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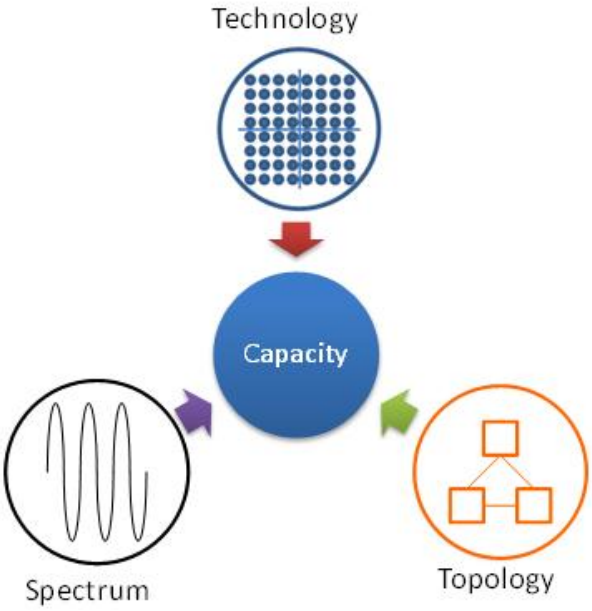
White Paper

Strategies for Mobile Network Capacity Expansion



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About Real Wireless

Real Wireless is a leading independent wireless consultancy, based in the U.K. and working internationally for enterprises, vendors, operators and regulators – indeed any organization which is serious about getting the best from wireless to the benefit of their business. We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process. We are experts in radio propagation, international spectrum regulation, wireless infrastructures, and much more besides. We have experience working at senior levels in vendors, operators, regulators and academia.

We have specific experience in LTE, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA – and many more.

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1 Mobile networks are experiencing unprecedented growth in demand

The mobile broadband data market has experienced dramatic growth in the last few years. Yet it is still at an early stage, with expectations of very significant growth still to come over the next five years and beyond. Demand accelerated significantly only in 2007, following the introduction of low-priced internet connectivity based on 3G modems (or 'dongles'). Smartphones have stimulated further demand, notably starting with the advent of the iPhone 3G in June 2008[1]. The number and range of devices incorporating mobile broadband is expanding, often leading to multiple devices per consumer, all "chatting" with the network even without user input. The expanding range of applications on each mobile device also drives demand, with predictions that the data consumed *per smartphone* will increase by 7x over the period 2010-2014[2] .

Figure 1: The expanding range of mobile broadband-connected devices

Mobile network operators have reported that these devices have produced astonishingly high data demand growth rates recently:

"The O2 network has seen an 18-fold increase in data carried over the network in the last year and traffic continues to double every three months."

Matthew Key, O2, November 2009

"Wireless data traffic on the AT&T network has grown more than 5,000 percent over the past three years...We see this usage trend continuing in the years to come."

John Donovan, AT&T CTO, 14 Feb 2010

Such impressive growth rates are relative to a low base, and are not a good predictor of longer-term trends. Over the next five years, however, analysts forecast global mobile data growth as high as

33x, corresponding to a cumulative annual rate of over 100%. However these forecasts vary over a wide range, making long-term capacity planning particularly challenging – see Figure 2.

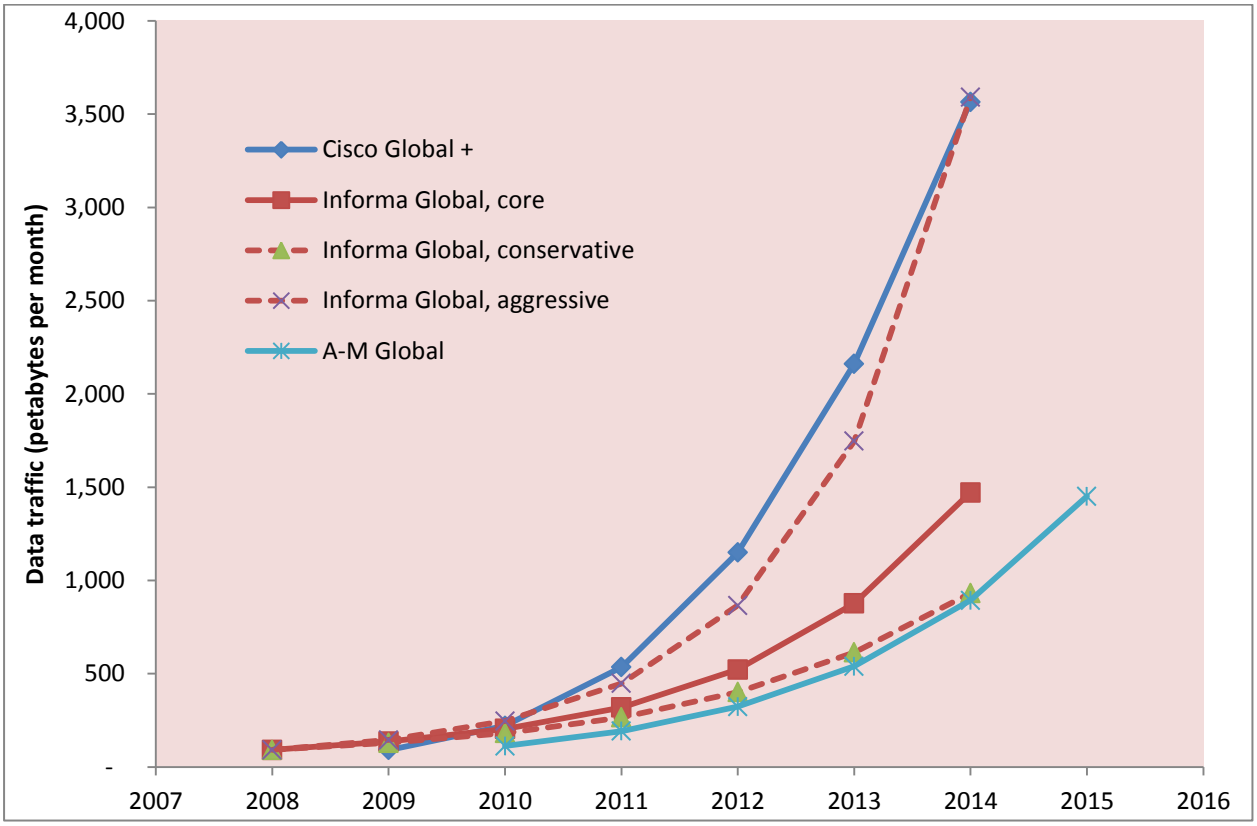


Figure 2: Global mobile data demand forecasts (Sources: Informa, Analysys-Mason, Cisco)

The demand is by no means uniform amongst users or by place, with a relatively small proportion of consumers responsible for a large proportion of the growth:

> *" three per cent of the ...smartphone users generate 40 per cent of wireless data traffic"*
>
> Ralph de la Vega, AT&T CEO , December 2009

Also, the majority of the demand occurs indoors in homes and offices, and is often in the range of 70-90% of the total demand, as shown in Figure 3.

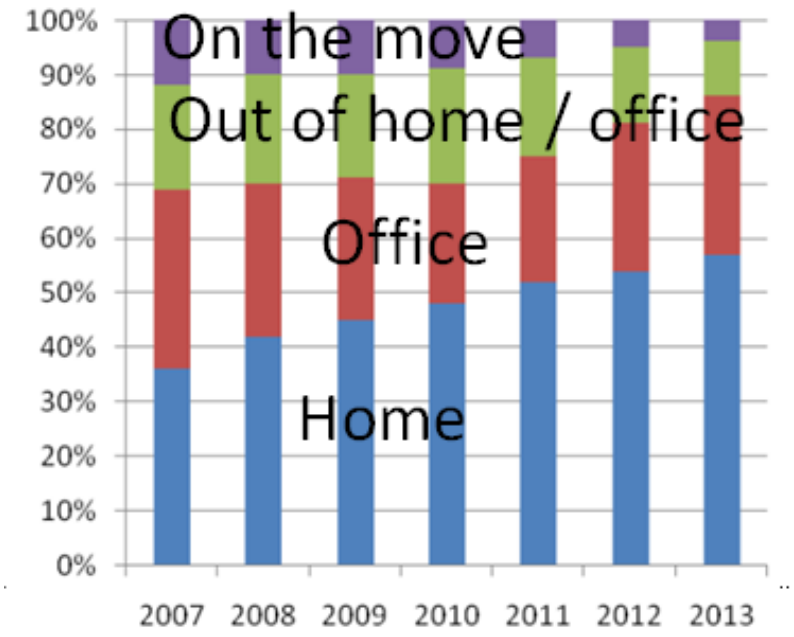


Figure 3: Increasing proportion of data consumed in the home and office (Source: Informa[3])

The good news arising from this increase in demand is that operator revenues from data are growing rapidly, replacing the decline in revenues from traditional voice and messaging sources and enabling continued strong business growth for mobile operators, despite the global recession. The challenge posed is that the data growth massively outpaces the revenue growth as shown in Figure 4, resulting in a steeply reducing opportunity for revenue per unit of data consumed.

Guide to mobile data volume units:

1 exabyte (EB) = 1,000 petabytes (PB)

1 petabyte = 1,000 terabytes (TB)

1 terabyte = 1,000 gigabytes (GB)

1 gigabyte = 1,000 megabytes (MB)

By the end of 1999, the sum of all human-produced information was about 12 exabytes. Cisco forecasts suggest this much data will pass over mobile networks in the course of 2012 alone.

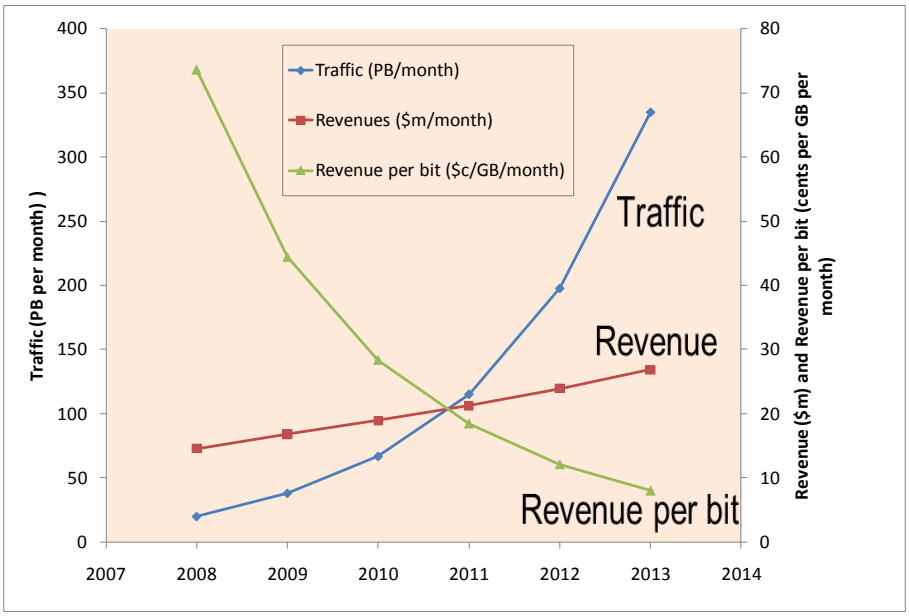


Figure 4: Mobile data traffic and revenue growth forecast (Source: Informa data [4], Real Wireless analysis.)

As a result of this challenge, commentators have begun to talk in apocalyptic terms of a *data tsumani*, *data explosion* or *exaflood* which threatens to overwhelm mobile networks, leading to steeply increasing prices, deteriorating service quality and stringent caps on data volumes. In this paper we will argue that there are plenty of tools available to mobile operators to manage this growth in a sustainable fashion, provided they form a clear strategy for dealing with it and start now to put this strategy into action.

2 Strategies for coping with mobile data growth do exist and can meet the demand while reducing costs

There is clearly a need to dramatically expand the capacity of mobile networks, while simultaneously meeting the rising customer expectations for consistent service availability, near-ubiquitous coverage and ever-increasing data speeds.

In simple terms, the capacity of a mobile network can be expressed as:

Capacity	= *Quantity of spectrum*	x *Spectral Efficiency*	x *Number of cells*
[bits per second]	*[hertz]*	*[bits per second per hertz]*	*[no units]*
	Spectrum	***Technology***	***Topology***

This expression reveals the three key elements which come together to yield the overall network capacity (Figure 5):

- The ***spectrum*** used to deliver the service
- The ***technology*** which delivers bits over the air via the spectrum via links between mobile stations and base stations
- The ***topology*** of the cells which comprise the network, i.e. the cell types and the way in which they are arranged

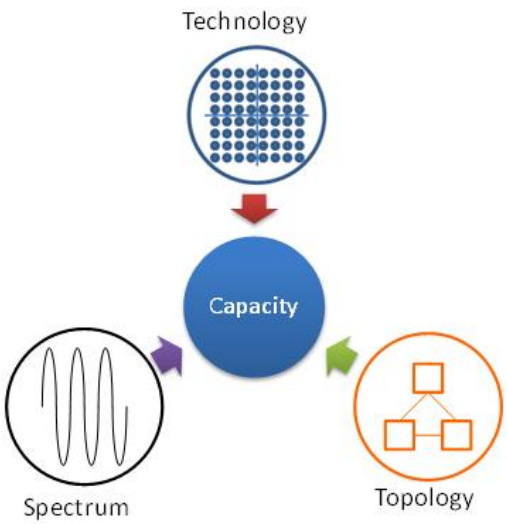


Figure 5: Mobile network capacity depends on a combination of the properties of the spectrum, technology and topology of the network

These three areas have very different characteristics and the right emphasis differs according to the individual operator's existing network, customer profile, local regulatory situation and many other factors. But given appropriate emphasis, we believe that there is plenty of scope for the mobile broadband market to continue to grow in a sustainable fashion.

We now examine each of these factors in turn.

3 Spectrum is an essential input and more is needed, but progress can be slow and expectations must be realistic

Access to appropriate radio spectrum is a clearly an essential asset for any wireless service. If the quantity of spectrum available to an operator is increased, in principle the available capacity increases directly without any need to add additional cell sites. In practice, however, spectrum is not a neutral resource. The particular choice of frequency band relates directly to the global economies of scale which determine whether user devices are available in sufficient quantities and price points to be attractive. Although regulators increasingly make spectrum available on a 'liberalised' or technology neutral basis, in practice market forces mean that there is a close mapping between frequency bands and technologies: in Europe, for example, use of the 800 MHz and 2.6 GHz bands essentially dictates the use of LTE (both bands) and/or WiMAX (2.6 GHz) with no support from existing 3G equipment, despite the inclusion of these bands in the 3G standards.

Further, the specific frequency band impacts directly on the economics of network roll-out. From a capacity viewpoint, provided interference is carefully managed, 1 Hz of spectrum delivers essentially the same capacity in any frequency band. However, interference management may be more challenging at lower frequencies, requiring larger antennas and more careful site optimisation. Overwhelmingly, the number of sites required to deliver coverage at lower frequencies (less than 1 GHz) is much lower than at higher frequencies (Figure 6). When combined with a sufficient total quantity of spectrum – which typically requires use of some higher frequency bands – operators can rollout initially at low cost and build up capacity progressively as demand evolves. However, this will only help with capacity if users can be equipped with devices which support the relevant frequency bands and technologies in time to meet the demand. So operators need the *right* spectrum at the *right* time.

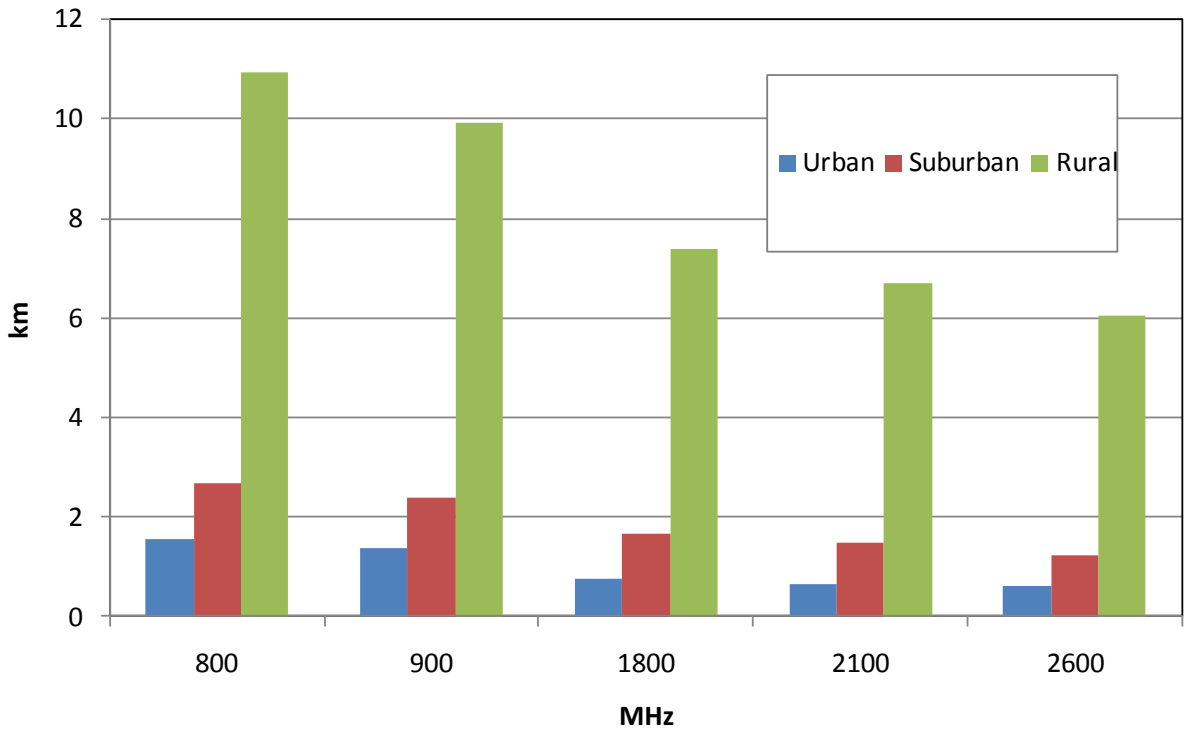


Figure 6: Comparative LTE macrocell coverage radius for equivalent service quality depending on frequency band and environment (Source: Real Wireless)

Finally, the big downside of using spectrum to ease capacity bottlenecks is that changes in spectrum are slow to implement, and are subject to regulatory and commercial forces beyond the operator's control, while also introducing competitive threats for the operators (and potentially the burden of expenditure on multiple similar networks for consumers). In many cases this introduces delays which mean the major spectrum changes may only serve significant proportions of the overall demand beyond 2015. For example, Figure 7 indicates expected changes in the mobile spectrum landscape in the UK over the next 2-3 years. With the liberalisation of 900 and 1800 MHz bands, and the introduction of the 800 and 2.6 GHz bands, the quantity of spectrum available should roughly double. However it will take 3-5 years to actually build networks to make extensive use of this spectrum, giving little benefit in serving traffic peaks meanwhile. And a doubling of spectrum on its own will only account for one year's demand growth at current rates.

Some governments have recognised the need to take action to introduce more spectrum. In June 2010 President Barack Obama committed the US federal government to auctioning off 500 MHz of federal and commercial spectrum – over ten years[5]. In a strikingly similar announcement, in October 2010 the UK chancellor of the exchequer announced plans to release at least 500 MHz of public sector spectrum for mobile communication uses[6]. While such evolution is welcome as a long-term opportunity for additional capacity, it

should be noted that the federal/public sector spectrum which is the main source of new spectrum is not harmonised in any of the relevant standards at this stage.

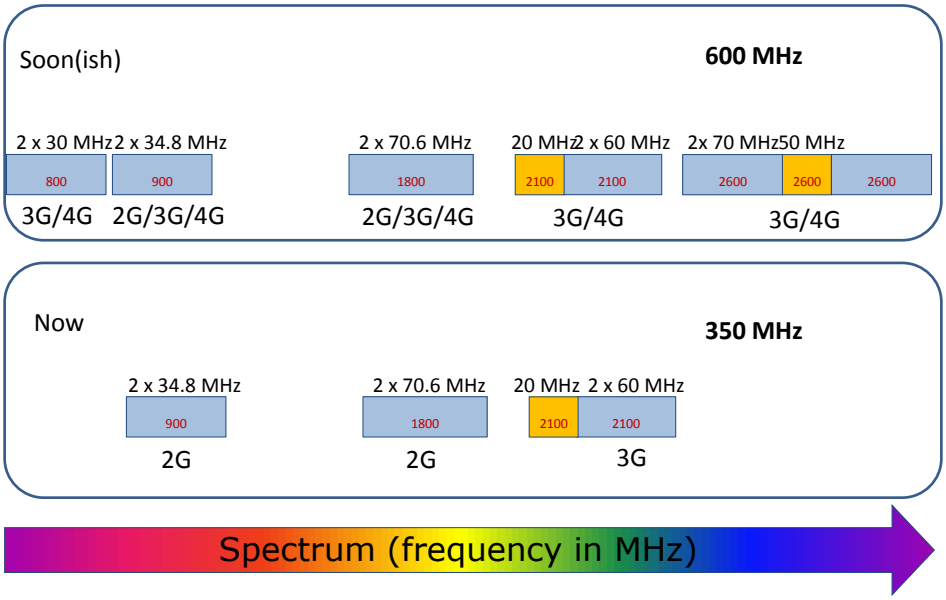


Figure 7: Growth in spectrum available for mobile broadband - UK example

4 Technology is evolving to make better use of spectrum and support better user experience, but the choices are complex and efficiency growth is hitting fundamental limits

The evolution of mobile standards between generations, from 2G and on to 3G and 3.5G has seen very substantial growth in the available spectrum efficiencies and has done much to allow huge capacity increases without the use of substantial new spectrum. It would be natural to expect another generation of technology to achieve a similar step forward. Both LTE and WiMAX technologies, via the use of MIMO antennas OFDMA access schemes and flexible modulation and coding schemes do indeed achieve spectrum efficiency gains over 3G and LTE-Advanced and WiMAX 2 are slated to achieve a further increment. However, the gains are slowing with time with each successive generation of technology (Figure 8). This is understandable as the technology is beginning to run into fundamental limits such as Shannon's limit, as shown in Figure 9. Although further gains can in principle be achieved with additional antennas for MIMO and advanced technologies such as coordinated multipoint transmission (CoMP), these gains have to be weighed carefully against the associated costs and the practicality of cost and space in user devices.

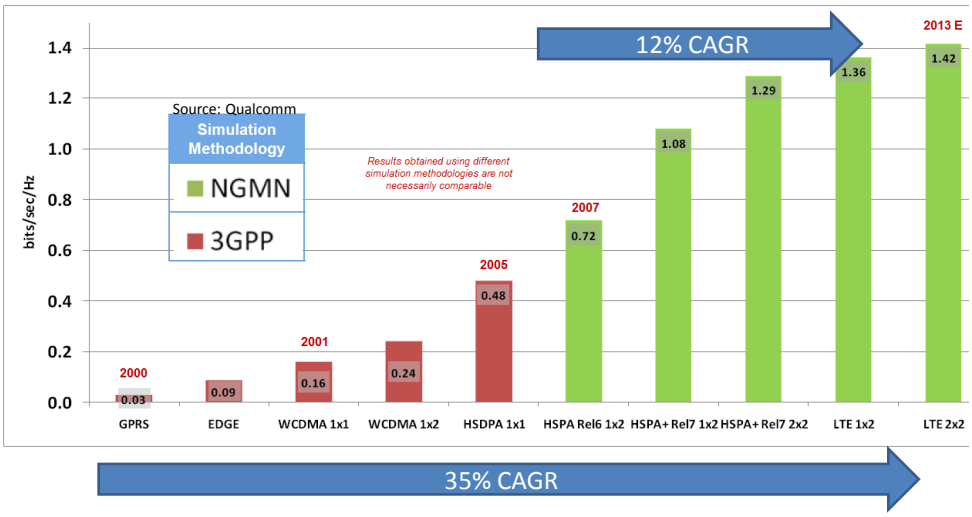


Figure 8: Growth of spectrum efficiency amongst 3GPP technologies **(Source: Qualcomm)**

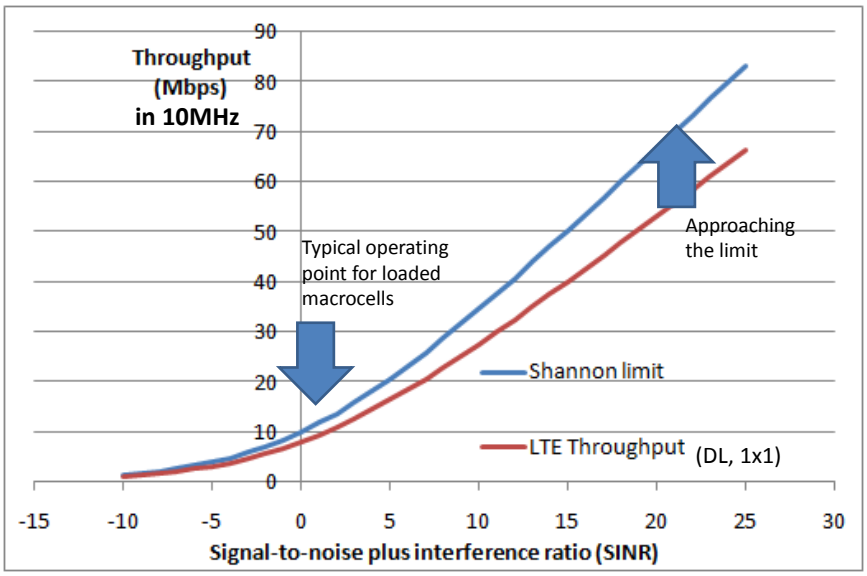


Figure 9: LTE approaches theoretical limits on performance (Source: Real Wireless)

The choice of technology roadmap is also very operator-specific, with a continuum of technology choices from HSPA, HSPA+ to LTE and LTE-Advanced, with WiMAX and CDMA variants creating significant complexity, which can only be resolved by a careful assessment of existing network assets and market conditions (Figure 10).

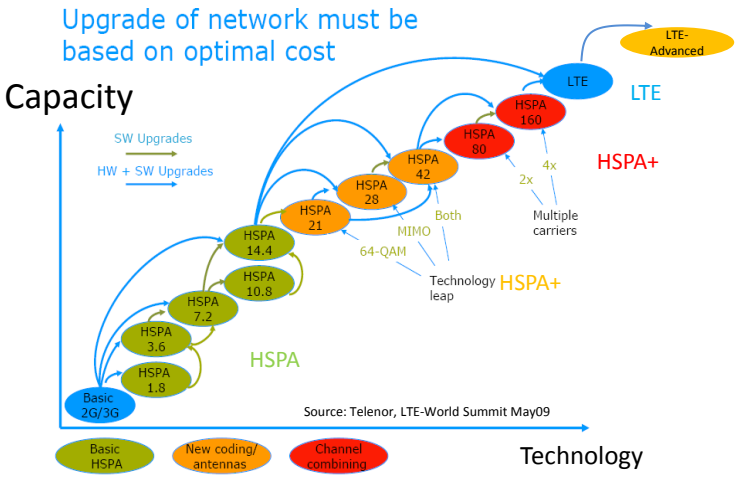


Figure 10: Many possible technology paths, involving different combinations of coding, antennas and spectrum to achieve higher capacity (Figure shows only 3GPP-family technologies: many more paths have to be considered when 3GPP2 and WiMAX technologies are included)

This is not to say that such new technologies are not worthwhile or cost effective: they deliver user benefits in terms of speed, an overall reduction in the cost per bit delivered, and open up the use of new spectrum bands, all of which helps operators to stay competitive and stimulates new services and associated revenues. But they may stimulate as much new demand as they serve, so spectrum efficiency and capacity *per se* may not be the main driving force for next-generation mobile system deployment. Moving to LTE and/or WiMAX does however open up new capacity indirectly via access to new spectrum bands where those technologies are especially supported by the industry.

5 Installing more cells allows capacity to grow almost without limit and improves user experience substantially, but requires a cheaper small cell network topology and a new delivery model

While new spectrum and technology have traditionally received the most attention as sources of extra capacity, a new frontier is opening up in the use of small cells, with femtocells and Wi-Fi in the vanguard. In a sense this is nothing new, as the central 'magic' of mobile radio is to manage interference in order to reuse a finite amount of spectrum to serve a theoretically unlimited number of users. However, traditional macrocells are growing slowly – if at all – due to the difficulties of obtaining suitable sites as well as due to the underlying costs. Smaller cells serve fewer users, so need to be at least proportionately cheaper to deliver and operate.

Femtocells have advanced in recent years to the point where many operators are now deploying for 3G, and there is much attention on the use of LTE Femtocells for the future. Femtocells – even when operated in the same spectrum as macrocells – can deliver an improved user experience for both the femtocell users and the macrocell users due to the reduced loading on the macrocell network (Figure 11). This increases overall air interface capacity by orders of magnitude – nearly one hundred times in the example of Figure 11. Although femtocells began as an approach for service in residential home environments, they are increasingly being developed for enterprise use and similar technology is envisaged for public, outdoor applications to enable rapid deployment of capacity as the need arises.

Wi-Fi can also provide similar benefits and has the advantage that Wi-Fi access points are already very widely deployed. There are limitations in ensuring that the customer experience is adequate given the interference which can be an issue in unlicenced spectrum. It can also be tricky to ensure simple access for users combined with secure authentication, but operator-managed Wi-Fi techniques are evolving rapidly to address some of these issues.

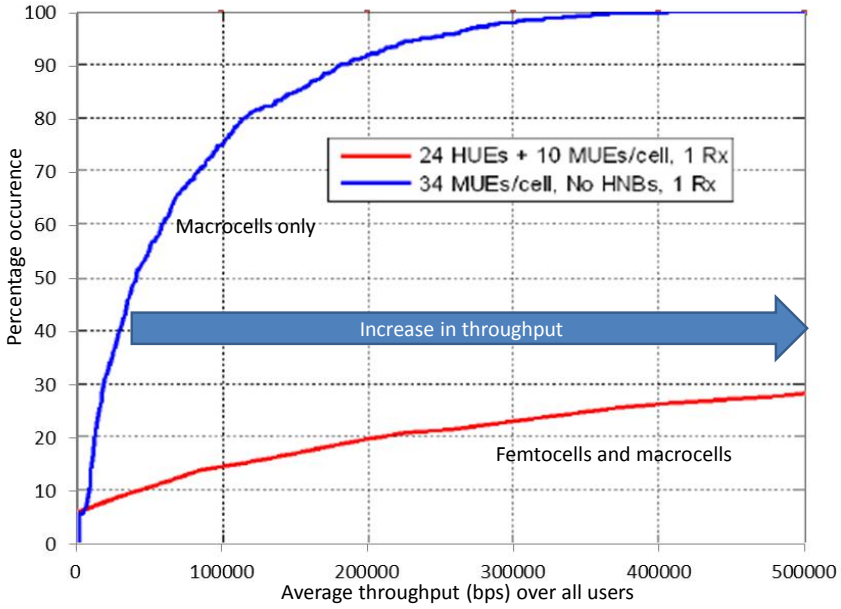


Figure 11: Improvement in customer experience from combining femtocells with macrocells (Source: Femto Forum)

When either femtocells or Wi-Fi are used to create a small-cell rollout, the radio and transport networks immediately benefit from the offload of data in the very locations where typically70-90% of usage typically occurs, so careful targetting of these techniques can have a significant effect on relieving capacity bottlenecks, even when deployment volumes are modest. Further, Figure 12 shows how both technologies have the ability to also offload the core network by ensuring that traffic destined for the internet does not have to pass needlessly through the core network, while retaining control of the customer experience by maintaining the signalling traffic with the mobile operator.

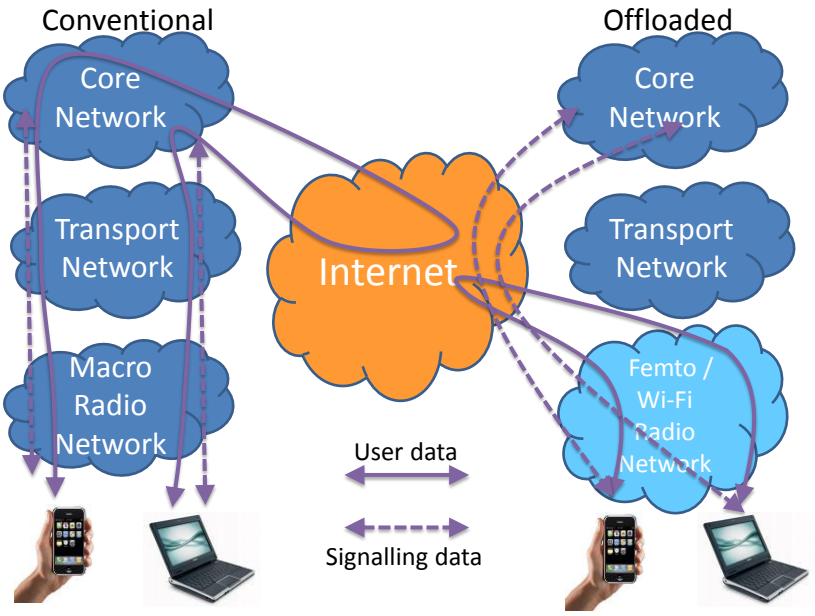


Figure 12: Network offload using femtocells or Wi-Fi

These techniques should be considered holistically to produce an integrated data offload strategy, facilitated by small cells. This can substantially reduce costs:

"Delivering data over femtocells is a hundred times cheaper than sending it over the regular mobile network"

- *Ben Verwaayen, Alcatel-Lucent CEO, quoted in*[7]

Such an approach also delivers a heterogeneous network, closely tuned to the needs of customers and substantially cost-optimised - Figure 13. Other network topology innovations such as coordinated multipoint transmission and intelligent relays will also contribute to this 'right-sizing' of mobile networks.

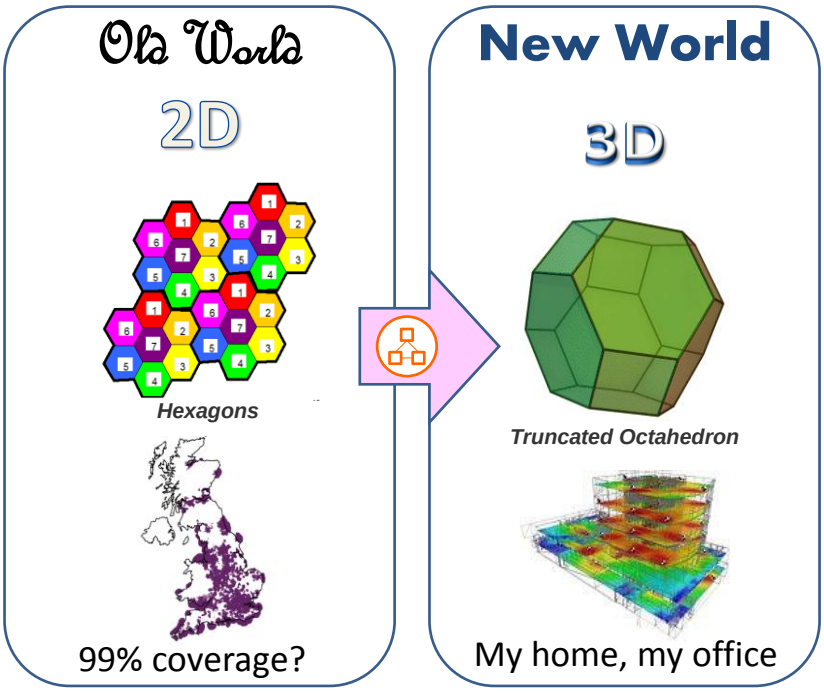
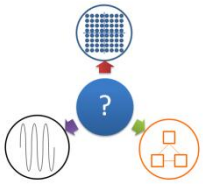


Figure 13: Using small cells to deliver a network which meets modern customer needs while delivering the capacity gains and cost reductions needed for sustainability

6 Careful combination of network assets can economically achieve the required capacity growth



The three-prong approach discussed here, using ***spectrum***, ***technology*** and ***topology***, may in some ways seem radical, relying as it does on fresh spectrum, the latest wireless technologies and brand-new cell architectures. Yet in some ways this reflects directly the way in which wireless has evolved over the last few decades. This is reflected in the observation by Martin Cooper – now often known as Cooper's Law – that all three approaches have contributed significantly to the capacity gains of wireless networks in the second half of the twentieth century, with the addition of more cells being the single biggest contributor – see Figure 14.

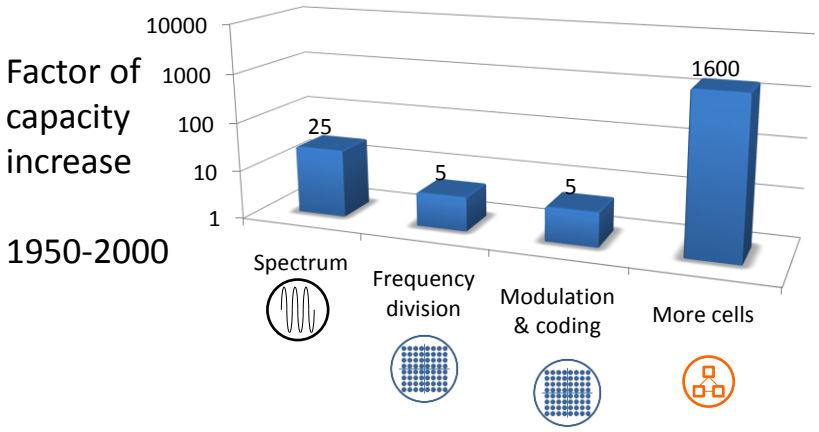


Figure 14: Cooper's Law - the sources of wireless capacity increase in the latter half of the twentieth century[8]

Projecting these opportunities forward for the next decade, we have suggested that gains in spectrum useful and impactful could be of order a doubling of capacity, gains in spectrum efficiency (with appropriate supporting hardware) could yield a further tripling, while small cells could yield a couple of orders of magnitude. This suggests that there is scope overall for a gain in capacity of order 500-1000 times, which suggests a continued bright future for mobile communications – see Figure 15.

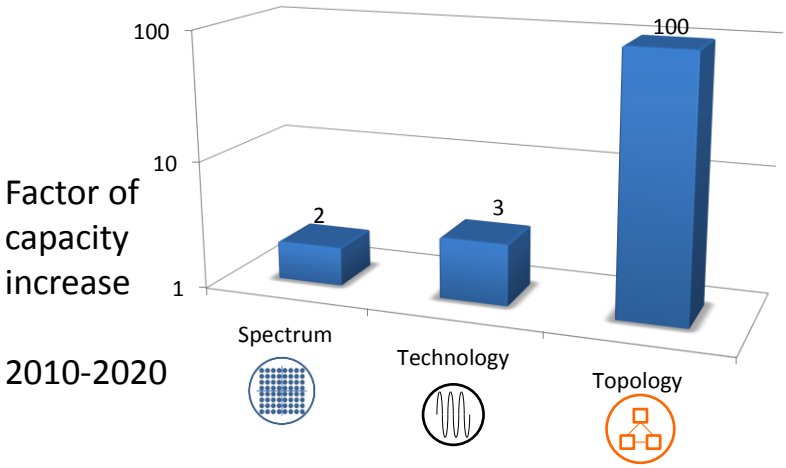


Figure 15: Sources of capacity increases over the coming decade (Source: Real Wireless – acknowledgements to Moray Rumney)

7 Operators, regulators and technology vendors need to answer a wide range of questions to determine the capacity growth strategy which is right for them

Although we see great scope for continued capacity increases in mobile networks into the long term, achieving these will not be easy. The correct strategy is specific to a given operator and market, can be advanced or retarded by regulatory and political policies, and requires that the right technology is delivered at the right price points. The uncertainties of the precise scope of future demand suggest that operators should hang back from investment until they are sure of the need to invest, yet they should urgently create a clear strategy for capacity expansion ready to enact swiftly in order to respond to competitive pressure and to put into action no later than the point at which the need arises. Such considerations apply equally to regulators and technology vendors who need to play their part to support capacity expansion via appropriate regulation and targeted technology innovation.

Figure 16 shows a small selection of the many questions which need to be answered in order to create a tailored and effective capacity expansion strategy.

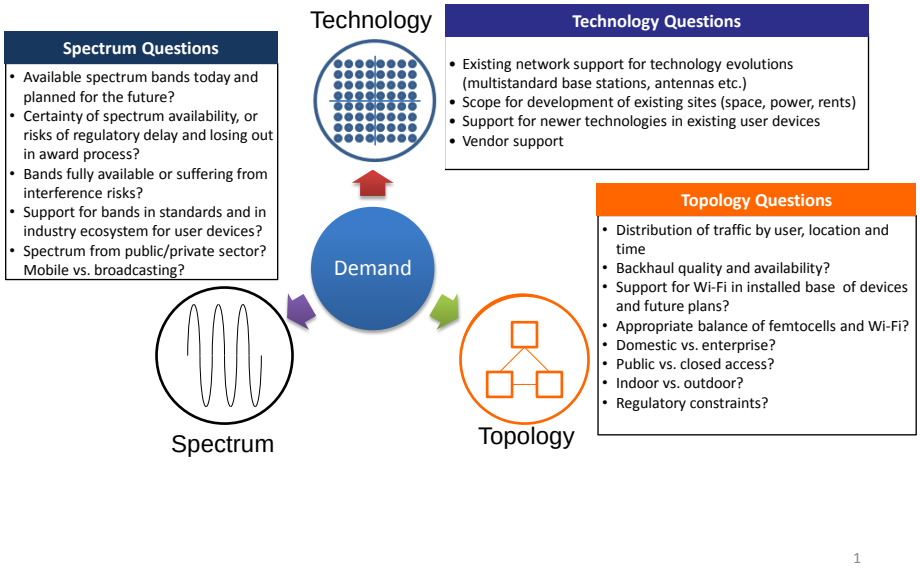


Figure 16: Selected questions to be addressed in forming a capacity expansion strategy

Real Wireless Support for Capacity Expansion Activities

Real Wireless provides support for capacity expansion planning via a wide range of services, building on our experience for regulators, governmental policy makers, technology vendors and operators alike. We provide unbiased advice, based on direct experience and without equipment to sell or a single solution to push. Some of these services are shown below, and all can be provided on a stand-alone basis or as elements in a comprehensive capacity expansion strategy. Contact us for further details.

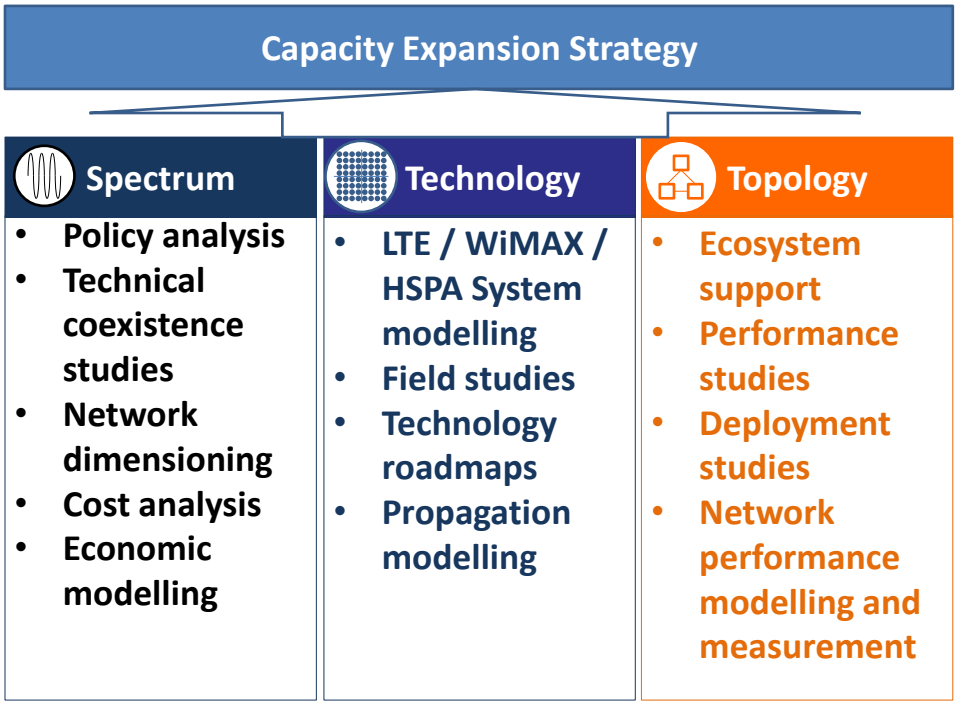


Figure 17: Real Wireless Services

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