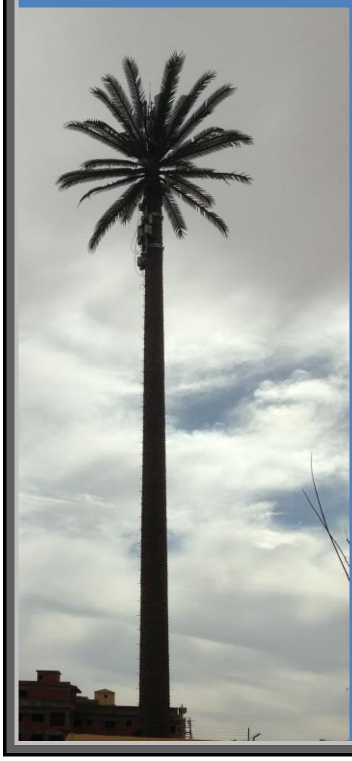
Telzed Limited

A guide to understanding broadband usage

Roger Steele

A discussion paper



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A guide to understanding broadband usage

Including: why mobile usually struggles to match fixed broadband

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Author: R Steele

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Telzed Limited UK. Consulting, Advisory and Interim Management Services
All correspondence: Lilac Cottage, Westerfield Road, Westerfield, Ipswich, IP6 9AJ, UK. Tel: +44 (0) 777 178 7607
Registered Office: Orchard House Park Lane, Reigate, RH3 8JX, UK

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1 Introduction

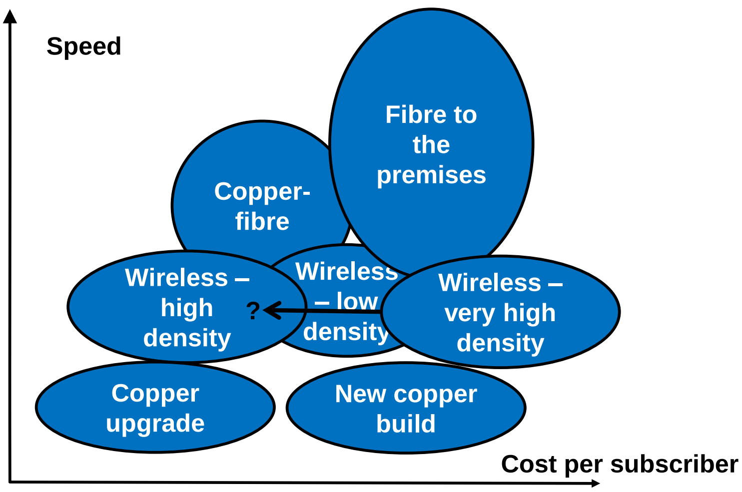
This report provides policy makers, managers, strategists, economic-modellers and decision makers with insights on broadband usage in fixed and mobile networks. The insights assist with understanding of both the underlying costs and the economic factors, that drive broadband service costs.

In this paper, some values of broadband usage are derived from published data, but others are illustrative. These are analysed to show the important information that must be understood in order to appreciate how network costs and capacities must evolve. This is done at a high level and detailed technical/engineering analysis is not provided. Almost anyone making decisions should have the ability to do similar calculations or at least fully appreciate the logic (if in doubt contact Telzed or your own engineering staff).

The document is intended to provoke some debate on the current discussions on the potential for 5G mobile to replace or supplement fixed broadband networks, in particular those networks that use fibre to the premises, or fibre terminating close the premises. An effective convergence is noted of “fixed” fibre and 3G, 4G or 5G “mobile.”

The essential economics of this paper are not new. Some of the key elements are shown below.

Figure 1 Relative costs and speeds of different broadband technologies



Source: based on Telzed paper for ITU 2013[1] and Telzed DSR submission to Ofcom. The diagram *is illustrative only*, to show general differences

This shows:

- New copper provides no significant speed improvement, so clearly this is pointless

[1] “Strategies for the deployment of NGN and NGA in a broadband environment – regulatory and economic aspects” on ITU web site or Telzed

- Fibre costs more than old copper (although even this is debatable[2]) and deployment is similar to new copper – both would need cables pulled through ducts and terminated at the customer. But fibre speeds are much higher
- Copper-fibre hybrids could cost less than an all fibre deployment, as it makes use of the existing copper for the final link into the customer premises. The speeds will not match a pure fibre solution and the cost savings are debatable
- Wireless (mobile) can match or even exceed copper network speeds (note that the "blobs" in the diagram should both overlap and have somewhat blurred boundaries)
- The cost of mobile solutions gets less as more subscribers use it – more handsets and customers is a good thing, of course. More base stations and a bigger network give economies of scale
- If the numbers of mobile customers and usage becomes very high then many more base stations are needed[3] and so the number of customers in each is small – the cost per customer then rises. This is the reason that we do not have 3G or 4G base stations at the end of every street. Costs might not quite rise to more than low density, as shown, but this depends on the technology, cost structures and the density of customers.

This basic logic does not change, even with 5G. Of course the "blob" size and positions can be altered as costs and technologies evolve. Fibre costs to deploy seem to fall over time. Copper/fibre technologies improve over time. Wireless/mobile gets faster. This view still provides a good high level starting point for understanding the cost structures.

These structures are examined further in this report, making use of actual usage data from the UK. The messages will still apply to most other countries.

The analysis and insights in this paper should already be basic knowledge to anyone leading strategy and policy. The same deductions were clear when mobile usage was less than one tenth of today's values. The analysis (even though it is very simple) will help with understanding of the costs and economics of broadband, especially for those new to the subject.

[2] The debate centres around: operational costs of fibre might be lower; copper is cheap as capital costs are mostly written off; fibre needs new investment; long run versus short run costs etc. In addition, the performance differences are clear, so in some way the comparisons are "apples to oranges"

[3] This is because the total amount of traffic in a base station is limited by the spectrum and the mobile technology. With a finite capacity, only a limited number of customers can use it at the same time, or else they get calls blocked and broadband that slows down

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2 What is broadband usage?

Most broadband users are familiar with two numbers:

- **The broadband speed** (usually around 2-50Mbit/s, but sometimes 100Mbit/s or even 1000Mbit/s [=1Gbit/s] if over fibre to the premises). There are web sites and apps to test your download speed. This is a headline figure in most broadband studies (see almost any international broadband comparison). The best mobile speeds are usually less than the best fixed broadband
- **A monthly download limit.** This might not exist in a fixed line service ("unlimited broadband"), but it might be "in the contract small print" where the supplier *could* impose a limit for excessive use, but may choose not to. Limits of 1, 2, 10, 50 or 100Gbyte in a month might be used. This is the total download that you can get before either you have to pay more or downloads are "throttled" to a slow rate. Some mobile contracts may also have unlimited downloads, but again there may be contract clauses, and in addition technical limitations tend to stop huge usage per month (mobile download speeds are often slow, so users might not attempt heavy usage). These "unlimited" contracts may be expensive.

A user might download a 2Gbyte film over a 10Mbit/s broadband link. This takes *at least* 27 minutes – longer due to overheads in the communications to ensure the packets all arrive safely. The viewing might be over an hour, so the film could start before it is all downloaded.

The advantage of 20 or 100Mbit/s for downloading big files is clear, but slower networks can be "just about OK" due the streaming and buffering. Stoppages are very annoying – so a fast link is preferred. The issue is: how fast do we really need? An increasing number of applications, more video, and more home workers all require rapid downloads of large files. With over 20Mbit/s averages today[4], 100Mbit/s+ will soon be the expected norm.

When building and dimensioning a network, the number of Gbytes that go through it are sometimes not too important – if you download 100Gbyte overnight, few network operators will care. But, all networks have a finite capacity. The traffic from many customers has to go through one system (say a router, switch, base station or a transmission link). These have finite capacities. More systems or bigger ones cost more[5]. This is a "point of concentration" where traffic to/from many subscribers joins together and all must pass through the same point. There may be several such points, but we consider here that only one will dominate in each of fixed and mobile networks.

If every customer had 10Mbit/s broadband speed and these all had to pass through a base station with 100Mbit/s limit, or a transmission link of 100Mbit/s capacity, then how many customers are possible? Ten would be one choice as everyone should then still have a perfect service. This is neither good economics nor good engineering. Users may download a film, but then they watch it and do other things. Users download a web shopping site, then

[4] UK fixed broadband – e.g. Ofcom 2016 Connected Nations report

[5] There never was and still is, "no free lunch" in networks. But the price falls both with time and with the size of the network, so you can "eat more" next year for the same amount. Big networks tend to have lower unit costs

spend ten minutes looking at the products. **The broadband is almost never fully used continuously**[6]. The *average usage should be much less than* 10Mbit/s. This average usage is what matters to the network and to the cost-engineering-planners. If the average usage was 1Mbit/s then there could be 100 customers. Many more could exist, but there is a greater statistical risk that more than 10 do simultaneous downloads and so experience the (all too familiar) slowdown of the download. 11 customers each downloading at 10Mbit/s exceeds the concentration point limit – *something* has to happen. So some will get a reduced performance (slower service or delayed packets).

The average usage that matters most is that in the busy hour or the busiest period[7] of the day when most subscribers use the broadband. Usage overnight has limited impact on the network capacity. Planners and engineers only need to spend more when there is more traffic in the busy period.

This example is a bit simplistic. In reality the router or base station with 100Mbit/s limit will really need to upgraded before the combined usage continuously reaches this figure unless the operator deliberately delays investments to save money and maximise profits (and of course this *is* done, with a resulting slow network at certain times of day). Traffic demands are random so there will be short peaks, and so the peak traffic will cause packets to be lost and downloads to be stopped. Perhaps a "65%" limit may be set by the engineers[8] – once the traffic averages more than this percentage of the complete limit (100Mbit/s), then more systems/bigger ones or a new base station is required. The decision is based on statistics – what percentage of traffic or customers get delayed/slowed downloads in the busy hour (shown by lower average download speeds than the 10Mbit/s physical speed that they paid for and expected). If an upgrade has a long planning or implementation time then lower thresholds might be considered. The network engineers will see the combined total averaging about 65Mbit/s, but peaks will hit the 100Mbit/s limit. Some base stations might be heavily overloaded – this high usage (perhaps averaging 90%) increases the profits of the business, but it causes a *frequent degradation* for customers as it is more likely that the random peaks exceed the limit. The decision to upgrade the network is also a strategic/economic/marketing one. More traffic overloads mean reduced performance and eventually increased customer churn – and lower profits.

In some countries, and in others just a few years ago, broadband usage can be remarkably low – a 2Mbit/s customer might only use 100kbit/s (0.1Mbit/s) in the busy hour *on average*. A 10Mbit/s user might use only 300kbit/s. The usage is not five times – the faster-service user probably downloads similar things from the Internet but also uses it a little more as it does not freeze so often. Low usage can happen where video watching over the Internet has not yet taken off. Usage is very country and culture specific. Also the average income has a huge

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[6] There are *some* users who download masses of data in background mode, or have many teenagers in the same house who may all combine to push the usage close the maximum for long periods. Average customers do not use the broadband continuously but high end users (with large volumes and need high speed) should not be held back by a slow "average" service – they probably generate the most GDP gains from hi-tech home working and business. Also no daily commute to work is required – an example of an easy economic gain

[7] The period could be 30 minutes or measured over several hours. This peak may be typically early evening or late afternoon when schools finish

[8] Illustrative, but similar values have been seen. Some cells are heavily overloaded and average usage can be near 100% - in this case there are very frequent slowdowns in the busy period. A 65% average still means that sometimes the traffic limit is reached, but less often. Basic statistics of random traffic events are behind this

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impact – low income subscribers will want to keep to a low network limit (#Gbytes per month), so less usage is made, resulting in lower average Mbit/s in the busy period. This allows more customers to all share the same concentration point in the network. This is why coverage using a mobile network is very economic compared to fixed networks – a single base station can cover 1000s of customers *so long as they do not all use the broadband a lot at the busy period*. Clearly digging cables to 1000s of customers is expensive – so, for low GDP or low income countries with no significant fixed network pre-existing, mobile has a "win" over fixed[9].

With this logic and average usage of say 0.5Mbit/s, we could have ~130 customers in a base station cell with 100Mbit/s limit (1300 if we have 1Gbit/s capacity), and the base station is not overloaded. In reality all customers are not the same, and only a few are very heavy users, so real analysis has to consider the "profile of users," both heavy and light, and how this alters over time. Also, many base stations are overloaded to allow 500 customers in the cell, but they will get a slow service, more frequently at some times of day.

The pressure on capacity growth at the concentration point is not the same as pressure for increases in the broadband physical access speed. These access speeds are moving up to perhaps 50 or 100Mbit/s on average, the pressures on this speed-increase are less important, once speeds are perhaps beyond 30Mbit/s (see Ofcom report in footnote 4 and the downloads per month becoming almost constant with further speed increases). Therefore the speed increase with time *potentially could* level off in the near future, alternatively a suitably high speed could be delivered in a technology step change (such as a move to service over fibre or just conceivably with 5G). In reality the physical speed may still have to rise further.

Currently about 30Mbit/s is probably "good enough" for most users, but with fibre, 100Mbit/s physical speeds cost almost the same, *and* a future speed-upgrade cost could be avoided. High end users who need faster speeds are likely to be ones who develop businesses and grow the GDP – these users are held back by slow speeds and a focus only on the average person. **The downloads (and the critical average peak period Mbit/s) however will continue to rise**. Throttling back this consumer demand by slowing the *access line* speed, so that downloads are tediously slow, is dictating what consumers can do – it is using one part of a network to "protect" the lack of capacity in the other (core or base station). Telecoms should be an industry, consumer and lifestyle *enabler* and not a limitation. It should not be a regulator's decision to decide that some new services cannot be allowed due to the busy hour demands – free markets and competitive telecoms networks *should* be the primary decider. However as superfast broadband is the enabler for so much GDP growth and telecom markets are not truly competitive, governments rightly see broadband as an essential infrastructure and so national policies can even consider intervention and monies to develop broadband. Most developed countries therefore have broadband policies, plans and regulations to encourage good outcomes[10]. A national policy to help achieve 100Mbit/s superfast to very home however would be useless if the monthly downloads were restricted to 1GByte per month or actual downloads in the busy period had to average much less than 1Mbit/s. Please note the distinction of customers averaging less than 1Mbit/s usage with their

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[9] There are caveats of course. It assumes the radio can really enter all premises in the large radio cell, and the capacity of many base stations might actually be much less than 100Mbit/s – it depends on the spectrum and technology used

[10] Policy and plans are relatively easy, but the regulations to help make them happen of course are often much less successful

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100Mbit/s service (they not strong video or game users) - which is not a concern - from customers *forced* to slower speeds from traffic limits within the network, which is a concern as it may restrict what consumers can or want do.

A fixed line may have 30Mbit/s download service or a mobile service that delivers 10Mbit/s, but why do customers not all see their downloads reduced to less than 1Mbit/s, as implied by this analysis? The main answer is that most really get 30Mbit/s but only use it in short download bursts and so the average usage *is* only about 1Mbit/s in the busy period (and the network can cope with this). The network limit of many such customers will then probably not be exceeded. A second answer is that slowdowns need to be seen from tests in the busy period. Further, a test is usually a short burst test, and there is a good probability no packets need be delayed/slowed. Only the average throughput might be limited, so a test would need a large traffic download or many short tests to be realistic. It depends on local situation and the network usage statistics whether a restriction is seen and if it is experienced for a sustained period. The slow down might only be brief, for many. Complaints that "the internet slows at some times" or "I am not getting the advertised download speed" show that capacity problems are real.

Problems are often not seen in fixed networks, the core costs that restrict capacity are low (huge economies of scale) and so it is much easier to ensure capacity is adequate. So one customer streaming at a full 30Mbit/s for the entire busy period has little impact and so users are unlikely to see significant restrictions (the *average usage* by 1000 customers, who make normal usage, is hardly altered from the 1Mbit/s average by a few mega-users). A mobile data service running at 10Mbit/s for the entire busy period is far more likely to experience some traffic slowdowns – the concentration point (base station) is shared by fewer customers, and the network operators have strong commercial pressures to avoid a second base station[11] – therefore overloads (slow downloads) will be seen more often. The busy hour average use could be 90% or more of the absolute limit and therefore the service has to slow down more often, as traffic "spikes" exceed the limit.

[11] This could double the costs, but doubling the core capacity of routers and transmission only causes a relatively small cost increase

3 Real network data shows the fixed and mobile usage differences

3.1 Mobile and fixed broadband usage – current values and trends

This section looks at some actual data on fixed and mobile broadband to illustrate the how the usage in Gbyte per month and the busy period Mbit/s are related, and so builds on the basic principles given above.

As described above the key values are the broadband speed and the download total downloads per month. The two are related.

A broadband customer with 100Mbit/s physical speed does not usually download ten times that of a 10Mbit/s customer, who in turn does not download 5 times a 2Mbit/s customer. There is a non-linear relationship of download versus speed – a logarithmic type of relationship. This is shown in Ofcom reports[12], for example. Over time the total downloads rise and more customers are on faster speeds. The general logarithmic trend of data downloads versus speed, is likely to remain true.

The amount downloaded is changing rapidly over time. This change reflects the change to more TV and video over the Internet ("over the top" type services – OTT). This is happening globally with varying rates of change. High end users will use more sophisticated applications and cloud services – which require more capacity.

UK fixed line broadband downloads were 132 Gbyte per month per customer in 2015[13] - up 35% on 2014. For illustration below we use 150Gbyte per month in the analysis to represent a developed broadband economy.

The average bit rate in the busy hour generated by 150Gbyte depends on the *time of day distribution of traffic*. This varies by country and culture. The percentage of traffic in the busy hour period (that drives costs) is taken here to be 9%[14]. Therefore the average busy hour usage is 13.5Gbyte, per month. This causes about 1.2Mbit/s of traffic in the peak period per customer[15] on average.

This is a high average figure and many countries will currently have lower values. In any event the number will continue to rise rapidly everywhere, as broadband usage develops.

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[12] Ofcom Connected Nations report 2016. Figure 14 shows a100Mbit/s fixed broadband customer has almost the same monthly download as a 40 or 50Mbit/s customer (150Gbyte), a 10Mbit/s customer downloads about 100Gbye and a 2-4Mbit/s customer about 50Gbyte

[13] Connected nations report 2014 S4.3. This shows the total fixed download that relates to ~20million subscribers (in reasonable agreement with other fixed broadband subscriber data).

[14] This is based on a time of day profile such as in the Ofcom connected nations report 2016 Fig 27. This is for mobile and the value will vary by operator and country. In this analysis we only need reasonably realistic values

[15] This is simple to derive. It assumes only 25 effective days per month (most households have some days of low usage).

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Note also that superfast (aka ultrafast) users tend to average a bit more and the few customers on 2-4Mbit/s will average a bit less (the logarithmic type relationship referred to earlier).

The same calculations can be derived from mobile data (also in the Ofcom Connected Nations report). This shows:

- 106Petabyte per month total mobile consumption
- About 1.2Gbyte per month per customer (which corresponds to about 88million mobile devices – which, as expected, is close to the number of SIMs given in the Ofcom report). **This is less than one percent of an average fixed line user[16].**

From this is it is simple to derive the mobile usage per customer in the busy hour. However mobile consumers are not all equal. Most may now have a data-capable service, but might make almost no data-use of it. Those deliberately using only 4G or with data-only "dongles" connected to a lap top are likely to be "serious" broadband users. Mobile-only households similarly will be strong users. It is reasonable to adjust the mobile subscriber numbers to get an estimate of "real" mobile data users. This can be estimated in several ways. Here we use the simple 80:20 rule – 80% of traffic is caused by 20% of consumers[17].

This means a busy hour average usage of about: 10kbit/s of traffic in the busy hour if all subscribers are considered to be the same, or a more realistic 50kbit/s[18] using the 80:20 analysis. This is equivalent to about 6Gbyte per month of download for "serious mobile users" (which of course fits within many of the typical monthly data allowances in the UK).

The Ofcom Connected Nation report noted "*106PB was sent over all mobile networks in June 2016, a 44% increase on the year before. Even so, this represents just 4% of the volume of data sent over fixed broadband networks*." This 4% download is done by many more subscribers than there are on the fixed network – which emphasises the huge difference between fixed and mobile. The annual percentage increase (which is not much different to the fixed increase) should be noted by all strategists!

3.2 The analysis shows that mobile network usage is far behind fixed networks

The above analysis and the Ofcom report provides a profound insight: **a mobile data user typically uses less than one tenth of the network capacity (in Mbit/s or kbit/s) than a fixed user**. The mobile download per customer is around 1% of a fixed broadband customer – but a large number of mobile customers are not really users of data to any significant degree (hence the 80:20 rule). With this 80:20 thinking, a "serious" mobile data user's download is perhaps as high as 10% of the fixed usage.

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[16] Some of the reasons for low mobile usage are obvious and some were noted in the Telzed submission to the Ofcom DSR review. The prices for mobile data are high the monthly allowances are typically 1-10Gbyte before an additional fee

[17] This is a guide only, but it is a reasonable approach for many countries or to give the required strategic insights. A more full analysis of mobile consumers' contract types and behaviour will show more realistic values. The mobile operators themselves should be monitoring usage by consumer type

[18] This used similar assumptions as used in the fixed calculations.

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Some important messages follow:

- Mobile customers mostly make far less downloads and so create much less traffic (Mbit/s) in the busy period than fixed customers
- Low downloads per month are surely caused by prices that are too high for large usage and by the low downloads speeds – caused by limits in mobile technology and overloading of the network in the busy periods. Has anyone *not* experienced very slow response on mobile 3G or even 4G?
- Mobile network operators have not attempted to match the fixed line performance. Some of reasons were discussed in other Telzed work, and it simply follows from the basic economics of mobile (see Figure 1)
- The UK industry strategy has been to provide only a limited mobile broadband service. Only a few mobile customers use the mobile network like fixed broadband. Mobile networks are mostly used because the "user is mobile" at times, not because it replaces fixed. Even this peripatetic use was limited by the fact that mobile coverage was so poor (UK data showed low 3G coverage by each operator[19]) – subscribers could not plan to be truly *mobile* users when coverage is unreliable
- If the mobile usage rose by more than a factor of ten, then it could match current fixed broadband. But the fixed usage is rapidly increasing, so mobile networks would have a major problem catching a fast-increasing performance. Any ambition of mobile operators (if it ever existed) to *significantly*[20] substitute for fixed broadband has failed and, as the gap is so large, it is hard to conceive of a major mobile replacement of fixed broadband.

Examination of UK mobile prices show why this outcome is seen (similar outcomes will probably be seen in many other countries). Almost all mobile services have a data limit per month – and this is far below the average usage seen on fixed. Some of these limits may be high (and have a price not too different from fixed broadband). But even a 30Gbyte/month mobile data limit is still well below fixed line usage. Furthermore, some mobiles strongly discourage significant usage as there can be almost punitive additional fees for additional Gbytes above the monthly limit. So a user on a 10Gbyte per month limit will not use 9Gbyte, just to stay in the limit, but may use just 2Gbyte or so. This reflects a natural reaction to the "additional fee threat," and the difficulty of knowing all the time exactly how much has been used so far this month (and: how much should the user leave in reserve for later in the month?). The data-limit aversion will of course be stronger in low income countries (which ironically tend to be mostly mobile based).

If the mobiles reduced prices and/or vastly increased the monthly data limits, then usage could become like fixed line (why bother with a fixed line if you can get the same performance on the mobile device *and* take it to a coffee shop/mall/friend's house etc.). To do this, the mobiles would have to increase the network capacity by factors of 20, or even 100.

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[19] Some countries allow national roaming so better coverage is seen by users. This was not done in the UK so poor coverage by each network operator causes problems even if the headline coverage by all operators was high (something that Ofcom tended to highlight). "Not spots" are regularly seen by most customers on any one network
[20] Certainly there are some "mobile only" users, but these are a small percentage of the total and they are also highly likely to make *some* significant use of WiFi services including home/fixed broadband

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A few counter points may be raised:

- The total mobile data usage is a large total. But this is made by many mobile consumers, so the net usage per customer is still low. Collectively the "country is mobile" (more SIMS than people, and the total data on mobile networks is large), but individually subscribers do not use mobile as much as fixed
- There are countries where mobile data using 3G or 4G is so fast and priced so reasonably that fixed line broadband is almost not worth considering. The speeds might be "good enough," even if not up to superfast.

The second point is important: a mobile-centred broadband economy can (and does) exist. Some factors that assist with this may include:

- Almost no fixed network might exist – this is true in many less developed countries or emerging economies
- Mobile operators had a strategy to cut costs and optimise the network with the intention of taking on the fixed line business (the UK outcomes suggest that this was *not* the UK operators' approach)
- Small countries and city-states can be cheap to cover with mobile stations
- The operators might allow the network to overload more often in the busy hour. This maximises profits, but degrades the service
- The country has relatively few high income users. These find the prices reasonable but they do not cause major costs as they are relatively few in number. The lower income users keep usage below perhaps 1Gbyte per month to avoid significant fees.

Of course other reasons may apply. Arguably these may be unlikely to easily translate into countries like the UK to give the factor or 10-100 improvement in mobile capacity without increasing costs and prices significantly. Average monthly mobile spends in UK (and many other countries) are relatively static or even falling. So would customers pay even twice the amount, in order to pay for the over ten times increase in capacity that is required?

3.3 Mobile network capacity limits

To give some numerical insights to support the above points and analysis, this sub section examines mobile usage in more detail.

The total Gbyte per month downloaded is only a small concern to a network manager, *if* this download were in off peak periods. **The busy period is what really matters most and, as shown above, mobile usage is around 50kbit/s and around 1.2Mbit/s by a fixed customer.**

The first concentration point is the base station. The total traffic through it mainly depends on the spectrum available in each cell, technology (3G, 4G or 5G), and the signal strength. The net effect is to define a maximum Mbit/s per cell. This could be as high as 100Mbit/s for some networks (current UK data shows ~20Mbit/s is a more realistic upper speed provided to a *single* 4G handsets but the total cell capacity should be much higher, so several subscribers can be active at the same time). There are some claims of 1Gbit/s with 5G for the cell capacity. If we take the high/optimistic figures as a basis, then we can cover about 1300 mobile subscribers at current usage levels (50kbit/s per subscriber average usage & 100Mbit/s *total cell capacity*) but only about 54 subscribers if their usage is similar to a fixed line equivalent subscriber (1.2Mbit/s usage and 100Mbit/s cell capacity, and allowing some margin for the peaks and the random nature of traffic).

These values could be about ten times better if ever a radio cell could deliver 1Gbit/s of total capacity.

In reality most masts (base station) typically have three sectors – so one mast could cover about 4200 customers (3x1300). The 100Mbit/s capacity per sector or cell may be an optimistic average today – which reduces the number of possible customers. Countering this is the fact that many customers actually cannot use the mobile (not enough signal in premises) and the busy hour performance can be degraded (they do not make the *average* 50kbit/s because the 10 or 20Mbit/s potential physical speed gets reduced). Traffic will typically get blocked more often in a mobile network than in a fixed network. Almost everyone has experience of waiting long periods for a mobile device to respond – which *increases* the potential number of subscribers per base station.

The calculation of *about* 4200 subscribers per base station can be verified by the fact that there are ~ 50,000 base stations in the UK[21]. This means about 8,800 subscribers per base station or about 1,760 "real data subscribers" per station if we use the 80:20 rule.

These values are only rough calculations and give rule of thumb figures, but they are enough to show the economic and strategic messages. The calculations agree with published UK network information. This paper does not attempt to be a tool to design networks!

Some conclusions follow:

- Current high capacity mobile cells that might be able to deliver 100Mbit/s of total traffic would need to be in "almost every second street" to take 50% of the fixed line broadband market
- Should 5G ever deliver 1Gbit/s of capacity per base station (this could be from 20, 50 or 100Mbit/s download services – it does not matter much), then it could deal with perhaps 600 fixed-equivalent customers per site (approximately only). But this *only delivers today's fixed line* performance as defined by the busy hour demands in Mbit/s. This is rising very fast, so the required delivery will be at least 3Mbit/s per customer in the busy period in just a few years. It is easy to see this being far outstripped.

The conclusion is **that current mobile networks cannot be a substitute for existing fixed demands.** The cost per cell (base station) would have to fall enormously, and a huge increase in base station numbers is required. This is why mobiles do not try to compete fully - the economics of the business case do not work (in many countries).

This fact has been clear for long time. An earlier ***2012*** Telzed report[22] on pre-existing Ofcom data from 2011 and before stated: "*There seems to be no direct attempt by mobile service providers to "take on" the fixed broadband market using mobile devices... The mobile operators would have more traffic, (and more capacity-costs)*". This reflects the facts that the

[21] http://www.mobilemastinfo.com/faqs/ and Connected Nation report
[22] "UK Ofcom market report 2012 Beyond the figures – implications for the telecommunications industry" on Telzed web site. E.g.: S3.2

economics of mobile networks carrying high volumes, requires many cells and this is unlikely to be profitable without a radical approach (which did not happened in the UK).

Future 5G might well deliver much more capacity (total Mbit/s per base station and faster downloads) but it will struggle to be a substitute for the average fixed line broadband user. For it to substitute, there must enough spectrum allocated and the technology must meet the headline speed claims. Also the cost per cell site has to be much lower than today because many more cells are needed. In addition, the total network cost must be similar to that of today, if it is to take major market shares from fixed broadband (roughly equal or lower prices are required for substitution). This is a very high hurdle to pass. **One has to be an optimist to expect 5G to be a *major* substitute for fixed broadband.** Of course it *will* be a partial substitute – perhaps more so than 3G or 4G.

3.4 Mobile cannot be a full substitute, but can still both compete with, and complement fixed broadband

The basic data from the UK plus the fundamental limits to: spectrum availability; mobile technology; and costs of base stations, together mean that most households cannot be only serviced by mobile networks. This is the case today – most mobile devices make use of fixed/WiFi services for a lot (or most) of the usage. Users can still use mobile devices *and mobile networks* for downloading and watching films. But the costs of doing this regularly over the mobile network may be prohibitive. The mobile networks mostly cannot cope with a *very high percentage of the population* making similar heavy fixed-broadband usage (150Gbyte per month and each *averaging* over 1Mbit/s in the busy period).

Mobile networks allow mobility[23] - and so this is why almost everyone needs a mobile device. Only if the coverage was better and the prices were low enough would users make more use of the mobile networks. Mobile network economics and technologies stopped this from happening. Also mobiles operators never properly addressed the coverage issue in the UK until recently - so there was little point of a plan while travelling to use the mobile network for anything urgent, as a signal could not be predicted with certainty. This reflects a failing in the past by both Ofcom and the operators. A society that is “predominantly mobile centred,” never developed.

So mobility means most consumers use/need mobile devices but these are also used on fixed/home broadband. A convergence is clear as the same devices are now used. Mobile is a fill-in service when on the move and out of the office or home. It complements the fixed service (and vice versa).

If 5G develops so that very small cells were economic and 5G really could deliver perhaps 50-100Mbit/s physical speed and **(much more importantly) deliver sustained average downloads of several Mbyte/s per subscriber,** then it could take significant parts of the fixed market share[24]. This requires 100s of Mbit/s or even >1Gbit/s of total capacity per base station and/or very small cells. A number of other things would need to occur:

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[23] It is also possible for some roaming to other private or public fixed-network WiFi spots to give a type of fixed service mobility. This is not a full substitute for a normal mobile network service

[24] Of course 5G will probably (?) be able to do this speed. But can the network have enough base stations to enable a lot of subscribers to do it at the same time?

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- Fixed line prices would need to remain similar (or higher) than today. If mobiles did take large substitutional market shares, would fixed operators not react?
- New base stations must be very cheap because they only service perhaps 100 households or possibly even fewer[25]
- The new ultrafast mobile broadband must have roughly similar prices to the existing mobile and fixed services. *Lower* prices would of course help, but this is surely unlikely
- The backhaul link from the base station to the core network also has to be cheap. This would typically be over fibre[26]. The cost might initially seem similar to fibre the premises, but with a "bit less cost" as it does not terminate in a house. But the reliability and performance need to be enhanced over domestic services. So the net cost of backhaul could remain significant, especially with many more sites to connect
- Cheap backhaul costs are probably based on cheap fibre (this discussion ignores the microwave alternative) - and this is conceivable with the duct being shared by copper or other fibres to fixed line premises (to give economies of scale). If the mobile service *substituted* for the fixed services then the access ducts and fibre to the base station must cost more[27]. So mobile success, by substituting for fixed, in part self limits by its own backhaul cost rising as more consumers (needing more base stations) use mobile, and less use fixed services.

There are other barriers to overcome:

- Consumer reluctance to give up the PSTN line. There are many PSTN-only households, in the UK and elsewhere. One reason is that it works! Almost everyone has some problem, even today, with mobile call quality
    - Additionally, if you already have a PSTN line, the marginal cost of broadband is not so large. A broadband-only service often does not cost much less than one with a PSTN line – again users are encouraged to maintain the PSTN line. The bundled price packages of broadband and PSTN versus broadband-only make this clear. The underlying costs of a copper or fibre line are the almost the same if one, two or even more services share it
    - The net effect is that most users take a fixed line service, stopping full substitution
- The management and operational costs of so many base stations. This will be significant with many more sites and backhaul links. Do many small base stations cost massively less, per station, than large ones? Economies of scale is an obvious factor (a few big cells are generally cheaper to manage than many smaller ones)

[25] A 1Gbit/s base station capacity could deal with over 800 subscribers equivalent, using the above data (1.2Mbit/s average usage and pushing the limit into overload, prudent engineering would only average maybe 65-80% of the limit), but with usage rising ~40% per year then in just 7 years we have 10Mbit/s usage

[26] Microwave is an alternative and has a major role in many mobile networks. This paper considers only the "bigger picture" and not the microwave versus fibre debate

[27] If only mobile cells' backhaul links are able to pay for the fixed duct network, then per-fibre costs must rise

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- Planning permission for so many new mobile sites. This is a major "headache"
- The performance must be good almost anywhere inside a premise – just as experienced with home WiFi. Again this requires more small base stations to get closer to the premises[28].

The net effect is that it is very unlikely that fixed broadband can be significantly substituted by mobile in many countries. Of course the same fibre deployment used for 5G (or maybe 4G) sites could be used for fixed broadband (or vice versa). This means that the same deployment of cables gives a significant synergy – *if* the fixed line operators move to fibre to the premises (or close to the premises with a short copper link) and also have cheap base station backhaul as part of the strategy.

It is open to speculation whether:

- The mobiles will really deploy the huge numbers of small cell sites to seriously impact the fixed line broadband usage
- Fibre to the premises, cabinet or near-to-premises is deployed to also provide cheap backhaul to the many small mobile sites: a converged strategy. In some countries the mobiles are "the enemy" of the fixed players
- The demands for capacity (busy hour Mbit/s) do not run away in the next few years. Currently the growth rate is large. Perhaps the growth is currently larger (percent per year) than normal, but a large growth in data has been happening for 30 years. It would be foolish to build policy, plans and networks based on an assumption that traffic will level off in a couple of years[29]. If the downloads and capacity-needs escalate even faster than the already high rates of increase, then the pure mobile business case is even harder.

It is reasonable to conclude that mobile has a huge role to play and is vital for many needs, especially when we travel or work in many locations. But the fixed line broadband is likely to remain the primary medium for most households and users. This does not mean that 4G or 5G cannot be the only service for some consumers. It has the speed, it has mobility, and *is used* as the only (or nearly only) broadband service by many consumers. Basic technical and economic factors mean that it cannot be the primary service for the majority of households, in many countries. The cost will be too high for the huge number of cells required. Almost everyone will use the 3G/4G and 5G services, but as a complementary *addition* to fixed broadband.

A key point to re-emphasise is that **the download physical speed (Mbit/s) of broadband is not the only issue**. Once a user has more than ~20 or 30Mbit/s[30], there are limited gains. This is just about good enough for most households today. **The key *cost driver* for core networks and base stations numbers is the *average* usage in Mbit/s in the busy hour.**

[28] There are ways around this, such as having one mobile termination unit and WiFi in the premises. Indoor mobile service is also another reason why mobile struggles to replace fixed – the fixed PSTN (cordless phone) and WiFi-broadband usually work throughout most of a household. Poor indoor mobile reception is still common in many areas
[29] An old engineering adage is: "data always expands to exceed the capacity available."
[30] Ofcom Connected Nation report shows limited increase in downloads per month for services faster than 20Mbit/s. Average broadband speeds are already in this region. In a few years this speed will be considered inadequate (some already need/want 100Mbit/s)

This is *related* to the monthly downloads, which is influenced by the speed as that impacts the consumer behaviour.

The fixed networks' costs are not overly driven by the speed in the access fibre, once the step change to fibre is made. Faster optical links are not hugely different[31] to slow ones. But the core network costs, where traffic has to all pass though trunk transmission and service routers or switches, *are driven* by the usage. **The usage that matters is the busy hour Mbit/s, and not the download physical speed.** This physical speed per service *relates* to the download per month and time of day usage profile. More Mbit/s in the busy hour requires a bigger network. This is why even fixed line broadband services may have some limits to the downloads, measured in Gbyte per month. This is effectively limiting the busy hour average Mbit/s. The upside is that a core network has huge economies of scale – 100% increases in demand ***do not*** "double the costs." Fixed line broadband might have little traffic concentration in the access network (this is technology dependent[32] of course) but traffic concentration exists after the data reaches the exchange sites - i.e. in the core network. This contrasts with mobile networks: if the capacity of a base station is exceeded, then another is required. This is why mobile networks have such strong controls on the downloads per month in the price plans. This will not change with 4G or 5G, just the key numbers will be altered.

Please note that 5G is not "simply" about delivering broadband (but that surely it is a major component). Other services will matter. This is beyond the scope of this paper. New services might increase the revenue per subscriber per month and help fund the enhanced network capacities. Some lessons on this 5G prediction should be familiar from the early days of 3G (please contact Telzed to discuss this further, if required).

3.5 International capacity costs impact the broadband significantly in some countries

Both fixed and mobile broadband services make use of core networks. In some small countries these are very small – and so the busy hour per-Mbit/s costs can be low and the effect of traffic concentration in the core can be small. **This core network provides the "traffic concentration point" in most fixed networks, but the base station is the limiting point in most mobile networks.** Both networks however also need to bring in and send huge traffic volumes overseas. Again this forms a traffic concentration point. The cost of international capacity (fibre cables, or sometimes satellite links) varies hugely by country. The cost driver for this is the busy-hour average usage (Mbit/s per subscriber), numbers of subscribers and the **percentage of traffic that is national versus international**. The percentage of broadband traffic that passes internationally varies hugely. In addition, some

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[31] Contact Telzed for further discussions on this and the related FTTC, P2P fibre, and PON variations

[32] Some fixed access technologies have "contention" where subscribers' traffic concentrates and each customer shares a finite capacity before the central exchange site. Similar simple maths applies here, as used for the core network concentration described in this paper. For simplicity this access contention is not covered in this paper. It can cause slow broadband problems, especially if you are located next to "pesky neighbours" who are big online video users or hi-tech home businesses

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countries' cables are priced far higher than others[33]. The international capacity cost therefore can be a significant portion of the total broadband cost for each consumer.

Some other factors to consider include:

- International cables have significant costs and lead times. So a new cable tends to each give a large step change in capacity and total cost. But the per unit costs ($ per Mbit/s) of more/larger cables falls as more cables are used
- Cable and capacity costs fall with time
- Retaining more traffic nationally reduces costs.

Much of this has been discussed in other Telzed work[34]. It is still vital that planners and strategist are familiar with the trends and cost drivers, and they should note that the national situations may each be very different. Traffic restrictions due to international capacity must be addressed in many countries, alongside the national broadband plans.

[33] This often is the case for lower income countries, land-locked ones, islands, and in emerging markets. So the unit cost per Mbyte/s is higher than in developed countries such as in the EU. Costs lower with demand and economies of scale but demand is reduced by the higher costs and resulting broadband prices

[34] See ITU report in footnote 1

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4 Conclusions

This paper provides an overview of the key factors that matter to subscribers, network managers, strategists, regulators and policy makers working on broadband. Example calculations are shown that illustrate how costs vary with demand in fixed and mobile networks. These calculations are not intended to give an accurate network designs or costs, but they simply show the key factors that **should be basic knowledge to everyone working in this field**.

The calculations are based on actual values from the UK. Other countries' values can be used and will mostly give similar messages[35]. These messages include:

- In many, or most cases, mobile networks cannot provide the capacity and performance of fixed line networks so that they can <u>fully substitute</u> for fixed line broadband
- Mobile usage is a factor of 10 or even 100 times less than fixed line usage per subscriber in the UK (values can be different in mobile-centred countries)
- If mobiles were to deliver the current fixed-line traffic demands, then a major new investment in many more smaller base-station cells is required
- The economics of so many cells is open to question. The total mobile revenues are unlikely to rise very much[36]; so where is the money to expand to come from?
- A service can offer 50Mbit/s download speed (fixed or mobile), but this is possibly close to useless if this feeds into a concentration point with only a few 100Mbit/s total capacity and it is shared by 1000s of customers. Policy makers *must* consider the average throughput (average busy period Mbit/s – which is related to the monthly downloads)
- Mobile download physical speed is a key headline figure. It is important and is used to compare many countries. It is not the only factor to understand
- Telcos (fixed or mobile) can overload the network to make more profits – but they can still advertise perhaps a 50Mbit/s physical speed. This physical download speed is not a guarantee of the average data download-speed at all times of day
- Fixed line traffic demands are increasing very rapidly, so any mobile operator strategy will fail, if it simply tries to match today's traffic, unless it expects to remain a "second choice" and to be "only" a complementary service to the fixed line services. This is <u>not a bad outcome</u> – arguably it is both good and sensible. It is what was done in the UK

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[35] There are of course exceptions - especially in developing countries or where there is almost no fixed line network extant. There are also some mobile centred countries that developed cheap mobile to compete with fixed broadband. Mobile use can be very high in some places and for some customers

[36] See almost any Ofcom market report (and probably in many other countries' market reports) – mobile revenue growth is limited or even negative and prices are not rising significantly. Some reports *do* show high/rising mobile data revenue growth, but this might also show lower voice and SMS revenues

- The synergies and convergence of mobile and fixed are clear. Common backhaul and fibre-access plans, shared core and international networks are obvious areas

- If vastly more base stations are required, then the mobile network converges to look more like today's fixed broadband with fibre to the home-WiFi - but the wireless part is simply moving "down the street" to a small base station. A converged technical strategy could be used, with "fixed" WiFi broadband supporting mobile service

- Most people will want and need mobility but will do (and probably *have* to do) the major downloads at "fixed[37]" network locations

- There should be limited "fixed-versus-mobile wars or arguments," as mobile is unlikely to deliver the capacity of fixed networks, unless huge changes happen with 5G. Will this happen? The basic economics behind the mobile-replacing fixed logic, are shown in this paper. Certainly mobile can *and will* replace fixed for many, but it not for everyone. A key point is that they should fit together and are complementary services - there are technical synergies. Mobile and fixed have convergence

- Mobile and fixed networks are both equally needed: plans should combine, link and continue the convergence of the networks. "A fixed network is a mobile network and a mobile network is really fixed[38]"

- This paper does not discuss uploads speed. This matters for many applications and its restrictions can be a "backdoor method" of effectively slowing overall usage and so reducing the demands for network investment – but at the penalty of harming the types of business that can be done over broadband

- The insights provided here are not new and should be part of the basic understanding of every leader and decision maker. The same conclusions were clear with 3G and when broadband capacities were mostly less than 2Mbit/s.

This paper's key messages are in alignment with the recent UK government 5G strategy[39] that states:

> **"To give a sense of scale, analysis for the NIC found that as many as 42,000 small cell sites could be needed to deliver the ultra-fast broadband speeds expected of future networks in an area the size of the City of London."**

The City is only one of the central areas within the greater London area. The population is about 7,000 but over 300,000 people commute and work there during the day. It is not representative of the entire UK, but shows how one cell site for less than 10 persons might be needed. 42,000 is about the same number of base stations currently in the *entire country*. Huge changes in both costs and mobile operators' strategies are needed for such a network to be deployed nationally. Is this really plausible? The past history of UK regulations, mobile

[37] Roaming onto other Fixed-line WiFi networks, say at another office, house or in a restaurant, is a type of mobility that converges with traditional mobile networks – even more so if 5G cells do become small and very widespread
[38] This should be obvious – see the ability to roam to other "fixed" WiFi networks and the way smaller mobile cells become more similar to fixed broadband with WiFi
[39] Next Generation Mobile Technologies: A 5G Strategy for the UK. March 2017

investment and lack of coverage (especially 3G) provide a good indication of the probable outcomes[40].

It is emphasised that this paper is not intended to downgrade the importance of 3/4/5G and mobile networks. These can be almost the only medium in some countries and for some subscribers. The paper shows that the realities of the technical and economic factors of both must be understood for policy/regulatory/business decisions. Both fixed and mobile are vital for most developed countries. Mobile may be the primary solution in some countries.

A vital take-away from this paper should be the awareness of capacity and demand growth. A number of soothsayers might claim that the broadband traffic growth will slow and predictions of traffic and OTT TV demands are known, so radical investments and unplanned capacity increases are not required. However, planners should also plan for the unexpected – demand will rise and new ways of working and new traffic sources will surely arise. One "known example" of traffic is that of video. Currently it already dominates many households' broadband, but the true impact is still to emerge. Currently only a tiny percentage of all video is actually OTT – most households still mainly watch broadcast TV. This will change and the only questions are: by how much and how quickly? This could cause a tsunami of traffic – and can mobile (4G or 5G) be the main carrier? The answers should be obvious.

Some planners and policy maker might simply believe that consumers should not be wasting time and network capacity watching certain video content, or using super high definition, nor should they be hi-tech users who do capacity-intensive games or work at home. If these planners were to succeed then fixed and mobile networks will not have the capacity and performance issues discussed here. Readers of this paper can make their own assessments of such persons.

[40] Contact Telzed for further discussions on this. The 3G history is highly relevant to 5G expectations. All strategists and decision makers ought be familiar with this, which might avoid some of the past poor outcomes seen in places such as the UK

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