TAKING THE WI-FI ROUTE

Most of the visions for 5G are not based on what we really need, says **WILLIAM WEBB.** Here he examines what problems we are trying to solve and why Wi-Fi is as important as cellular networks

There are flaws in the vision for 5G. I suggest that users do not value faster speed and that the need for capacity growth will in any case end shortly after 5G's widespread adoption. But there are a number of visions for 5G that are needed, such as enhanced coverage. Here I discuss these elements and how they might come about – and why Wi-Fi is a powerful and overlooked resource.

CONSISTENCY IS KEY

If internet servers were always responsive, and if mobile users always had a good signal level in uncongested cells, then speed would be more than adequate for all of the applications commonly in use today. The problem is that all of these conditions are rarely met. The situation is similar to the road networks – all would like quicker journeys but the limiting factor is not the top speed of cars but the capacity of the roads. That is why ad hoc surveys and anecdotal evidence suggests that for many, speed has reached the point where further gains are of limited value and what is becoming much more important is consistency.

Most people would rather have satisfactory data rates available everywhere than very fast rates in some places and a lack of any connectivity in others. It is the same for most vertical applications – for example, constant connectivity even at relatively low rates would be more helpful for autonomous vehicles than erratically available high data rates.

This raises the question as to why some mobile operators still advertise the high speeds their networks can achieve. This appears to be 'bragging rights' – using an attribute few care about directly to demonstrate the strength of the network. It is akin to carmakers promoting high-performance models that few will buy.

Concentrating on consistency now that there is a basic sufficiency of data rates is also more likely to improve productivity and social value – certainty of having a connection would enable new methods of business and better responsiveness.

Speeds above 10 Mbps (to the home) are currently almost entirely used for entertainment, which enhances pleasure but not productivity. With governments looking to improve productivity, global competitiveness and more, a focus on consistency rather than speed appears appropriate.

Everyone will experience different connectivity issues and they will vary hugely from country to country, and consistency is hard to deliver and hard to measure – there will always be a basement or remote area that does not have coverage. So, it is better to focus on locations where coverage or capacity is most problematic. These include:

- Rural areas
- Transport, mainly trains; less so, buses
- Buildings: homes, offices and public
- Very dense areas such as major train stations and stadiums.

RURAL AREAS

Covering rural areas is predominantly a matter of economics. It could be achieved with widespread deployment of cellular masts but these masts would generate less revenue than they would cost to deploy and maintain. Hence, few if any mobile operators would voluntarily deploy them. Getting better coverage could be achieved by:

- Appropriate financial incentives such as payment from governments in return for achieving certain coverage objectives
- Technology that enables a greater range from a base station thus requiring fewer base stations and so making the coverage more economic.

The first tends to happen indirectly using coverage obligations in spectrum licences. However, a better approach might be to encourage mobile operators and others to bid to deliver the required coverage. The government would then select the best bid and pay the winner to deploy their solution. That could then be shared among all operators such that all subscribers gain coverage at the lowest cost to the government.

Subsidising rural coverage is far from a new idea. For example, in Australia the federal government has a mobile blackspot programme that is intended to improve mobile coverage and competition in regional and rural Australia through subsidising the cost of building new base stations in areas without coverage. The government committed AUS$100 million in round 1 to deliver nearly 500 new and upgraded mobile base stations across Australia.[1]

Standards bodies have not tended to focus on technology that extends range as this is generally at the expense of higher data rates. The classic solution, used extensively in many internet of things (IoT) systems, is to use data spreading (known as direct sequence spread spectrum, DSSS) to increase the range at the expense of the data rate. This is precisely the solution used by GPS satellites to enable a low-power transmission from orbit to be received by small devices. Adding a DSSS mode into the standards would give operators flexibility to trade off data rate against range when it was appropriate to do so, facilitating rural coverage. Unfortunately, such a mode does not currently appear to be on the agenda of the key standards bodies.

ON TRAINS

Mobile operators have been trying to provide good coverage in trains for many years with variable success. The best solution to most of the problems is a Wi-Fi repeater within the train – and this is becoming increasingly widely deployed. A repeater overcomes the isolation problem caused by metallised windows – indeed it benefits from this isolation as it reduces any external interference, which helps in areas with high demand. It also solves the handover problem as far as the devices inside the carriage are concerned as they stay registered onto the one internal Wi-Fi access point. It can also help somewhat with the problem of cuttings and tunnels by using an external antenna mounted on the roof of the train with much better performance than handsets in the train.

The repeater could also transmit cellular signals alongside Wi-Fi signals. However, this tends to be problematic because cellular transmissions have to be on licensed frequencies owned by operators. Gaining their approval and then selecting frequencies that do not cause interference to their external network is difficult, and the repeater becomes much more complex, having to cover multiple bands.

Finally, for most users, data connectivity is more important than voice because they can then browse, receive emails and make calls using voice-over-Wi-Fi solutions such as Skype and WhatsApp. The only problem is not being able to receive incoming calls via the cellular network.

However, the repeater transfers the coverage problem to the backhaul connection between the carriage and the network. With many tens of users in a carriage, all able to use laptops or tablets, total data rate requirements within a packed carriage could potentially exceed 100 Mbps at peak times. That is beyond the capacity of most existing backhaul systems. Instead, base stations mounted alongside the track are needed where they can provide good coverage along a length of line.

> **“Mobile operators have been trying to provide coverage in trains with variable success.”**

But these are predominantly logistical problems, requiring legislation and incentives on various players in the railway industry to resolve. They could materially improve train communications, delivering a big improvement on the situation today.

IN THE HOME

For most, data coverage in the home is provided via self-deployed Wi-Fi, which generally gives excellent data rates as long as the home broadband connection is acceptable, there is no significant Wi-Fi interference, and the signal level throughout the home is strong. Interference can often be addressed by changing channel and poor signal levels by using repeaters or better siting of the access point.

The remaining issues are then cellular coverage and possibly coverage for visitors. Cellular coverage can be important, particularly in receiving incoming calls. Outgoing calls can be made from the home cordless phone or using Wi-Fi calling apps. Various attempts have been made by mobile operators in the past to get in-home coverage using femtocells but mostly these have failed because:

- Home owners do not want an extra box in the home
- The solution is tied to one mobile operator (unless multiple boxes are installed) which makes switching harder and may not suit all members of the family
- Integrating the home femtocell into the operator’s network can be complex and expensive.

As Wi-Fi continues to gain traction it seems unlikely that femtocells will see a resurgence; instead, ways around poor cellular coverage using Wi-Fi will be developed for the home. Wi-Fi coverage

WHY 5G IS A MYTH – FLAWS IN THE CURRENT VISION

- The 5G community cannot be accused of being short of visions – but they are utopian. Achieving them would require astonishing breakthroughs in radio technology and for subscribers to be prepared to significantly increase their spending. The visions of 10x to 100x faster speeds and 1,000x increases in capacity set out by the key players are unrealisable, and the technology to deliver a new generation has not materialised; 5G as currently proposed is a myth. While technology has improved dramatically over previous generations it has now reached a point where further improvements are hard won.
- Current mobile data speeds are more than adequate for all foreseeable uses. Even 4k video requires only about 20 Mbps.[2] This is an upper limit as most mobile screens are far too small to make watching video at this resolution worthwhile. Operators have found that 'throttling' video to 1 Mbps or even less has no noticeable impact on mobile handset users.
- Regarding latency (the speed needed for instant web browsing), beyond a certain speed other factors such as the maximum turnaround time at the server and the delays inherent in the internet become constraining.[3] This data rate is currently about 4-8 Mbps and so most users will not notice an improved browsing experience once data rates rise above this point.
- Demand for data has exploded, growing around 100-fold in the five years from 2007 to 2011, and has continued to grow rapidly since. But growth is predicted to fall to 37% a year by 2020 and, if the trend continues, to zero by around 2027. Once users are watching video in all their free moments while downloading updates and attachments there is little more that they could usefully download.
- Without growing average revenues from users (ARPUs), the only rationale for mobile operators to invest in new technology is to prevent subscriber churn to their competitors. This threat has resulted in them moving quickly to deploy 4G, which does have material benefits for subscribers. But without any clear benefits from 5G there is limited incentive to upgrade networks.
- Of course, there is the possibility of another 'iPhone moment' – the emergence of either a device or service, including the internet of things, that causes another step-change in demand – but see box on page 30.
- There is the argument that 'if we don't build it they won't come' but new applications often emerge on sub-optimal networks, demonstrate potential, and then network enhancement can be justified. The need to build before applications appear might apply in the case of the 'tactile internet'. But it seems likely that many applications such as virtual reality could be trialled indoors initially, with outdoor capability being provided if needed in due course. It will be challenging to engineer the low latency and reliability needed for applications such as these.

for visitors can be achieved just by telling the visitor the password. This is workable but somewhat clunky and a more automated process could be envisaged. This might be part of a broader solution to automate the process of signing into Wi-Fi access points (see also page 31).

IN THE OFFICE

To a fair degree this is the same set of issues as in the home. Wi-Fi provides a good solution but cellular coverage can be poor. Femtocells and small cells have not proven widely popular and that seems unlikely to change. Using the same set of solutions as the home to provide Wi-Fi calling and a simplified way to gain passwords would resolve most issues.

IN PUBLIC BUILDINGS

Technically, public buildings are not different from office buildings (although some, such as museums, can be larger and so more challenging to cover). Hence, as with the home and the office, the same solutions apply of relying on Wi-Fi. Administratively, this requires the deployment of Wi-Fi and a mechanism to enable easy access. If governments did deploy a universal password solution for public buildings, this might be of value in delivering universal password solutions more widely – for example the same solution could be adopted for homes and offices. Alternatively, governments could make use of solutions being developed in the private sector.

The European Commission has recently proposed funding to assist in such deployments – see the latest on the WiFi4EU scheme for promoting internet connectivity in local communities.[4]

DENSE AREAS

Areas of very high user density such as major train stations and stadiums present particular problems. Cellular solutions struggle to cope with the need for extremely small cells in often a very open environment where there is little to prevent interference from one cell with another.

In stadiums there are specific Wi-Fi solutions where access points are deployed across the inside of the roof, providing downward pointing beams that might target only 20 seats or so. Similar solutions could be deployed for cellular, but again it is difficult to deploy one solution per operator and the building owner may prefer to deploy a self-owned/operated solution rather than negotiate with the mobile network operators.

> **Femtocells have not proven widely popular and that seems unlikely to change.**

Similar solutions could be envisaged in train stations. At present, most Wi-Fi in these venues is provided by shop owners or similar in an ad hoc manner and so tends to have poor coverage in some areas and to interfere in others. Centralising the planning and deployment of Wi-Fi would dramatically improve the situation. This would require agreement from shop owners, some of whom might deploy specific solutions as part of

their franchise (e.g. in Starbucks). As with railway coverage, it might take government intervention to bring about an improvement in major train stations. In areas such as malls, there may be sufficient commercial self-interest from the mall owner to make centralised deployment occur.

MOVING FORWARD

So across the various solutions there are a number of common threads, namely:

- Intervention from government in aspects such as train franchises, Wi-Fi in major stations and trackside coverage to force through change, and in awarding contracts for rural coverage
- Sharing of infrastructure among all mobile operators in rural areas and possibly other places
- The addition of a DSSS mode in cellular to enable greater range for rural coverage
- The ability for incoming cellphone calls to be re-routed across Wi-Fi such that if there is no cellular connectivity people are still in contact
- The ability for devices to be sent information on Wi-Fi network names and passwords rather than users having to manually enter details. This could be generic (along the lines of BT's OpenZone where any customer can use the Wi-Fi router of any other customer) or it could be based on various criteria (e.g. allowing friends on Facebook access to the password, linking hotel bookings made using a browser with a download of the Wi-Fi details, etc.)

> **It is worth recalling that we already live in a Wi-Fi-first world.**

A WI-FI-FIRST WORLD

Previous calls for enhanced coverage have mostly focused on cellular, and previous efforts to provide widespread Wi-Fi municipal coverage have generally been seen as a failure. The steps I have set out would move Wi-Fi back centre stage in the world of communications. Is this plausible, and have lessons been learnt from previous attempts to deploy widespread Wi-Fi?

It is worth recalling that we already live in a Wi-Fi-first world. Well over 50% of the traffic from our mobile phones flows over Wi-Fi and typically 100% of the data from tablets and laptops. Wi-Fi carries at least an order of magnitude more data than cellular, perhaps even two orders of magnitude. We typically own only one cellular-connected device but often five or more Wi-Fi-connected devices. There are probably around 20 million Wi-Fi access points in a country like the UK, but only around 60,000 cellular base stations. A hotel or office without Wi-Fi would be seen as unacceptable; one without cellular coverage merely irritating.

There are good reasons why Wi-Fi is preferred in most cases. Cellular is expensive to provide and has inherently limited capacity. Wi-Fi is almost free to provide and we are still a long way from reaching the capacity of current systems. This is not because of technology or spectrum – both use near-identical technologies (OFDM) and have near-identical amounts of spectrum available to them (around 500 MHz in total). The difference comes from the deployment model. Deploying coverage 'inside out' is much more efficient than 'outside in'.

With most data usage taking place inside buildings and with the outer walls of the buildings forming a partial barrier to radio waves, then delivering the radio signal from inside the building ensures users have a strong signal and takes advantage of the isolation provided by the walls to reduce interference to other users. Conversely, cellular systems have to try to blast through the outside walls, delivering poor signals inside, which reduces overall cell capacity, and results in interference between outdoor cells.

In principle, cellular could deploy indoors too – and many attempts to do so using femtocells and similar have been tried. But the scale of the deployment challenge is beyond a single company and only achieved with Wi-Fi through the actions of millions of users deploying their own access points. Now that we have Wi-Fi widely deployed, the rationale for also deploying cellular indoors is reduced and a self-fulfilling movement towards Wi-Fi-only devices has happened.

This is not to attempt to replace cellular. Wi-Fi can never provide connectivity in rural areas, along most roads and for most people when moving. Cellular is an essential component of our complete communications infrastructure, just not the best way to deliver the final elements needed for ubiquity in most cases. There are a number of issues still to address, including:

WHAT ABOUT THE INTERNET OF THINGS?

Predictions for the number of connected 'things' range from 50 billion to a trillion. There seems little doubt that there is benefit in connecting many of the things around us, and that this will increasingly happen as the various pieces of the technological and logistical puzzle fall into place. The connectivity to enable IoT need not await 5G. Many operators have enthusiastically embraced the 4G technologies designed for IoT, including LTE-M and NB-IoT, which can be deployed as software updates to existing base stations.

IoT may also involve some element of self-provision or provision by alternative emerging operators. By analogy, mobile communications are delivered via a mix of operators using licensed spectrum and self-deployment of Wi-Fi access points by myriad entities in unlicensed spectrum. The combination of both is needed to meet the coverage and capacity challenges.

Already, a number of unlicensed IoT technologies are being deployed including those from Sigfox, LoRa and based on the Weightless standard. Operators such as Arqiva in the UK and Comcast in the US are using unlicensed solutions as a way to enter the market, and others such as Orange in France plan to deploy both licensed and unlicensed solutions in a complementary manner.

Some user communities, such as campus-based organisations and airports, are considering deployment across their area. But the path towards a widely deployed unlicensed solution is less clear. It is uncertain which technology or standard will be the winner, or indeed whether there will be multiple winners. It is also unclear whether the route to widespread deployment will be via a single operator or through community action with shared access. Governments could engage in smart procurement of a nationwide IoT service, spurring suppliers and operators into action. Regardless, IoT is emerging and will grow strongly over the next few years.

Re-routing incoming cellular calls. For a device only connected to Wi-Fi (and not via cellular), making a voice call is simple. However, the routing of an incoming call made to a cellular number can be problematic. It generally requires the mobile operator to receive signalling from the phone with details of the current connection and then to take appropriate action. Other options are possible. A simple one is to use a numbering scheme not tied directly to cellular which aims to contact the handset via Wi-Fi – effectively a Skype or WhatsApp 'handle' acts in this manner. However, this may not be convenient for the user. Alternatively, the automatic 'divert on not-reachable' for an incoming cellular call could be to a Wi-Fi access enabler to assess whether a voice-over-Wi-Fi call is possible. Some regulatory intervention might be needed if mobile operators refuse to allow any access to their numbering systems or call routing functionality.

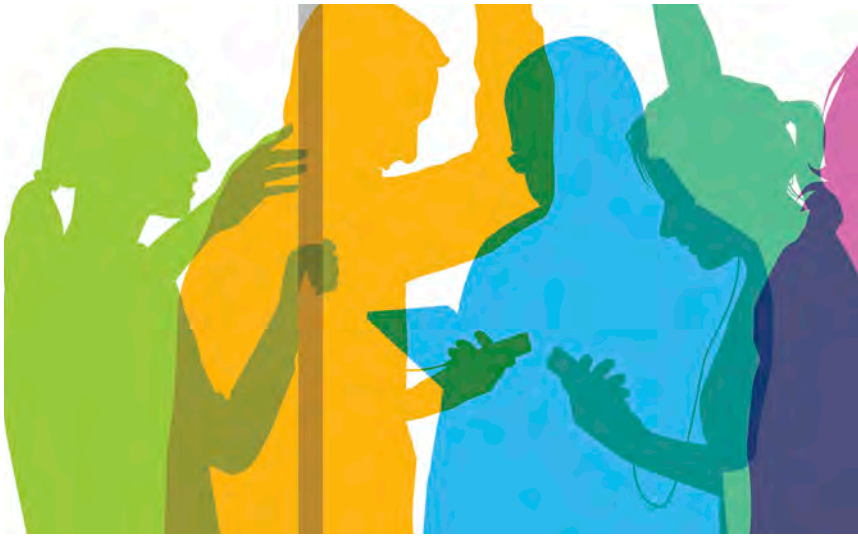
Automated passwords. It is normal for travellers to ask, "What's the Wi-Fi password?" at hotel check-in, even before they enquire about breakfast and other arrangements. Manually selecting networks and entering passwords is a workable solution but far from ideal. Logical partitioning of the access point can overcome this. Having a separate part which others can access and which has no direct connection to the owner's network and over which the owner's traffic has priority prevents concerns about hackers and makes free riders less of an issue. Modes of operation could be envisaged where an unknown device is allowed onto a network purely for the purposes of sending an automated registration request along with suitable credentials. A valid request would receive the password in response which would then allow full access to the network.

A more proactive stance would be for governments or regulators to mandate that all routers sold should make some small fraction of their capacity available for visitors for the first few days that the visitor seeks usage – this provides access that would be sufficient for most while preventing the problem of long-term 'borrowing' of resources.

In most countries there is no requirement for a company providing Wi-Fi connectivity as part of a larger business offering (such as a hotel) to record details of those using the Wi-Fi. Security agencies can ask that such recording be put in place if they suspect the Wi-Fi connection is being used for illegal purposes. Many organisations currently appear to either be misreading the law or applying excessive gating just in case.

Security. Wi-Fi can provide excellent security as long as appropriate modes of encryption are used. The biggest threat is rogue access points that seem to offer connectivity but yet will inspect traffic, looking to extract passwords and other valuable information. Many ways to resolve this could be envisaged such as:

- User applications encrypting data end-to-end to prevent a 'man-in-the-middle' being able to extract important information. This is already done routinely



- Use of a central validation server. For example, a Wi-Fi device could send the service set identifier (SSID) and password to this server along with other contextual information such as the SSIDs of other visible Wi-Fi nodes. This would allow the validation server to verify that the node is known and had been appropriately certified
- Use of a system managed by a single company – again the BT OpenZone system is a solution to this.

There does not appear to be any significant security-related reason for Wi-Fi not to adopt a more significant role.

Reliance on unlicensed spectrum. Wi-Fi uses unlicensed spectrum that could, in principal, become congested or suffer interference. In practice, we have seen that congestion builds slowly over years, allowing time for it to be addressed, and that regulators have provided additional frequency bands, such as 5 GHz, when needed. In the future, any emerging problems will likely happen slowly and be addressed through regulation.

This does imply that regulators should pay close attention to unlicensed spectrum. With a Wi-Fi-first policy, spectrum for Wi-Fi becomes more important than that for cellular, and commensurate resources should be devoted to it. This might involve more monitoring to understand congestion and a preference to provide unlicensed spectrum over licensed spectrum. Statements suggesting that the regulator would address issues that reduce the efficiency of Wi-Fi as a matter of great importance would also help reassure users and investors. More generally, a review of policy towards unlicensed spectrum and its role and value in the modern environment at both a national and international level would be appropriate.

Failure of municipal Wi-Fi. There have been various attempts to cover entire cities with Wi-Fi which have all failed, mostly because the scale of the challenge is large and the revenues small. My suggestion is different – not to expand Wi-Fi coverage into areas where there already is cellular coverage, but to selectively deploy Wi-Fi, predominantly indoors, to provide consistency, funded mostly by government in various ways. This might include direct funding for government buildings and indirect funding via licence obligations on franchises and similar.

ROLE FOR 5G

Much of 5G is focused on higher data rates and much increased capacity in dense areas. I have suggested that the delivery of ever higher speeds, above the 100 Mbps already theoretically possible with 4G, is unnecessary. Delivering increased capacity in dense urban areas would be of value, but the key solution proposed of using small cells and microwave frequencies appears uneconomic and unlikely to address the majority of data users, who are indoors.

Some elements of 5G are useful. The separation of control and data planes and the possibility of better linkage to Wi-Fi could help form a more seamless use of cellular and Wi-Fi networks. Similarly, the use of software defined networks (SDN) and network function

virtualisation (NFV) could make integration with third-party systems simpler and faster *(see also Richard Feasey's article in Intermedia, January 2017)*.

Another potential development that might impact on this area is licensed assisted access (LAA). This is an approach where mobile operators use unlicensed spectrum alongside their licensed allocation to improve throughput. Often the control link to the device is retained in the licensed spectrum, with data download occurring opportunistically in unlicensed spectrum. LAA is typically assumed to use the same 5 GHz band as Wi-Fi and is being developed as part of 4G, so might be deployed prior to the 5G era.

Simplistically, LAA might not change much. The handset will choose whether to download its required data from LAA or Wi-Fi. Both use the same frequency bands and both use similar technology. One would simply substitute for the other with little net effect. However, LAA does allow mobile operators to have more control over the operation of the handset, which might bring some benefits especially if some of the developments needed to integrate Wi-Fi and cellular more tightly fail to materialise. If delivered from a home hub, LAA might provide mobile operators with a rationale for a stronger in-home presence which could also have an impact on the industry dynamics.

REGULATORY AND GOVERNMENTAL ACTION

For such a world of consistent communications to happen requires government action of various sorts, as listed earlier. Governments and regulators need to change policies away from those focused on speed and towards those aimed at connectivity. This section considers those policies that are no longer needed and the new ones that should be started.

In considering policy and regulatory stance, some thought is needed as to potential industry structure under such a vision. At present, consumers typically have a contract for their home line with a company like BT in the UK, and a contract for their mobile with a company like Vodafone. Wi-Fi is self-provided or they use multiple different hotspots run by various companies like Starbucks. Regulation is typically focused on engineering as much competition as possible. In mobile communications this is through maintaining three or four operators. In fixed it can be through unbundled access or other forms of competition above the physical access layer. Success of regulation is measured through access speed and consumer cost with some interest also in universal service provision on fixed lines.

In future, consumers might also add some form of Wi-Fi access enabler to their list of contracts. This could be a company like BT providing hotspots in some cases, or like Google, providing passwords and certification of access points deployed by others. They may also have accounts with the government for access in public buildings. The majority of their data traffic might flow across this Wi-Fi network. Their phone may be provided by their Wi-Fi access enabler rather than their mobile operator, pre-programmed to work effectively using voice over Wi-Fi solutions. Incoming calls might be routed first to the Wi-Fi access enabler and only onto the mobile network if access over Wi-Fi is not available. The contract with the mobile operator might even be handled by the Wi-Fi access enabler.

> **Governments and regulators should focus on connectivity rather than speed.**

Shared network access is likely to grow. Mobile operators will deliver some of their services across Wi-Fi. Backhaul to Wi-Fi on trains might be delivered through a shared network owned by a third party but using spectrum from the operators. Similarly, a single rural network might be constructed that all operators use.

This is not a radically changed world, but it does have significant changes, not least in policy.

Policies no longer needed. Aiming for consistent connectivity would render some current regulatory and policy approaches unnecessary including:

- Fibre to the home initiatives and more generally a desire to be high in global speed league tables. A universal service obligation set at around 10 Mbps to the home is appropriate but most home broadband needs can be met via solutions such as FTTC and then VDSL or G.Fast over the last drop. Requiring more speed takes investment time and money away from areas such as universal Wi-Fi networks that incumbents are typically well placed to deliver
- 5G testbeds that focus on high data rates. Instead, testbeds that improve integration between cellular and Wi-Fi, that demonstrate improved rural connectivity or better backhaul to trains would be valuable
- Seeking competition among the mobile players – other providers may be more important and mobile operators may be encouraged into network sharing in some cases.

Policies to be started. The various policies that governments need to embark on include:

- Investment in Wi-Fi networks in public buildings including museums, schools, hospitals, universities and offices in city centres. This includes not only the deployment of the access points but also the introduction or adoption of a universal sign-in system. This should be a relatively inexpensive investment, with access points purchased in bulk and installed by the buildings team
- Investment in rural cellular coverage through awards of funds against specific coverage objectives
- Obligations on railway franchise holders and possibly also bus franchise holders to deploy Wi-Fi with accompanying obligations on track owners to work to enable effective backhaul provision
- Potentially, greater regulation for Wi-Fi in areas such as spectrum, security and competition regulation for any Wi-Fi providers that might have significant market power
- Potentially, regulation to assist in routing incoming calls to Wi-Fi-connected phones. This could be a modified form of number portability or similar.

Each of these are clear and can be embarked on immediately. They typically do not require new legislation and the funding requirements are relatively modest.

In the second part of this article I will look more closely at regulatory policies.

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REFERENCES **1** Australian Government. Mobile Black Spot Program. bit.ly/2cDopc0 **2** For example, see Netflix's recommended data rates: nflx.it/1v1HhCM. It suggests 5 Mbps for HD and 25 Mbps for 4k UHD. Others expect coding efficiencies to improve and the UHD rate to fall – see: 4k video streaming issues. Videomaker, May, 2014. bit.ly/2pIKN0G **3** For a detailed discussion see: Getty J (2013). Traditional AQM is not enough! bit.ly/2oMEin3. **4** European Commission. WiFi4EU: Free Wi-Fi for Europeans. bit.ly/2eJDsEy