Rail 'Not-spots' - Technical Solutions & Practical Issues

Report

January 2012

Ofcom
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Ofcom
Issue and revision record

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Ofcom is committed to understanding the extent of mobile network not-spots across the country and has commissioned this study to further its understanding of the technical challenges of providing reliable mobile coverage on trains. Providing reliable mobile network coverage on trains is a challenge. There are a number of barriers to achieving on-board coverage, many reflecting the complex structure of the rail industry. In order to develop a comprehensive view on the subject, this short, desk-based research study, was required to

- Describe the challenges to providing reliable mobile network coverage on-board trains;
- Identify the technical solutions to providing such coverage, along with the likely evolution of the technology;
- Explore the steps that may need to be taken, and by which stakeholders, in order to implement and deploy such technology.

The findings from this report are expected to contribute to Ofcom’s understanding of the role that technical developments could play in its objectives to improve mobile coverage of the rail network.
Executive Summary

This document provides the findings of a desk research based study into the technical solutions and options available to address the problem of ‘not-spots’ for passengers on trains, particularly for voice communications. The study’s objectives were to identify the challenges to delivering usable mobile signal to passengers on trains and to identify possible technical solutions to improving the provision of mobile signal.

The two key parts of the technical challenge are to enhance mobile network coverage to the rail corridor where it passes through underserved areas and to overcome the differing degrees of signal attenuation through trains. However, it should not be overlooked that key commercial challenges will also affect the ability to implement technical solutions.

- The first part of the technical solution to rail not-spots is, ideally, “filling in” mobile network coverage adjacent to rail tracks where coverage is currently poor. This is certainly possible, but would require more active cooperation between Network Rail and the major mobile network operators (MNOs), where little or no benefit is perceived by those MNOs at the moment.

- The second part of the technical solution is on-train installation of active equipment such as repeaters or gateways for mobile signal supported by passive equipment such as housings, wiring and interfaces. This is the only technical solution to overcome serious attenuation of mobile signal by the train carriage walls and windows, where it exists. As more modern trains are progressively introduced into the rail fleets, the attenuation problem will only increase.

MNO participation in developing the solutions will be essential to either extending coverage or enabling repeater/femtocell/gateway functionality. The rail industry’s current consideration of operational mobile communications requirements may also provide an opportunity to have the issue of fitment of on-train equipment addressed more immediately.

As a result of the findings presented, there are a number of possible activities that Ofcom could undertake which could include the following initiatives.

- Undertake a more extensive audit of rail coverage from the 2G and 3G public mobile network operators to provide more quantified data on the true extent of
“coverage holes” across rail routes, as well as undertaking actual attenuation measurements for different rail carriage types and different route types.

- Another possibility would be for Ofcom to correlate GSM-R site coverage with existing 2G/3G not-spot information. This would identify ‘hot-not-spots’ where, for example, (were the attendant regulatory issues to be addressed) the use of GSM-R infrastructure, or allowing trackside land to be used, to add further MNO transmitters could potentially ease the problems in areas of most impact.

- Review the regulatory position with regard to the possible authorisation of mobile repeaters specifically for the applications on trains. In conjunction with this, Ofcom could perform a coordinating role between train operating companies (TOCs), on-train service providers and particularly MNOs to explore their attitudes to potentially enabling repeater technology to be used on trains under the control of MNOs.

Ofcom may wish to consider a number of coordination actions that might include:

- facilitating greater interaction between Network Rail and the major MNOs to reduce the costs, and any inappropriate barriers, to extending mobile coverage using rail land;
- working with DfT to ensure that the passenger communications issues are considered when specifying and procuring new rolling stock;
- Encouraging dialogue between DfT, Ofcom and DCMS to align public development agendas related to not-spots, broadband in rural areas and rail operational communications.
This section sets out the objectives and background to this short study.

1.1 **Objectives of this study**

This document provides the findings of a study into the technical solutions and options available to address the problem of ‘not-spots’ for passengers on trains. The study’s objectives were to identify the challenges to delivering useable mobile signal to passengers on trains and to identify possible technical solutions to improving the provision of mobile signal.

Ofcom was also seeking an understanding of the rail industry stakeholders and the dynamics of interactions between stakeholders which may constrain or enhance the commercial options for improving mobile coverage.

1.2 **Approach**

Information for the study has been gathered primarily by desk research, supplemented where necessary by discussions with suppliers to the rail industry.

1.3 **Context - background to rail not-spots**

‘Not-spots’ is the term used for areas or locations where mobile service coverage is lacking from one or more of the mobile network operators (MNOs). Interrupted coverage ‘on the move’ has been identified as one of the key issues for consumers and addressing not-spots has been identified as a priority area for Ofcom. Within its remit to ‘secure the availability of communications services’ for customers, Ofcom has been researching the causes of not-spots and published a report in 2009 together with a further update on its research in November 2010.

The focus of Ofcom’s research is primarily on not-spots for voice communications. In the context of the rapid development of the mobile data market, the definition of a not-spot could potentially be extended to cover where there is insufficient signal for access to the internet for basic tasks such as e-mail access. However, Ofcom’s view is that internet access is likely to be effectively addressed by the present implementations of WiFi on trains; hence its focus remains primarily on addressing not-spots for voice.
1.3.1 Mobile network coverage

The rail corridor is notoriously difficult to cover from the public mobile networks. Mobile network deployment strategy, at a simplistic level, often follows a basic pattern:

- Mobile networks, traditionally, are deployed to serve the largest populated areas first thus delivering the best return on investment for operators

- Once the largest populated areas are served, strategically important areas are then served such as shopping centres, business and retail parks etc.

- Other populated areas are served by mobile network operators (MNOs), small towns, villages and rural communities however, other pockets of ‘no coverage’ also exist which may not always be in rural or remote areas.

As a result of this general approach to rolling out cellular networks, not spots can also appear in some urban areas, roads, and rail corridors due to the specific topographic characteristics of these areas.

1.3.2 Technical challenges

A PA Consulting study on behalf of Ofcom in 2009\(^1\) evaluated a number of case studies to understand the causes and impacts of not spots. The study confirmed the widely recognised technical challenges to good mobile service for passengers which are providing coverage to the rail network and delivering useable signal into train coaches.

The rail network in Great Britain extends for some 15,750 km of which 1,270km is freight only track and 14,480km is passenger and freight track. The passenger network is classified by Network Rail according to route types and comprises - Primary (also known as ‘intercity’) routes 3,750km, Secondary routes 6,300km, London & South East commuter routes 2,250km and Rural routes 2,700km. Network Rail’s data suggest that across this network there are approximately 6,300km of cuttings of various depths and 335km of tunnels on the routes – the key geographic features that create difficulties for providing coverage from cellular base stations. In addition the rail routes traverse much sparsely populated countryside where is has not been economically attractive for the major public mobile network operators to provide coverage.
Delivering useable signal into train coaches is the second key technical challenge. Across the Great Britain rail network, there are approximately 3,300 passenger train sets (approx 12,000 coaches) of many varied designs from 30-year old simple 1 or 2-car diesel units to modern sealed and pressurised units such as the 9 and 11-car Pendolino trains. By their construction, train coaches create attenuation to radio signals. The degree of attenuation varies by age and type of coach and can vary between -5 to -35dB of signal.

The technical challenges and their potential technical solutions are discussed in Sections 2 and 3.

1.3.3 Commercial challenges

In addition to the technical challenges, there are commercial factors that potentially compound the problem of delivering contiguous mobile signal to rail passengers. The principal commercial challenges arise from:

- a lack of immediate benefit to the major public mobile network operators to extend good coverage along the full length of all rail routes; and

- A lack of financial incentive on the train operating companies to implement physical enhancements to their trains to enable better signal delivery for voice where necessary.

These commercial challenges are discussed briefly in Section 5.

1.4 Ofcom’s objectives within its wider remit

Ofcom recognises that the causes of not-spots can be complex and, in particular, planning related issues may contribute to the lower level of coverage of some rail routes. On-train ‘not-spots’ are mostly caused by a combination of poor coverage and signal attenuation in the train environment. Market developments such as the general extension of mobile network operator’s 3G networks, the merger of Orange and T-mobile and mast sharing partnerships, may help to lessen gaps in coverage from particular operators. However, it is understood that progress on the potential to install repeaters on the newer trains, which suffer from greater signal attenuation, has been slow.

Ofcom has indicated in its November 2010 report that it will try to facilitate an improvement in railway coverage. However, it notes that there may be co-ordination issues between the major MNOs and rail
industry stakeholders that are hampering discussions and access to the rail corridor and rolling stock. This may be an area where Ofcom can take a coordinating role to encourage progress. In addition, Ofcom also needs to understand the extent to which technical developments and solutions could assist in overcoming the combined effects of coverage and attenuation for voice calls.

The findings from this report are expected to contribute to Ofcom’s understanding of the role that technical developments could play in its objectives to improve mobile coverage of the rail network.
2. Current challenges to providing good service on trains

This section sets out the challenges created by trying to provide a useable cellular signal to passengers on trains. The technical challenges to good mobile service for passengers are widely recognised to be: providing coverage to the rail network; and delivering useable signal into train coaches. The section is sub-divided into three themes; the user experience of mobile service on trains to illustrate the problem, the coverage challenge and the attenuation challenge.

2.1 User experience

A useful illustration of the user experience is demonstrated by using empirical data measurements from mobile phone users on-board trains. A report conducted for Ofcom by PA Consulting provides the results from measurements of the duration of a voice call which were made whilst travelling made on two key rail main line routes and tested across four mobile operators’ networks.

The charts in Figure 2.1 and Figure 2.2 show how the probability of maintaining a 2G call for a given duration varies between the East Coast and West Coast main lines.

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1 PA Consulting Group; Not-spots research - Impacts, causes and potential solutions for areas of poor coverage, not-spots; April 2010
Figure 2.1: Probability of maintaining a call – West Coast main line

Source: PA Consulting report for Ofcom

Figure 2.2: Probability of maintaining a call – East Coast main line

Source: PA Consulting report for Ofcom
The charts show how the user experience of a voice call diminishes over time due to the reduction in availability of the operators’ coverage as the train travels along the track.

The results demonstrated that coverage was significantly better on the West Coast Mainline compared to the East Coast mainline for all 4 operators. A detailed explanation of the reasons why specific differences are apparent between the two routes is provided in the PA report and beyond the scope of this report.

The users’ experience is measured by the length time a call is maintained and a sharp reduction in probability suggests that the coverage is limited over that section of track. Therefore, the longer a call can be maintained; it can be assumed the better the coverage. The report confirmed that the main causes of poor in-train coverage were lack of coverage to the rail corridor and attenuation of the signal through the train body.

The user experience was also assessed by a report compiled by Analysys Mason in 2009. This report illustrates the difference between the predicted outdoor coverage from an UMTS network along the Glasgow to Edinburgh rail line in Figure 2.3, compared against the on-board measurements captured in Figure 2.4. The red trails indicate the locations along the route where there is no coverage which indicates a significant different to the coverage predictions.

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2 Analysys Mason, 2009. Investigation of Mobile Telephone Signal Coverage on the Main Glasgow-to-Edinburgh Rail Line; Manchester; Edinburgh-Glasgow City Collaboration.
The results suggest that coverage in the trains was only available where good coverage, implying the strongest radio signal, was present along short sections of the line.
There is potential scope for more widespread signal attenuation measurements of UK rail passenger carriage types in 900/1800/2100 MHz bands using Smartphone ‘apps’. This uses the idea of individual users collecting data on their own experience for compilation as a survey (i.e. “crowdsourcing”). This does provide a mechanism for assessing coverage but it may be slightly misleading because, as it represents an “opt-in” type of survey by users, it does not necessarily provide certainty that a particular area has been completely tested for coverage. Figure 2.5 below shows the output from one of such applications from Opensignalmaps.com.

Figure 2.5: User experience of coverage south of London

Source:Opensignalmaps.com - Solid line = ‘A’ roads; Dashed line = rail route
2.2 **Coverage challenge**

The rail corridor is notoriously difficult to cover from the public mobile networks. Cellular mast locations are not normally located to serve the rail corridor. However, there are some exceptions, where operators have deployed sites that are close to the railway to specifically target rail passengers.\(^3\)

In an urban and suburban environment cellular masts (macro cells) are typically located on building rooftops or separate mast sites often above the clutter and positioned to serve wide areas, buildings and along the numerous street canyons. Microcells or smaller Pico cells can often be located at or below rooftop height to serve deeper into buildings or more densely populated areas.

The nature and location of the rail track limits the opportunity to provide a good service to the rail corridor. The illustration below shows how the ground height of the rail track can vary from ground level, to below ground level and in some locations above ground level. Providing any sort of contiguous coverage along the rail corridor within such an environment would require specific site locations (and site height) and deployment design to ensure the minimum coverage levels are maintained along the route.

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Another challenge to providing coverage along the rail corridor is the significant proportion of the rail track that runs through rural areas. Some routes can run tens of kilometres between towns and villages and not encounter a single mobile phone mast\(^4\). This affects contiguous coverage of the rail routes and poses a challenge to providing coverage in these particular areas.

This section has described the challenge of providing mobile coverage to the rail corridor. While coverage does exist in certain areas (typically urban and suburban), the coverage is not contiguous and is insufficiently reliable to deliver a good quality of service to passengers. It is not just the lack of coverage that causes the problem of delivering a usable mobile signal within trains but also the loss of signal due to the body of the train carriage itself which compounds the problem. This attenuation challenge is addressed in more detail in the next section.

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\(^4\) High level research conducted using Ofcom Sitefinder found examples of long stretches of rail track with no adjacent mobile phone masts.
2.3 **Attenuation challenge**

The following diagram illustrates some of the practical detail that affects the mobile signals penetrating the train carriage.

![Figure 2.7: Illustration of in carriage signal attenuation](image)

A train carriage can be considered to be like a ‘Faraday cage’ which is generally used to block radio frequency signals from getting in to (or out of) an area. The metal skin attenuates the incoming cellular signal by varying amounts depending on the carriage design and carrier frequency of the signal (The higher the frequency the more attenuation to the signal). In more modern trains the attenuation can be up to -30 dB (This means the RF signal needs to 1000 times stronger to provide an equivalent service to users outside the train) this is because trains are now designed to be sealed units to enhance the heating, air conditioning and ventilation systems.

On some trains, the carriage windows, which can sometimes offer slightly reduced attenuation, now use a metallic film designed to act as a sun shade for passengers. This metallic film also attenuates the RF signal thus making signal penetration much more challenging. Older train designs with large windows and no metallic film have lower train carriage penetration levels (around -10 dB) and this could be the difference between making a successful call and receiving no service whilst on-board the train.
Delivering a useable signal into train coaches is also frequency dependent. Lower frequencies (<1GHz) have better indoor penetration properties compared to higher frequencies, such as those above 1 GHz. Therefore, GSM900 is likely to provide a better signal onboard trains compared to GSM1800 assuming similar terminal devices are used - this would benefit those users on a GSM900 network.

Coverage to indoor locations is challenging regardless if it’s in a train car, building etc. Depth of coverage is another challenge in providing a mobile service to a train. Passengers in the middle of the train (or deeper within the train) have to also overcome “body loss” from other passengers, this weakens the signal further to the those mobile users onboard the train. This effect may be reduced if the mobile users are next to the window however.

Notable references which illustrate the impact of the train carriage penetration based on practical and theoretical attenuation values are provided below.

- At GSM 900 MHz, measured -15 to -25 dB loss due to train carriage wall (variance due to location within carriage). Additional 0 to -10 dB loss due to train passenger density (variance due to number of people within carriage). (Zhang, 2005)\(^5\)

- Greater attenuation is predicted at 1800 and 2100 MHz At 2400 MHz, measured -40 to -50 dB loss due to train carriage wall. (Deniau, 2009, p22)\(^6\)

- “The approximate penetration loss for current train carriages in operation can vary between -5 dB and -25 dB, including approximately 8dB standard deviation. In some cases, increased losses may be introduced due to the use of metalized carriage windows.” (Michel and Ramasarma, 2005)\(^7\)

- These losses are greater than static building penetration predictions of the COST231 propagation model (Saunders, 1999)\(^8\) - possibly

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\(^6\) Deniau, V., 2009. Analysis of the attenuation of the WIFI [sic] signals inside and outside a railway vehicle. EC: RAILCOM


due to metal structure, high grazing angle loss (cell sites adjacent to line) and in-motion multipath fast fading effects.

It should be noted that the signal attenuation on-board the train affects both the downlink and uplink in the network. The impact of this can vary the user experience, as often networks can be ‘uplink limited’ which means the extent of coverage is dependent on the received signal from the mobile back to the base station and if the signal is attenuated enough by the train carriage it can result in a mobile not spot occurring. This is dependent on a number of factors such as the device type, the base station receive equipment and location of the site relative to the track.

2.3.1 User experience on board trains also varies due to consumer choice of devices

There is a significant mix of different devices operating on mobile networks today. The largest proportion of devices, and those normally used on trains, are handsets for users to make voice calls. The increasing use of smartphones, laptops and tablets, however, indicates a changing mix of form factors of devices which invariably means a mix of user experience. This is determined by how the user accesses the network and types of data applications that are used in addition to voice calls. Working within the rail environment the type of device matters especially for operational purposes. This means devices must be robust, durable and fit for purpose. The travelling public, however, have a choice of form factor for their devices which can impact quality of reception when trying to access the mobile network.

In contrast to today’s mobile devices, early mobile phone design used external ‘stubby’ antennas which helped with reception (and transmission) quality. Furthermore, only one, or maybe two frequency bands were supported and the receiver need tune only to those few frequency bands which meant mobile device receivers were inherently good.

Over time mobile devices have become more sophisticated and the electronic circuitry minimised to incorporate more and more enhanced features such as better screens, more applications, more frequency bands and improved functionality. These enhanced features can come at a cost to the radio performance of the handset as multi band phones incorporate wider band receivers which weaken the performance for any one single band. This reduced performance is coupled with multiband antennas becoming integrated into the handsets themselves making reception onboard trains even more challenging.
Consumers, therefore, may experience different quality of service levels onboard trains based on the mix of device types. This factor should be taken into account when addressing the issue of mobile coverage on board trains particularly if this problem is going to compound the attenuation problem over time.
3. Technical solutions and options

This section provides a description of the available technical solutions to address the challenges described in Section 2. The section discusses potential technical solutions to the coverage problem followed by potential technical solutions to the attenuation problem and related issues.

3.1 Introduction

It is useful to structure a discussion of the technical solutions to rail not-spots in terms of the problems which must be overcome. These problems have been expressed in Section 2. To develop these further, Figure 3.1 is one way of depicting the technical causes of rail not-spots, grouping them by the radio wave propagation factors involved.

**Limited rural coverage** refers to those rail route general locations where normal outdoor or first-room signal strength is not available because the free space path loss is too great. More simply put, it is those locations which are too far from a base station as determined by looking at a map. It is equivalent to the coverage boundaries as predicted by RF planning tools (as these typically do not take into account specific local shadowing effects in rural areas), and as reported to the public by the mobile operators.

**Tunnels and cuttings** refers to the RF signal attenuation caused by local shadowing along the rail corridor due to earthworks.
Taken together, the effects of limited rural coverage and tunnels and cuttings create not-spots along the rail route. These not-spots are present even when a train is not, and as such would be noticeable to pedestrians and trackside maintenance workers walking alongside the rail route. We refer to this as the coverage problem.

Carriage attenuation refers to the signal strength reduction caused by the train, including the carriage wall and the passengers themselves. It also includes fast fading of the signal due to multipath effects when the train is moving. We refer to this as the attenuation problem.

Both the coverage and the attenuation problems must be solved in order to eliminate or reduce rail mobile not-spots. There are a number of ways in which the first can be solved, and a more limited number of ways in which the second can be solved. We have grouped these ways into two general types of solution for each problem, as shown in Figure 3.2.

Figure 3.2: Technical solutions to the challenges

The selection of one solution is tied to the selection of the other solution, so they cannot be considered independently. However, it is useful to describe them separately in this report in order to explain the possibilities. These solutions are discussed in sections 3.3 and 3.4 below.
3.2 Defining success

Before investigating solutions it is useful to define what a successful solution would achieve. Ofcom may have a not-spot definition; however, for the purposes of this report we suggest two very simple scenarios based on the rail passenger experience.

Ideally no configuration or point-of-use payment would be required by users in order to enable voice calls. We imagine that this scenario might suggest the minimum passenger communications experience:

**Minimum** A passenger boards a train with her phone in her bag. Whilst enjoying the rural scenery she unexpectedly receives a call. She chats for a few minutes while the train goes through tunnels, and then sends a text.

We would also suggest that reasonable Internet access (e.g. at least 1Mbps to the handset, in contention with other passengers) might be a useful additional not-spot elimination goal. This Internet access goal is perhaps one which might be preferred over voice by some passengers, and we expect that it may become more important to and appreciated by many passengers over time. The following scenario might suggest the ideal passenger communications experience: it is clearly not the ideal journey, but such situations are when reliable communications can be most helpful.

**Ideal** After chatting and texting, our passenger also checks her email. The train pauses for a while at a red signal in a deep cutting, so she re-plans her onward journey online and sends an instant message to her daughter to advise her that she will be late. At the same time, other passengers around her are also making calls, sending messages, and accessing the Internet.

While noting the ideal goal, we recognise that the key focus for Ofcom for the present is addressing voice not-spots since internet access is far more likely to be addressed by present-day WiFi implementations.
3.3 Solving the coverage problem

3.3.1 Add standard infrastructure (normal base stations)

This solution involves relying upon existing mobile network coverage growth near rail routes. This is how the mobile networks have grown to date, and rail not-spots exist only because there is not enough traffic or it has not yet been considered profitable to expand the networks to cover those locations.

As a (perhaps unintentional) implementation example, onboard coverage is much more likely when trains are moving through highly-populated areas of cities and towns. In these areas high capacity is required and so cells are smaller and therefore closer to the rail line.

As this solution is inextricably linked with the effects of carriage attenuation on the link budget, the quantities of base stations involved are discussed at that point later in this document.

3.3.2 Install trackside infrastructure to provide linear coverage

This solution involves the installation of trackside infrastructure, which would give more linear coverage along the track (rather than the typically circular coverage which standard infrastructure gives), and may extend this coverage into tunnels and cuttings.

This differs from standard infrastructure in that it is specifically designed to provide coverage along rail routes, and is much closer to the trackside. The fundamental principle is that a large number of small cells, with power output more uniformly distributed, are more efficient at providing linear coverage. A greater quantity of lower-power transceivers along rail routes, or a distributed antenna system/leaky feeder can achieve this.

In Japan, leaky coaxial cable is installed alongside the track for operational radio communication with trains. A 2.4 GHz signal is also transmitted, providing 768 kbps of passenger broadband capacity to each train, with transceivers up to 17km apart. Leaky coaxial antennas also serve the Heathrow Express and Channel Tunnel railways.

Allowing mobile operators or wholesale infrastructure providers to install base stations with specialised antennas trackside on Network Rail land would also significantly improve coverage, provided the commercial incentives were in place to do so. Developments such as Alcatel-Lucent’s small cube-shaped transmitters (lightRadio) and other efforts
enabled by RF-over-fibre aimed at moving the base station towards the rear of the network all provide more ways of achieving more uniform multi-operator coverage and with fewer handoffs.

Access to and use of railway land

Whether such infrastructure could be installed on railway land or on private land nearby is subject to the will and the commercial relationships of the organisations involved.

Network Rail may consider allowing the use of spare capacity on its fixed trackside fibre or on the network it forms, known as the FTN, to interconnect trackside emitters.

To extend coverage into tunnels, distributed infrastructure within the tunnel is required. This may be via radiating coaxial cable or multiple point emitters, and this method is in use in many rail tunnels e.g. the Channel Tunnel and the Heathrow Express. The in-tunnel distribution concept is identical to the onboard distribution concept shown in Figure 3.4 except fitted inside a tunnel instead of inside a train.

3.4 Solving the attenuation problem

3.4.1 Install onboard active equipment

By installing active equipment on the train it is possible to eliminate the attenuation problem, turning the train itself into a type of base station, but in motion alongside the passenger handsets. Implementation would require involvement of the relevant train operating company and train OEM. It should be noted that the installation of active equipment will also be dependent on the installation of passive equipment such as equipment housings and racks, cabling, inter-carriage links and standardised interfaces. There are, however, initiatives within the rail industry which may help to address passive equipment installation in the short to medium term (see Section 4.7).

There are two different radio links to consider. Each link type has different air interface technology requirements and constraints.
Referring to Figure 3.3:

- **Link 1a**: Link between the wholesale or mobile service provider/s and the train-mounted "gateway";

- **Link 1b**: Link between train-mounted “gateway” and handsets or other mobile devices

Links 1a and 1b are interconnected onboard the train by a piece of active equipment. This onboard active equipment has two transceivers, one connected to a roof-mounted antenna for link 1a off-train, and one connected to a carriage interior antenna(s) for link 1b to the handsets.

For comparison, Figure 3.3 also shows the normal situation.

- **Link 2**: Direct link between mobile service provider and handset or other mobile devices. This is subject to the carriage attenuation problem.
3.4.1.1 Link 1a: shared train uplink

Link 1a, the shared train uplink, needs to be able to provide sufficient backhaul capacity to support the predicted traffic load generated by a full carriage or full train of passengers.

A European standard is emerging from the rail industry (IEC61375 Train Communication Network) for active onboard equipment to switch between multiple backhaul links as desired based on channel cost, location, signal strength, and traffic source. It recognises and provides a framework for solutions to the problems of sharing access to a single onboard train network and multiple train-to-ground, train-to-train, and train-to-mobile-device links, including the ability to handle the wide range of train types and radio network types throughout Europe.

There are a variety of possibilities for the air interface technology, determined primarily by whether GSM voice handling is required (or just packet data), and by the existence of a viable commercial provider at the fixed end of the link. Examples of suitable protocols include W-CDMA (3G), HSPA (3G), LTE, WiMAX, DVB-RCS (satellite).

Implementation examples include:

- Icomera launched one of the world's first high-speed Internet solutions for trains in September 2002 and is today a leading provider of open Internet connectivity and application platforms for passenger transport and public safety. Products are deployed on rail, road and sea, serving more than 15 million Wi-Fi users in over 20 countries and providing high-speed access for fleet tracking and mission-critical on-board systems. (sources: icomera.com)

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9 http://www.iec.ch/dyn/www/?p=103:14:0::FSP_ORG_ID,FSP_LANG_ID:1588,25
10 This standard is primarily set at a system level, for example specifying high-level onboard and ground node and gateway functions, addressing schemes, and train-to-shore link selection algorithms. It appears primarily intended to standardise a means of enabling a broad range of operational and maintenance information flows between the train and the ground (in both directions), but with the capability of also including passenger-device information flows. It is unlikely to disallow the installation of completely separate passenger communication equipment; instead it provides an opportunity for such equipment to be included in a low-layer converged network (including off-board links). We recognise that this type of systems integration is only one approach to a solution, and that at present multiple separate communication links are likely to be more straightforward to implement without industry-wide and cross-industry coordination. However, it does present a vision and an opportunity for a combined future system.
Nomad Digital was the first company in the UK to trial Wi-Fi on board trains and the first to trial IEEE802.16 as a backhaul technology for trains. Nomad has rail customers in UK, Europe, North America, the Middle East, India and China, and their equipment provides free Wi-Fi on Amtrak trains in the USA. (source: uknomad.com\(^{12}\))

21Net is a Belgian company which provides onboard Wi-Fi for train operators such as Thalys, SNCF, RENFE, VIA Rail, NTV and Indian Railways. They use a bi-directional Ku-band satellite link to send and receive up to 4Mbps on the downlink and 2Mbps on the uplink via a Nokia Siemens Networks ground station in Madrid. VoIP traffic (e.g. Skype) is allowed. (source: 21net.com\(^{13}\))

3.4.1.2 Link 1b, on-train distribution link

Link 1b, the on-train distribution link, is constrained by the air interfaces available in mass-market handsets.

New air interface proposals appear at frequent intervals, but in reality those built into mass-market handsets change quite slowly. There is an average of two years between publication of a new standard and the first commercial implementation, and an average of six years between publication and widespread adoption (defined as 50 million subscribers).

The available link protocols may be grouped according to spectrum license type:

- Handset air interfaces using UK mobile operators' licensed spectrum:
  - GSM, GPRS, EDGE (2G)
  - W-CDMA, HSPA (3G)
  - LTE is imminent, likely followed by LTE-advanced

- Handset air interfaces using unlicensed spectrum:
  - Wi-Fi

\(^{12}\) http://www.uknomad.com/about.html
\(^{13}\) http://www.21net.com/solutions/internet-on-board
Repeating or extending mobile phone signals for voice differs from providing onboard internet access via Wi-Fi.

There are three broad architecture options for the onboard equipment, and each will be discussed in turn:

- **IP data access points** (e.g. Wi-Fi access points using unlicensed spectrum)
- **GSM/UMTS wideband repeaters** (i.e. unmanaged signal amplifiers using licensed spectrum)
- **GSM/UMTS picocells/femtocells** (i.e. managed miniature base stations using licensed spectrum)

**IP data access points**

Ideally no configuration or special payment would be required by users in order to enable calls. This would disfavour the use of Wi-Fi or Bluetooth as the onboard access link for spot elimination for voice calls. However, to deliver mobile broadband data access to passenger devices, Wi-Fi is an ideal link 1b solution and there are many current implementation examples of this on trains, e.g. services provided by Nomad Digital, Icomera and 21net. Notably, the IP data service provided by 21Net specifically allows VoIP calls, so while this might not meet our earlier definition of success; it would be a useful solution for many passengers.

Because GSM/UMTS cannot by definition use Wi-Fi as the air interface, then for trains which are already fitted for mobile broadband access via Wi-Fi, separate parallel active equipment is likely to be required to enable voice not-spot elimination, and possibly separate RF distribution equipment and a separate roof antenna. Eventually, the provision of an onboard 3G or LTE repeater (or picocell) might reduce demand for a separate Wi-Fi service.

**GSM/UMTS wideband repeaters**

Installation or use of repeater devices is illegal unless the equipment is compliant with all relevant EU regulatory requirements, including the Radio equipment and Telecommunications Terminal Equipment (R&TTE) Directive and the use of the equipment is specifically authorised in the UK, either via a licence or by regulations made by
Ofcom to exempt the use from licensing\textsuperscript{14}. Ofcom has not made regulations exempting the use of any cellular repeater devices and so their unlicensed use remains illegal in the UK. Only the mobile network operators (MNOs) are licensed to use equipment that transmits in the cellular frequency bands and repeaters would fall into this category. Hence consideration of the further use of repeaters on trains will necessarily involve working in collaboration with the major MNOs.

Nevertheless, GSM/UMTS repeaters are available from several vendors:

- **Commscope:** “The Andrew Solutions in-train repeater is a versatile, cost-effective, multi-band, multi-technology solution designed for GSM, GSM-R and UMTS. Each frequency band (GSM-R, (E)GSM900, GSM1800, and UMTS) fits into one 19” chassis of 1U which can be combined externally.

- **Comlab AG:** “Single band GSM-R or multiband repeaters are available. Supply to train combinations can be ensured with in-train repeaters.”

- **Axell Wireless:** “a multiband, multi-operator repeater which is small and flexible specifically designed to provide coverage within train carriages. It is designed to withstand the physical environment inside a train and meet all required standards of train equipment. The OnBoard repeater can be equipped with any combination of the frequency bands; GSM-R, GSM900, GSM 1800 and UMTS.” 300 repeaters installed on trains in Sweden, 56 repeaters installed on trains in Norway.

In 2007 and 2008 Virgin Trains fitted some trains with GSM repeaters. These were fitted by Orange and Vodafone, so only customers of those mobile operators benefited at that time. Call completion rates reportedly improved by 60%.

In Italy, Telecom Italia has fitted the Frecciarossa high-speed trains which serve the main intercity long distance routes with Andrew/Commscope multi-operator repeaters. The Andrew Solutions Node A is a digital multi-band repeater and claims to provide selective transmission of interleaved sub-bands for amplification of GSM, EDGE,
iDEN, TDMA, CDMA, W-CDMA, HSDPA, TETRA, Tetrapol, and WiMAX signals within multiple frequency bands\(^{15,16,17}\)

GSM/UMTS picocells or femtocells

Picocells and femtocells have been successfully used for several years by mobile network operators as miniature base stations to eliminate small not-spots, and might be used on trains to provide the onboard link 1b. An off-train data link (link 1a) would also be required to backhaul the generated traffic. These devices transmit in the mobile network operators’ licensed bands so their lead would be necessary.

The difference in terminology between these devices is not strictly defined, and is based upon the number of active users, the range and the network management method.

- **Picocells** typically serve 16 to 64 or more active users, are used to provide coverage to office floors and street corners, and are able to be fully configured and managed from within the mobile operator’s network to adjust to adjacent cells. Supervisory control from an associated BSC and MSC is required and therefore a compatible backhaul connection is necessary.

- **Femtocells** typically serve 4 to 32 active users, are intended to provide coverage to homes or small office rooms, and almost always configure and manage themselves (in network terms). Supervisory network control is not possible and interference between cells might occur if not for the short range.

- **Enterprise femtocells** are an emerging development, providing the capacity and range of a picocell, but also including the BSC and MSC functions within the cell, enabling a variety of backhaul methods and improving call handoff capability.

Physical-layer distribution

Regardless of the active equipment architecture, a means of evenly distributing the signal throughout the train is required. Figure 3.4 shows one means of distributing link 1b, the onboard signal within the carriage,

\(^{15}\)http://www.commscope.com/andrew/eng/product/cov_cap/rf_coverage/1206539_13521.html

\(^{16}\)http://www.cellular-news.com/story/46591.php

\(^{17}\)http://www.cellular-news.com/story/47438.php
by use of a distributed antenna system. Such systems are used for trackside infrastructure, shopping centres, airports and stadia – wherever multiple lower-power emitters are desirable, rather than a single large emitter.

Figure 3.4: Distributed antenna options for providing signal along a train unit

Source: Mott MacDonald

3.4.2 Increase fixed-infrastructure link budgets by 15 to 35 dB

This solution does not involve the use of onboard active equipment. It is inefficient and inelegant, but must be considered as it is the mechanism by which the majority of handset connections (i.e. “I’m on the train” conversations) can occur on UK rail carriages at present.

The advantage of not requiring onboard active equipment, and possibly the reason why this is currently the most frequent access method, is that permission from, and commercial relationships with, train operating companies and rolling stock owners is not required for implementation.

Referring to Figure 3.3, only link 2 is involved.

3.4.2.1 Link 2: Link between fixed base station and handset

Current link technology between handsets and base stations is set by international standardisation, through the 3GPP forum, and in the UK these links are currently GSM/GPRS/EDGE/W-CDMA/HSPA. This will not change based on UK railway needs. Future handsets are likely to also include an LTE air interface, possibly followed by LTE-advanced, but no other new air interfaces for at least six years. This constrains the implementation of this particular solution to the service provided by the major UK mobile operators i.e. O2, Vodafone, Everything Everywhere etc.
Mobile service providers must have sufficient economic incentive to improve coverage on rail routes (and providing sufficient coverage to overcome carriage attenuation will be expensive, especially in remote areas).

### 3.4.2.2 Implications of increased link budgets

This solution is essentially an extrapolation of the standard and trackside infrastructure coverage solutions, and involves significantly improving the signal strength of link 2 such that onboard active equipment is not needed. The extrapolation is that instead of radio-frequency planning to provide normal outdoor or first-room coverage, link budgets are instead set in order to overcome train carriage and passenger density attenuation.

As base station and handset maximum output powers are limited, the solution is to reduce the distance which link 2 must traverse. This means placing base stations sufficiently close to handsets to overcome the effects of carriage attenuation.

As noted in the coverage challenges section of this report, typically up to -15 to -25 dB of signal loss may occur due to the train carriage wall (the variance is due to the location within the carriage). There is also an additional 0 to -10 dB of signal loss due to passenger body density (the variance is due to the number of people within the carriage). These figures apply at 900 MHz, and still greater loss is expected in the 1800 MHz and 2100 MHz bands.

Basic modelling, under specific set of scenario assumptions, suggests a significantly greater number of base stations would be required. Assuming a ‘typical’ mobile broadband network deployment along the rail routes utilising 2 sector antennas at max 15m antenna height and using the SE21 propagation model; at least a six-fold increase in sites would be required. For example modelling for a 1Mbps data service based on HSPA at 900 MHz from trackside base stations:

- From a theoretical study of 950 km of primary and commuter track through urban, suburban & rural environments, ~1160 base stations would be required to achieve coverage without onboard active equipment fitted, but only ~180 base stations would be required if connecting via onboard equipment.

- From a theoretical study of 980 km of primary intercity track through largely rural environments, ~520 base stations would be required to achieve coverage without onboard active equipment fitted, but only
~80 base stations would be required if connecting via onboard equipment.

### 3.4.3 Other technical complications and their solutions

There are additional technical complications arising from the rail environment. These are noted in Table 3.1, along with how these complications are typically handled.

<table>
<thead>
<tr>
<th>Complication</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed trains full of subscribers causing frequent handoffs in the mobile operators’ networks</td>
<td>RF-over-fibre fixed infrastructure, allowing the spectrum to follow the train across several cells</td>
</tr>
<tr>
<td>High-vibration, high-interference installation environment for equipment, with lengthy periods between preventative maintenance</td>
<td>Construction of equipment to meet industrial standards</td>
</tr>
<tr>
<td>Each day, there are constant additions and removals of multiple-carriage sets to form and re-form trains. Maintaining wired or optical signal integrity between carriage sets through coupler contacts, which can become dirty, is sometimes difficult.</td>
<td>Fitment of multiple active devices, integration at design and construction stage, use of secondary wireless links between carriages (e.g. using 5.8 GHz unlicensed spectrum), or modulating signals onto existing circuits e.g. lighting.</td>
</tr>
</tbody>
</table>

### 3.4.4 GSM-R as an exemplar

This chapter has described the technical solutions for overcoming the coverage challenge and the attenuation challenge for delivering mobile communications along the rail corridor.

The rail industry has been faced with these challenges for many years and some technology and solutions developed to tackle these challenges have been already been designed and implemented. The original requirement from the rail perspective was to provide secure train cab radio systems, so that the driver can contact the signaller in the case of an emergency or any other related issue. The resulting solution known as Cab Secure Radio (CSR) used a form of analogue Private Mobile Radio (PMR) to deliver secure mobile coverage along the rail corridor using on-track directional transmitters to serve the majority of the routes.

This technology has now been replaced by the latest solution, GSM-R which is currently being deployed using over 2,000 mast sites across
the rail network. GSM-R provides secure digital voice and data along the rail corridor to the train cab via an external antenna on the roof so that full contiguous coverage is delivered to over 95% of the track. Both CSR and GSM-R only required secure communications to be provided to the driver’s cab. Hence the implementations solved the following problems to deliver robust and reliable operational communication systems to the train:

- the coverage problem by building dedicated trackside radio mast infrastructure; and

- the attenuation problem by using external roof mounted antennae with internal fixed wiring to the driver terminals in the train cabs.

However, because these are specifically train control and signalling systems with limited traffic separation, limited spectrum and low capacity, they are not presently able to be extended to allow passenger access to the communications link.
4. Key stakeholders in rail industry

This section describes the key stakeholders that make up the GB rail industry and the potential influence each of them may have on delivering technical solutions to the challenge of delivering useable mobile signal to train passengers.

4.1 Rail stakeholders

The main stakeholders in the rail industry and their financial relationships are illustrated the diagram in Figure 4.1 below which is drawn from a National Audit Office (NAO) report on the industry. In summary:

- The Department for Transport (DfT), Transport Scotland and the Office of the Rail Regulator (ORR) provide policy guidance and regulation to the industry;
- Network Rail (NR) operates the physical rail ‘infrastructure’ and charges operating companies for its use;
- Train Operating Companies (TOCs) and Freight Operating Companies (FOCs) provide the “retail” services to;
- Passengers and freight customers who are the ultimate beneficiaries of the system.
- Rolling stock leasing companies (ROSCOs) own train vehicles which are leased to TOCs and FOCs; and
- The Rail supply industry comprises a wide range of contractors and suppliers providing component systems and implementation support.

Passenger rail revenues in GB are increasing at about 3.5% per year and have reached £6.66 billion per year in 2010-11. The current government subsidy is approximately £4.6 billion (2009-10). The majority of this subsidy goes to NR.
4.2 Rail commercial structure

‘GB rail’ is a regulated industry with ownership and operation of the infrastructure (rails) separated from ownership and operation of the services (trains) running over it. This regulatory separation is set at the European level. DfT (for England and Wales) and Transport Scotland award franchises to TOCs to run passenger trains and ORR licenses the operators and acts as the economic regulator for NR setting access charges and cost, asset management and efficiency goals. Following the rail Value for Money (VfM) report this year, it is possible that more regulatory responsibility will be transferred from DfT to ORR (see below).

Passenger train services are divided between 17 franchises which have a regional focus – long distance, commuter and regional. To date, franchises have typically been 7 to 10 years – and the terms enabled the Government to “revoke” a franchise if a TOC was not considered to be performing well. TOCs (and their owning groups) typically regard this length of franchise as insufficiently long to justify investment in services or rolling stock beyond the first couple of years of a franchise term. TOCs have been thus reluctant to consider investments in their
trains unless it is at the very beginning of a franchise period. A major round of re-franchising is about to occur which may change this perspective (see below).

Many current TOC franchise agreements contain “cap and collar” revenue share/support arrangements where a significant portion (e.g. 80%) of any incremental revenue flows back to DfT (or the TOC receives government support if its revenues fall below a threshold). This does not incentivise the TOC to increase its passenger numbers, and revenues significantly, and hence might not encourage the TOC to implement additional passenger added services or investments that “improve the journey experience” and entice more passengers on to the trains.

The rolling stock – locomotives and coaches - is mostly owned by ROSCOs who lease the trains to TOCs. This arrangement was created at privatisation so that train stock could be passed between different TOCs at franchise renewal points and TOCs would not hold rolling stock assets on their balance sheets. The average life of rolling stock is typically expected to be about 35 years. The result is that TOCs and ROSCOs have to agree what fitments are made to trains and how this might be funded. NR has no interest in rolling stock except as vehicles that use its tracks - TOCs pay NR access charges based on the types, weights and frequency of train stock using the track.

One of the issues with ROSCO ownership of train stock is that, in some cases, at the end of franchises TOCs are required to remove any fitments in the trains that have been made during the franchise; especially as the TOC may not win the franchise re-bid. This also discourages TOC investment in the train stock and may make it more difficult to get a common piece of communications equipment fitted across a range of train fleets.

4.3 Rail “Value for Money” report

During 2010-11 the Government commissioned a major study led by Sir Roy McNulty into the ‘value for money’ that passengers and the government were receiving from the GB rail industry. The VfM report, published in May 2011, found that rail costs, and ticket prices, were approximately 30% higher than they ought to be in an efficiently run network. There were many causes of excessive costs including inefficiencies and poor coordination across stakeholders in the industry. A range of recommendations from the VfM report are now beginning to be implemented.
The VfM report has stimulated changes in the structure and governance of the industry – a high level Rail Delivery Group (RDG) has been formed to initiate industry wide changes that can improve performance and reduce cost. The full impact of the recommendations is yet to be worked into defined plans from each of the rail stakeholders. There is, however, expected to be a greater focus on closer regional coordination between NR and the relevant TOCs.

4.4 Refranchising

In response to consultations between ATOC, TOC owning groups and the DfT, and in part to the VfM findings, the DfT is entering a period of significant re-franchising. Up to 9 route franchises are to be re-let in the next 2 years – representing 60% of current passenger km. The DfT has indicated that new franchises will typically be for a 15-year period which is aimed at encouraging greater investment from TOCs. The new franchises are also expected no longer to include revenue share/support schemes – TOCs must bid and commit exactly how much they believe they can return to Government from their revenues and profits.

More generally, it is understood that the DfT’s new franchising policy will be to specify only the minimum service requirements from a franchisee in terms of a timetable. Many of the previous franchise conditions related to performance are expected to be come under the ORR as licence conditions under the new franchises. The level of provision of passenger information (PI), in particular at times of service disruption, is currently being consulted upon by ORR as a possible licence requirement. The need to meet licence requirements on PI may act to stimulate greater installation of real-time communications capability to the trains by TOCs/ROSCOs and this may be opportune in enabling the possibility that voice communications provision on the train could be addressed at the same time.

4.5 Industry re-organisation

In recognition of some of the organisational efficiency points raised by the VfM report, Network Rail has begun a re-organisation. This is expected to produce a return to a more regional rather than centralised structure with closer cooperation between NR regional managers and the respective TOCs operating in that region.

While the track operations are being de-centralised the telecommunications assets, including the GSM-R network and the country wide fibre FTN (Fixed Telecommunications Network), and
operations will be centralised into an organisation to be known as Network Rail Telecom (NRT). A new head of NRT has been appointed from outside the rail industry in order to focus attention of service delivery. It is understood that options for more extensive utilisation of these assets may be considered in the future.

4.6 Access to rail land and infrastructure

Access to rail property and infrastructure is controlled by Network Rail, although it does “encourage” the enhancement of the rail corridor. Network Rail grants ‘easements’ and ‘wayleaves’ to statutory providers of utilities and telecoms networks to run services along, under or over its land including arrangements to facilitate the installation of cables and masts for most major telecommunications network operators.

NR reports on its website that there are currently over 600 radio masts on rail land. It is understood, however, that these masts are not directly adjacent to the rail tracks (located in car parks or edges of depots, for example). These masts are also not located near GSM-R masts as there is understood to be a requirement for a minimum separation of 50m between GSM-R mast and other radio masts. There is currently no option to share the GSM-R infrastructure for commercial or other radio service provision.

4.7 Operational Communications

The rail industry is also collectively focussing on the development of operational applications which will benefit greatly from access to wireless communications. This focus is supported by the current cross-industry research project on Strategy Options for Rail Mobile Communications (T964). Hence the industry’s communications focus (alongside delivering safety critical voice services through GSM-R) is on delivering broadband mobile data capability; although some of this is already achieved through extensive use of GPRS SIMs from the MNOs embedded in devices on trains and at trackside.

Interest in delivering services for passengers is very much secondary in TOC business considerations, primarily because, it is understood, few positive business cases have been created. Voice communications for passengers appears even lower on the list of priorities and is presumed to be solely the responsibility of the public MNOs.
5. Commercial factors

This section discusses some of the commercial factors that might affect the feasibility of using technical solutions to address rail not-spots.

5.1 Introduction

While there are clear technical challenges to delivering mobile signal to trains, the implementation of technical solutions is equally constrained by a number of commercial challenges that will need to be considered. Addressing the current lack of commercial incentives and the relationships between stakeholders will be just as important in facilitating a technical solution.

5.2 Incentives for mobile network operators

Currently there is no incentive on the MNO to extend coverage to train services from “off-rail” base stations in rural areas where it does not already have bases stations in proximity to the rail corridor. The potential revenue increment has not been sufficient to justify the capital expenditure. Train passengers receive a relatively useable signal for some part of their journeys and probably adjust their calling behaviour to suit these conditions. The additional call traffic that might arise, were coverage to be more fully extended along rail routes, especially in rural areas, has not previously justified (and probably still does not justify) the necessary capital costs of finding sites and building base stations to provide sufficient network coverage for rail not-spots. This lack of incentive applies equally to data traffic as well as voice, since at present mobile network operators are finding it difficult to drive up revenues from the rapidly increasing data demand.

There has also been no strong incentive for MNOs to build base stations close to or on the rail corridor because of the complex process of the safety and approvals regime required by Network Rail for gaining safe access to suitable sites. The approvals requirements and necessarily stringent safety requirements added significant cost and time to the process of identifying and implementing trackside sites. Combining this with a minimal incremental revenue opportunity ensured that such developments were a low priority.

5.3 Incentives for operating companies

In a similar vein, (with the exception of Virgin Trains installation of voice repeaters) there has been little incentive on the TOC (or its ROSCO) to consider enhancements to coaches that could improve signal delivery
where this is necessary for voice calls. Any additional revenue from voice calls or data traffic will not, at present, accrue to the rail industry stakeholders. Moreover, as noted above, currently there is little incentive on TOCs to seriously attract greater passenger numbers (increased useable mobile coverage may improve passenger journey experience and stimulate further demand) under much of the present franchise and timetabling conditions.

### 5.4 Commercial opportunities

Commercial opportunities ought to emerge with creation of appropriate economic incentives for each of the stakeholders.

The most important incentive from an MNO perspective is likely to be better enabled access to trackside for the installation of its base station equipment.

Following the creation of NRT, there is potential for NR to review its asset management policy and actively seek exploitation of assets and infrastructure. This should enable more timely access to rail corridor land and possibly access to shared infrastructure. In the long term the rail industry will certainly need a closer relationship to mobile providers. GSM-R will become obsolete during the 2020s and it is very unlikely that the next generation safety critical systems (possibly based on LTE) would be created in the same manner as GSM-R was created. The sooner that NR uses MNOs to deliver infrastructure on the rail corridor the easier the transition to next generation services will be for it.

There also may be the potential to grant access to the backhaul capacity of NR’s FTN to third parties such as MNOs. Access to FTN for backhaul from radio sites given its geographic coverage would be of great value to an MNO as mobile traffic grows exponentially due to the spread of mobile data and internet services.

These access incentives may well raise the interest of MNOs in adjusting their 3G (and 4G) network extension and in-fill plans to address some not-spot areas as a higher priority than might otherwise have been the case.

A better understanding of what mobile services train passengers would really like to use when travelling, based on direct research, would also be valuable to both the MNOs and rail stakeholders in order to allow decisions on investment to be made in a more coordinated manner.
Ultimately, MNO interest in enabling “repeater-like” functionality on train vehicles for voice traffic will need to be stimulated to fully address the attenuation problem of not spots. MNOs might be encouraged to at least consider contributing to repeater investment if that involvement was associated with enabling and collecting additional data traffic as well (presuming the additional traffic could be ‘monetised’). This potential could be realised if current rail industry initiatives to develop operational communications capability (under the cross industry T964 Rail Mobile Communications Strategy project and revisions to the Rail Technical Strategy) leads to the specification and development of more standardised communications “gateway” functionality and passive connecting equipment for train vehicles. There is a growing realisation among TOCs that wireless communications systems can enhance the operational efficiency of trains and this is likely also to stimulate more implementations of communications capability across train fleets. If such capability (which could serve both operational and passenger data communication needs) were to be installed progressively across fleets, it would appear sensible to try and address the train vehicle attenuation problem of not-spots at the same time through the installation of voice repeater or femtocell functionality as well.
6. Findings and recommendations for action

This section sets out the findings of the research and makes preliminary recommendations for initiatives that could be undertaken to address the technical challenges.

6.1 Findings

The research has confirmed the view that the key technical challenges are to enhance mobile network coverage to the rail corridor where it passes through underserved areas and to overcome the differing degrees of signal attenuation through train carriages. However, it should not be overlooked that key commercial challenges will also affect the ability to implement technical solutions.

The first part of the technical solution to rail not-spots is ideally filling in mobile network coverage adjacent to rail tracks. This is certainly possible but requires more active cooperation between Network Rail and the major MNOs where little or no financial incentive for the MNOs exists at the moment.

The second part of the technical solution is installing active equipment on trains such as voice repeaters or gateways for mobile signal. This is the only technical solution to overcome serious attenuation of signal where it exists. But there is currently little incentive for TOCs/ROSCOs to pursue this or to hold initial discussions with MNOs to explore how it might be achieved for voice traffic.

As more modern trains are progressively introduced, the attenuation problem will increase. Specifying repeater technology (or at least the 'space', passive equipment and onboard distributed wideband antenna system to support it) at train design would have negligible cost implications, but the effect of this would not be seen for at least 5 years – new fleets are ordered rarely. There is a risk that the IEP procurement may have already overlooked this issue - (this will need to be clarified with DfT), and it has not been deliberately factored into the 1,200 vehicle Thameslink procurement.

The rail industry’s consideration of operational mobile communications requirements may provide an opportunity to have the issue addressed more immediately. A key enabler for operational applications will be the installation of gateway capabilities and passive equipment with more standardized interfaces and connections on train vehicles. It would
appear sensible to address the attenuation issue of not-spots in parallel.

Identifying or creating the economic incentives for MNOs to become more actively involved in achieving coverage of not-spots through any of the technical approaches will be crucial to a successful outcome. MNO participation in the solutions is essential to either extending coverage or enabling repeater/femtocell/gateway functionality.

6.2 Recommendations

As a result of the analysis and findings presented, there are a number of possible activities that Ofcom could undertake to stimulate solutions to the challenges raised. Preliminary recommendations for action could include the following initiatives.

- Undertake a more extensive audit of rail coverage from the 2G and 3G public mobile network operators to provide more quantified data on the true extent of “coverage holes” across rail routes. Such an audit could assess the ability to achieve both voice and data connectivity and would be of interest to both Ofcom and rail stakeholders.

- Undertake actual attenuation measurements for different rail carriage types and different route types. This could provide more definitive data on signal strengths in different rail carriages depending on, for example, the proximity of the radio mast and speed of the train.

- Another possibility would be for Ofcom to correlate GSM-R site coverage and transpose it onto existing 2G/3G not-spot information. This would identify ‘hot-not-spots’ where, were the attendant regulatory issues to be addressed, use of GSM-R infrastructure to add further MNO transmitters could potentially ease areas of most impact.

- Ofcom could act to facilitate greater interaction between Network Rail and the MNOs to reduce the costs, and any inappropriate barriers, to extending mobile coverage using rail land.

- Review the regulatory position with regard to the possible authorisation of mobile repeaters specifically for application in trains. Such a review would require the active participation of the MNOs
since they are currently the only entities allowed to deploy repeaters. This review could also identify whether different types of repeater functionality are considered active or passive radio equipment – as the distinction will affect who can own/fit such devices. In conjunction with this, Ofcom could perform a coordinating role between TOCs, on-train service providers and particularly MNOs to explore their attitudes to the potential for repeater technology to be used on trains.

- Ofcom should explore actions that could be taken in concert with DfT to ensure that the communications issues are considered when specifying and procuring new rolling stock. Ofcom could also consider whether it wishes to be involved in making a more overt economic case as to impact of rail not-spots, in conjunction with other government departments.

- Ofcom could also encourage dialogue between DfT, Ofcom and DCMS to align public development agendas related to not-spots, broadband in rural areas and rail operational communications.

- Finally, a perhaps more controversial option would be to include an obligation for rail corridor coverage (with or without agreed NR access) in future licenses granted as a result of upcoming spectrum auctions.