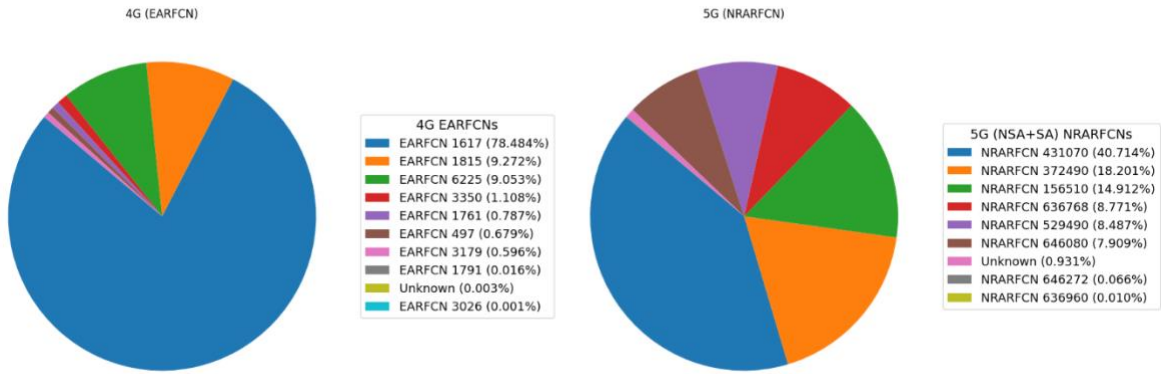


Figure 36: EE's ARFCN distribution on 4G and 5G.

Frequency Distribution: O2

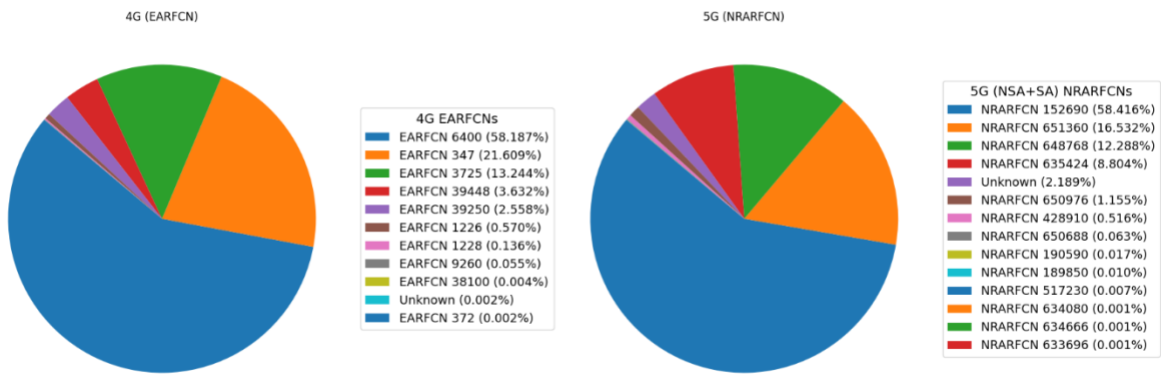


Figure 37: O2's ARFCN distribution on 4G and 5G.

Frequency Distribution: Three

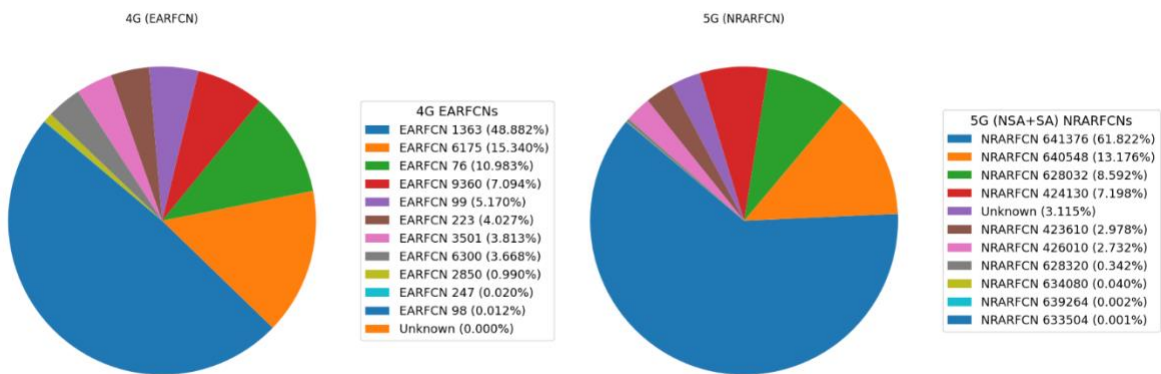


Figure 38: Three's ARFCN distribution on 4G and 5G.

Frequency Distribution: Vodafone

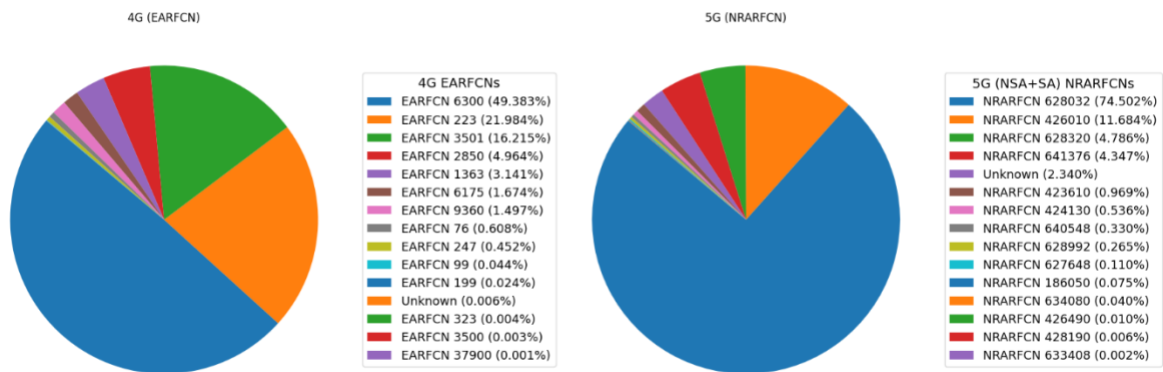


Figure 39: Vodafone's ARFCN distribution on 4G and 5G.

Operator	B1	B3	B7	B8	B20	B28	B38	B40
EE	0.680	88.563	1.705	N/A	9.053	—	N/A	N/A
Three	20.212	48.882	0.990	3.813	19.008	7.094	—	N/A
O2	21.612	0.706	N/A	13.244	58.188	0.055	0.004	6.190
Vodafone	23.118	3.141	4.965	16.219	51.060	1.497	0.001	N/A

Table 9: 4G Band Distribution (rounded to 3 decimal places). 'N/A' denotes that operator not having spectrum licenses in that band. '—' denotes no observations.

Operator	n1	n3	n7	n8	n28	n38	n78
EE	41.097	18.372	8.567	N/A	15.052	N/A	16.913
Three	13.323	—	—	—	—	—	86.677
O2	0.528	—	N/A	0.028	59.723	0.007	39.714
Vodafone	13.521	—	—	0.076	—	—	86.403

Table 10: 5G Band Distribution (rounded to 3 decimal places). 'N/A' denotes that operator not having spectrum licenses in that band. '—' denotes no observations.

Appendix for Signal to Throughput Efficiency

Operator	Mean Combined RSRP (dBm)	Median Combined RSRP (dBm)	Mean SS-RSRP (dBm)	Median SS-RSRP (dBm)	Mean RSRP (dBm)	Median RSRP (dBm)
EE	-101.19	-102.00	-98.83	-100.00	-102.03	-103.00
O2	-102.74	-104.00	-101.97	-103.00	-100.72	-101.00
Three	-108.11	-109.00	-107.57	-109.00	-105.59	-106.00
Vodafone	-102.42	-103.00	-103.49	-104.00	-101.41	-102.00

Table 11: Overall RSRP statistics by operator.

Operator	Band 1	Band 3	Band 7	Band 8	Band 20	Band 28	Band 38	Band 40
EE	-103.92	-100.62	-110.37	N/A	-115.94	N/A	N/A	N/A
O2	-99.82	-107.52	N/A	-100.75	-101.12	-111.34	N/A	-99.05
Three	-103.48	-105.60	-97.81	-99.73	-107.68	-110.52	N/A	N/A
Vodafone	-98.93	-107.66	-102.56	-101.82	-101.71	-110.51	N/A	N/A

Table 12: Mean LTE RSRP (dBm) by operator and band. Grey cells indicate bands the operator does not use; "N/A" on a white cell indicates fewer than 100 samples.

Operator	n1	n3	n7	n8	n28	n38	n78
EE	-97.13	-97.75	-100.72	N/A	-101.36	N/A	-100.60
O2	-94.19	N/A	N/A	N/A	-100.03	N/A	-104.37
Three	-102.98	N/A	N/A	N/A	N/A	N/A	-108.03
Vodafone	-104.44	N/A	N/A	N/A	N/A	N/A	-103.01

Table 13: Mean 5G NR SS-RSRP (dBm) by operator and band. Grey cells indicate bands the operator does not use; "N/A" on a white cell indicates fewer than 100 samples.

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