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14th October, 2014

Dr. Rahul Khullar,
Chairman, Telecom Regulatory Authority of India
Mahanagar Doorsanchar Bhawan,
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Via Facsimile: +91□11□23235249

Sub: Response on TRAI's Consultation Paper on "Delivering Broadband Quickly: What do we need to do?"

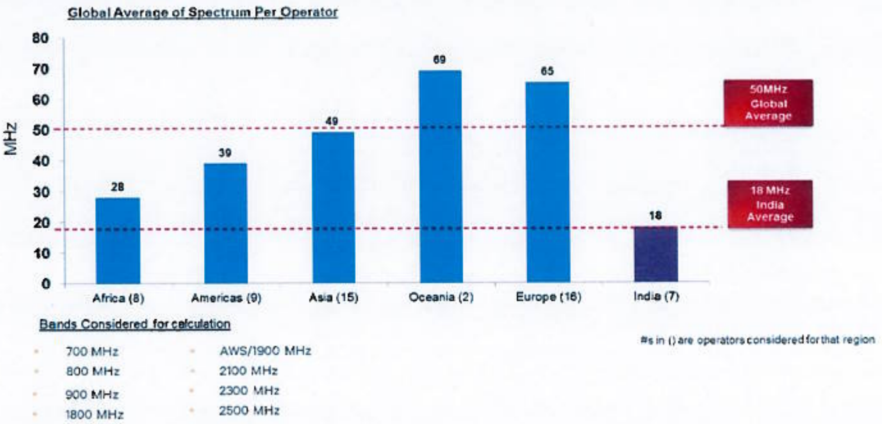
Dear Dr. Khullar,

Qualcomm appreciates the opportunity to comment on the Telecommunications Regulatory Authority of India (TRAI) Consultation Paper on "*Delivering Broadband Quickly: What do we need to do*?" dated 24th September 2014.

Qualcomm endorses TRAI's priority to speedy rollout of broadband in India. It especially recognizes the focus on regulatory measures to facilitate access to broadband networks and expanding data usage. The TRAI document also rightly reflects the importance of wireless technologies in since extending India's sparse fixed line connectivity will require much more time and funds. A conducive environment for growth of wireless networks holds the key to developing data markets in India.

Access to the radio frequency spectrum is therefore central to India's broadband aspirations. For India to exploit the full value of powerful wireless technologies, it is imperative that companies deploying them can obtain sufficient amounts of contiguous spectrum in a transparently competitive process.

Spectrum Holding Comparison: However, India's operators face serious shortages of spectrum. This, as the figure below shows, is in direct contrast to their counterparts abroad.



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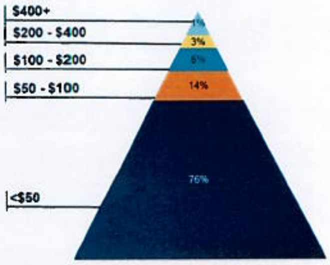
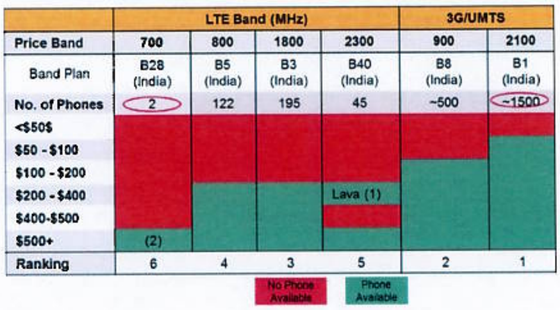
Mature Broadband Spectrum: The current limited spectrum assignment, will severely constrain capacity of wireless networks, irrespective of the technology used. Further, the smaller quantum of spectrum is a bigger hindrance in deploying the more powerful wireless technologies. Unlike the 2G technologies deployed currently, and in need of upgrade, since the advanced technologies require contiguous spectrum. Therefore, India's ability to deliver affordable mobile broadband services will depend on each operator having sufficient amount of contiguous spectrum - in mature spectrum bands that can exploit global economies of scale. The accompanying figure shows which spectrum bands, offer the greatest such economies for mobile broadband technologies (i.e. LTE and HSPA) and why India needs to prioritize them for allocation to mobile operators.



75%+ of the total mobile devices purchased are under Rs. 3000/-



Source: IDC, GSA, Public statements by OEMs. Price does not consider operator or other subsidies. Some prices are estimated by similar device on other bands/operators. Data as on date: 24th Feb 2014

Spectrum Locked with Government Agencies: A very large part of the commercially valuable spectrum bands, which are key to providing affordable broadband, are allocated to government agencies.

The following table provides an overview:

Bands	Total as per band plan (each SA) (MHz)	Total as per band plan (x22 – for Pan-India) (MHz)	Total assigned for commercial (MHz)	Not assigned for commercial (MHz)	Not assigned for commercial (%)
900 MHz	25	550	430.8	119.2	21.7%
1800 MHz	75	1650	1020.9	629.1	38.1%
2100 MHz	60	1320	465	855	64.8%
2500 MHz	190	4180	Nil	4180	100%

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In most of the cases, it is possible to refarm these agencies in a time frame of 6-9 months, (although some cases may take much longer due to legacy issues). We recommend that DoT and defence use their existing mechanism to help vacate commercial spectrum immediately, in all those cases, where alternate means of communication are available. The Licensed Shared Access (LSA) model, described below, offers a powerful and secure way to share spectrum allocated to government agencies, e.g. defence, to use on 'as and when required' basis.

Licensed Shared Access (LSA) Model: LSA permits incumbents to control the spectrum while authorizing licensees to utilize spectrum bandwidth in a given geography or for a particular time duration. This allows mature commercial spectrum bands to be deployed effectively for public use without diluting priority to government agencies. Internationally, the EC, CEPT, ETSI and the RSPG have all been working on LSA. Currently, work on the harmonized use of the 2300 MHz frequency band for mobile broadband and sharing in the 3.6-3.8 GHz frequency range under LSA framework is in progress in Europe.

CEPT approved ECC Report 205 in February 2014 which provides an overall definition and guidelines for the implementation of LSA. The EC issued a mandate to CEPT to develop harmonized technical conditions for the 2300-2400 MHz frequency band in the EU for the provision of wireless broadband electronic communications services in March 2014. CEPT Response to the Task 1 of the EC Mandate (CEPT Report 55) was approved in October 2014. It provides common and minimal technical conditions for wireless broadband usage of the 2300-2400 MHz frequency band based on the provisions developed in

ECC/DEC((14)02. CEPT Response to the Task 2 of the EC Mandate (CEPT Report B1) on technological and regulatory options will be approved in November 2014 for Public Consultation. In September 2014, CEPT ECC PT1 agreed to open a new Work Item focusing on the sharing, in the 3.6 – 3.8 GHz frequency range, between Fixed Satellite Service Earth Stations and Fixed Service radio links and mobile systems

Qualcomm is working closely with the US government and other industry leaders on LSA. Recently in March 2014, Qualcomm participated in joint lab testing with NTIA for testing co-existence between LTE-based small cells and radars in the 3.5 GHz band-- both on interference from the radars to the LTE small cells, and vice versa. The tests showed that using the LSA framework, and low power LTE small cells, there can be co-existence between the radars and the LTE small cells with minimal exclusion zones. NTIA has published two reports with the test results (http://www.its.bldrdoc.gov/publications/2759.aspx
and http://www.its.bldrdoc.gov/publications/2760.aspx). Qualcomm is also working with Verizon, and Ericsson on performing joint field tests in the 3.5 GHz band shortly.

A concept paper on LSA model is also enclosed as **annexure**.

Future IMT Spectrum: In the last few years, global mobile traffic has been nearly doubling annually. India's data markets, though nascent, can be no exception in the long run. Future IMT growth will require adequate spectrum in the relevant bands identified by competent bodies, internationally. We identify below the prime candidates for IMT deployments across the world and in India with our comments.

(a) **470-698 MHz**: This band has attractive propagation characteristics. However, a large amount of spectrum in this band is locked with the government agencies (Broadcasting and others) and can be vacated in a time bound manner.

(b) **1452-1492 MHz**: This band offers additional capacity and coverage. ECC DEC (13)03 has already approved this band for Supplemental Downlink (SDL) to increase the downlink capacity. 3GPP too has completed its work in June 2014 of standardization of L band (1452-1492 MHz) combinations for both LTE and UMTS for SDL operations. The L band is now 3GPP Band 32.

(c) **3400-3600 MHz** - The 3400-3600 MHz of the band has already been identified for IMT in India. This spectrum provides an excellent opportunity to deploy Small Cells to provide coverage and capacity for indoor use/high-rise buildings and to support densification of cell sites. A brief note on Small Cells is given in the **annexure** enclosed.

We will be delighted to provide additional inputs to this task of manifest national importance.

Sincerely,

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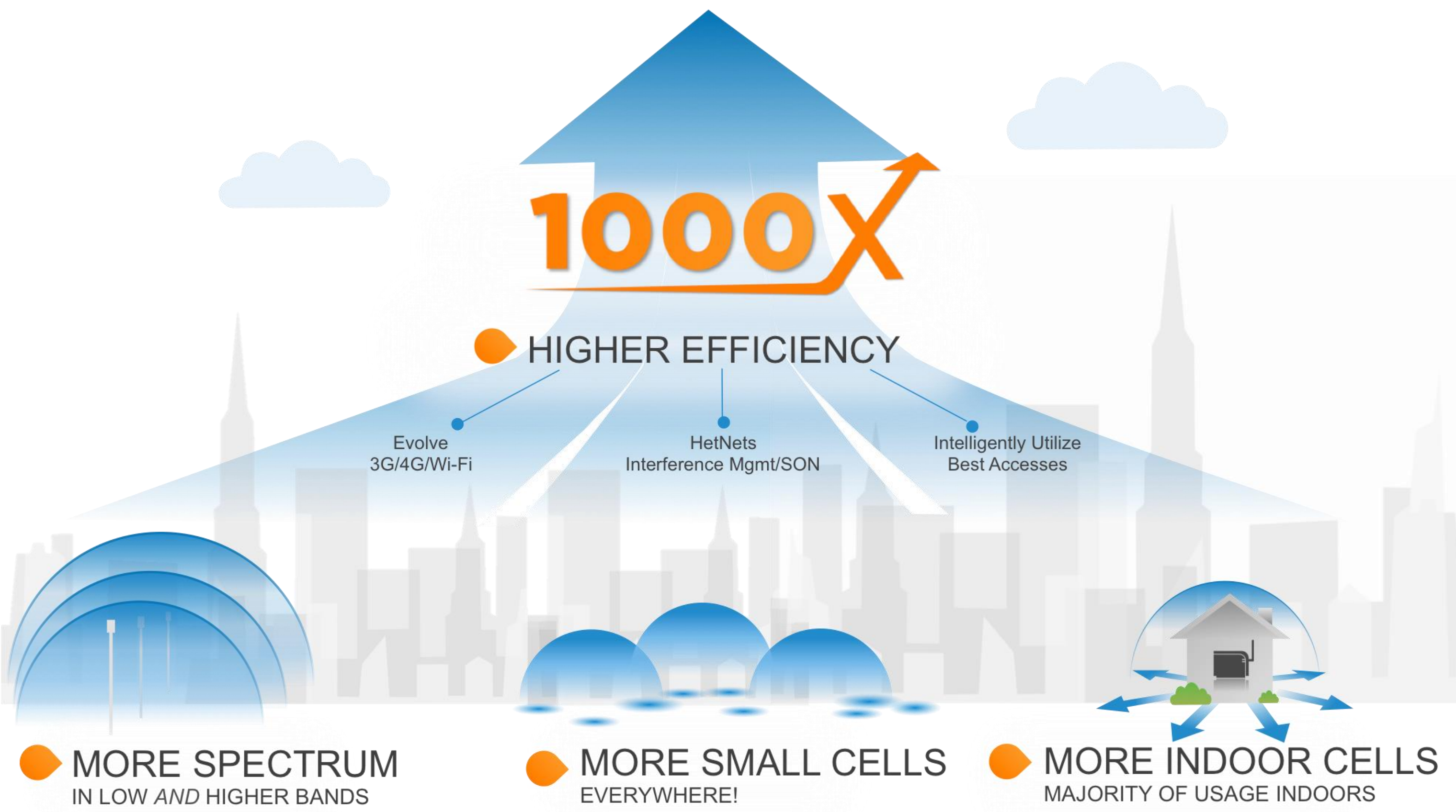
Rising to Meet the 1000x Mobile Data Challenge



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1 Executive Summary

The mobile industry has a history of overcoming great obstacles, and today we're facing a formidable one: the "1000x challenge."

The genesis of this term is rooted in the phenomenal growth in the global demand for mobile broadband data services—mobile data traffic has been approximately doubling every year. All the indications point to this growth continuing unabated. While the projections vary, the goal of "1000x increase" truly captures the sentiment of the industry.

The positive news is that mobile industry's latest wireless technologies offer solutions capable of meeting the 1000x challenge—some of which are already developed—and there is a robust roadmap for many more. The solutions are not simply about throwing more resources at the challenge. The solutions require a radically different approach to acquiring, deploying and managing resources.

The focus of this paper is to set a vision for the efforts needed by the industry to meet the 1000x challenge as well as provide solid proof points for the initial concepts and technologies that are building blocks of the overall vision.

Conceptually, all the efforts can be summed up in to three main groups: 1) more spectrum; 2) small cells everywhere; 3) higher efficiency across the system.

Spectrum is the life blood of wireless networks. There are many enhancements to increase the efficiency of existing spectrum. But meeting an increase of the magnitude of 1000x will unquestionably require more spectrum. The questions to ponder are: how much more, which bands, licensed or unlicensed, and how to get it in a timely manner?

Small cells are already popular and are here to stay. How dense can they get, and where—indoor, outdoor or both? All indicators say that most mobile traffic will occur indoors. Small cells are a good match there. Does this mean a small cell in every house, shop or office? What about the interference? How about new deployment models? Finally, how do you get higher efficiency from all the networks, devices, applications and services? Does the notion of "the whole is much more than the sum of its parts" hold true in this case?

This paper explores all these questions, sometimes proposing unconventional solutions and path-breaking approaches. Our end goal is to show that the mobile wireless industry can cost-effectively face the 1000x challenge while continuing to provide the best possible mobile broadband experience to users.

2 More Spectrum – Licensed, Unlicensed, and an Innovative Approach

As wireless networks strain to meet the growing demand for mobile broadband services, spectrum has become a hot-button issue. Operators are always looking for more of it at bands that are suitable for their use in a cost-effective way. At the same time, regulators are working to identify, clear and allocate new spectrum for mobile services. As shown in Fig. 2.1, there are three approaches to making new spectrum available:

1) Traditional licensing process for 3G and 4G LTE

2) A new and innovative regime called Licensed Shared Access (LSA)

3) Unlicensed spectrum, in which LTE and Wi-Fi services can be deployed

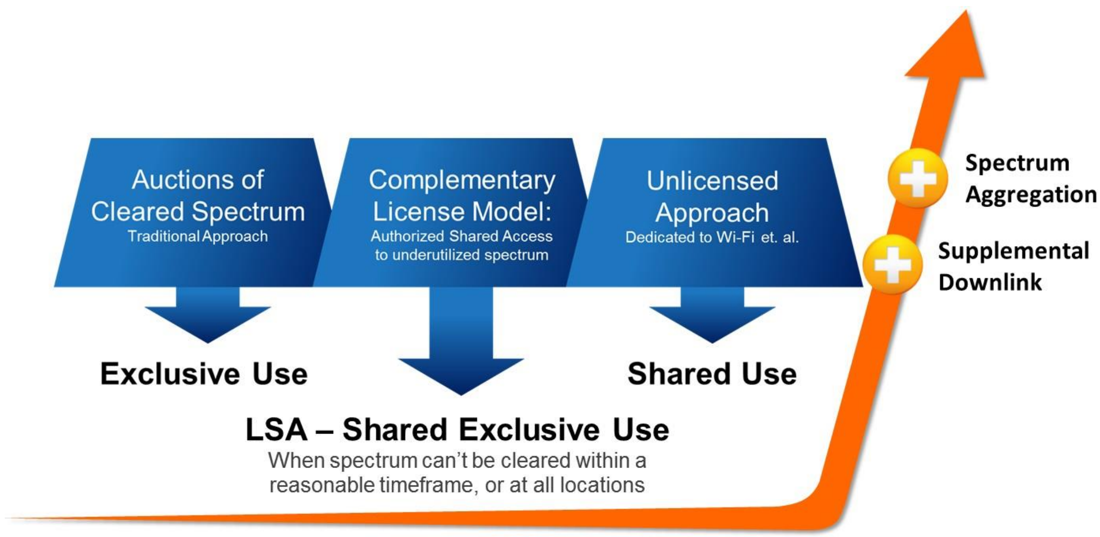


Fig. 2.1 Sources of new mobile broadband spectrum

Each of these approaches has a specific usage scenario. The traditionally licensed spectrum gives exclusive rights to the licensee on a nationwide, 24x7 basis. The exclusive use allows planned and orderly deployment, resulting in predictable performance. Identifying, allocating and clearing this spectrum is a long and arduous process. Globally, regulators have demonstrated the effectiveness of this approach.

In cases when the spectrum cannot be cleared for licensing within a reasonable timeframe, or on a nationwide basis, Qualcomm and its partners are proposing a new approach called LSA. LSA can potentially unlock a large quantity of underutilized high-quality spectrum in higher bands for 3G/4G services, in a cost-effective and timely manner. LSA also allows predictable Quality of Service (QoS), which is important for consumers. Section 2.1 discusses LSA in detail.

Globally, there is unlicensed spectrum in the 2.4 GHz and 5 GHz bands. In this spectrum, by definition, no single entity has control over how the networks are planned, deployed and used. Because of this, the interference situation for very dense deployments is unpredictable, making it difficult to guarantee QoS for delay-sensitive apps such as multiplayer interactive games, VoIP, video telephony, etc.

Qualcomm is working on enabling LTE in unlicensed spectrum. LTE offers substantial performance benefits and will co-exist successfully with Wi Fi and other technologies that already use unlicensed spectrum.

Also, the 60 GHz band is already earmarked for specific Wi-Fi applications such as wireless displays and wireless docking operating within a very close range (e.g., within a room).

Wireless evolution enhancements such as spectrum aggregation and supplemental downlink can further increase the usability of the entire available spectrum. Spectrum aggregation can be done between different bands of the same technology (e.g., 900 MHz and 2.1 GHz of HSPA+), which is possible today, or across different technologies (e.g., LTE with Wi-Fi) in the future. Supplemental downlink, on the other hand, combines unpaired spectrum with the downlink of paired spectrum, considerably augmenting downlink capacity.

As the industry is working tirelessly to identify new globally harmonized bands for mobile services, it is evident that exploring higher bands is one of the options. The 3.4–3.8 GHz spectrum is one such band. Because of its propagation characteristics that lead to smaller coverage area, this band is suitable for small cell deployments. Parts of this spectrum may be available to be licensed traditionally, and others can be licensed through LSA.

2.1 Licensed Shared Access (LSA)

Spectrum being a finite resource, every effort should be made to utilize it to the fullest extent possible. But some spectrum holders, such as government users, because of the nature of their operations, may not be using the entire block of allocated spectrum in every part of their geographic boundaries on a 24x7 basis. For example, while spectrum for military radar might be allocated on a countrywide basis, the radar operations may only be using the spectrum at certain locations such as along the coastline, or may not be using it 24x7. There are many similar examples in a variety of sectors including defense, satellite communications, and many more.

LSA proposes a new regulatory framework for such instances. It allows the grant of exclusive spectrum rights of use to qualified stakeholders, to operate a commercial 3G/4G network in this underutilized spectrum, whenever and wherever it’s available, subject to the usage needs and requirement of the incumbent spectrum rights holder. Here's one example of how this could work. In a simple process, the incumbent spectrum rights holder, the 3G/4G operator and the regulator sign a compensation-bearing agreement that makes the incumbent's spectrum assets available for mobile broadband usage by the 3G/4G operator after they obtain a license. Or, the exclusive LSA rights could also be auctioned subject to the defined usage needs of the incumbent. No matter what the arrangement is, there will only be one stakeholder using the spectrum at any given time within the defined geographical boundary. This shared exclusive use ensures predictability in terms of availability and performance (because of guaranteed non-interference) for 3G/4G operators. Furthermore, this predictability offers protection for operator investments.

From an incumbent's perspective, LSA offers an opportunity to monetize its underutilized spectrum assets without hampering operations in any way, as the agreement ensures that there will absolutely be no undue interference from the 3G/4G operations while using the LSA spectrum. From the operator's perspective, LSA allows it to access high-quality 3G/4G spectrum whenever and wherever needed. From the government's perspective, LSA helps ensure that spectrum is used efficiently and the derived benefits will spread across the economy.

Since it is critical for 3G/4G operators not to interfere, small cells using higher frequency bands are the ideal option for LSA, thanks to their lower transmit power (coverage) and their indoor or low-height outdoor deployments. This is important as it allows small cell deployments geographically closer to incumbents' operations. Macrocell deployments are also possible farther away, as shown in Fig 2.2.

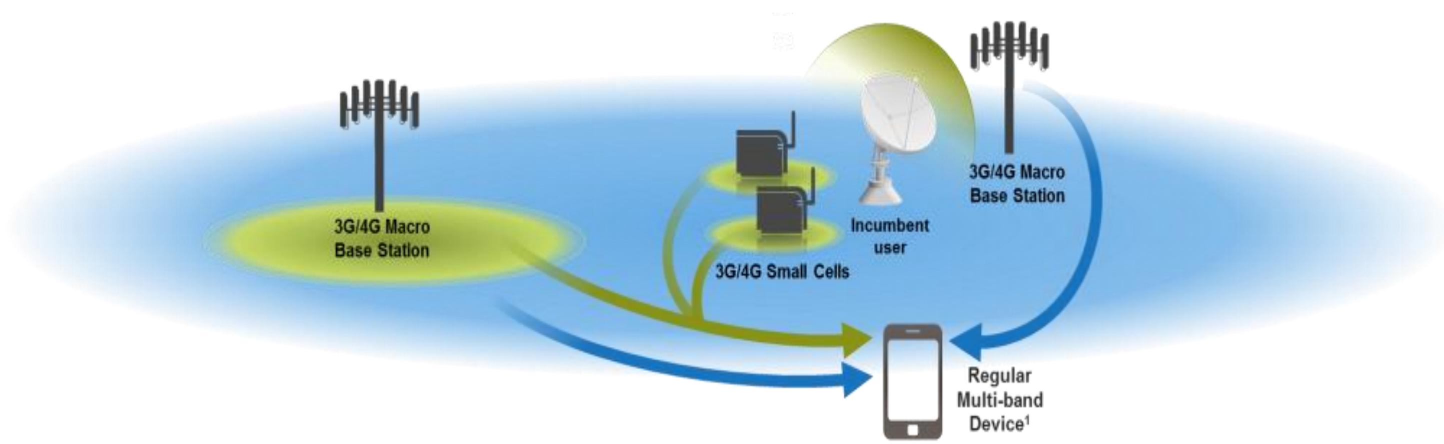


Fig 2.2 – Small cells are optimal for LSA

LSA can potentially unlock hundreds of megahertz of high-quality spectrum for 3G and 4G. Qualcomm along with its partners is already working on identifying globally harmonized spectrum bands for LSA. The initial focus is to target bands for which commercial devices are either already available in the market or will soon be available. For example, the 2.3 GHz band is a prime LSA candidate for Europe as this band is earmarked for LTE in China and India, and for which commercial devices are available. The 3.5 GHz band is also another attractive LSA candidate for the U.S., Europe, Latin America, Southeast Asia and Middle East. The advantage of using harmonized bands with commercial devices is that operators can quickly start using the LSA spectrum and leverage large economies of scale. Moreover, LSA doesn't need any standards change, making it simple to deploy.

In essence, everyone wins with LSA—it offers compensation for incumbents; it provides cost-effective, high-quality spectrum for 3G/4G operators; and it offers a pragmatic, fast-track solution for regulators to increase the efficient use of spectrum and to address the ever-increasing demand for new mobile broadband spectrum.

3 More Small Cells – Taking Hetnets to a New Level

The benefit of small cells in providing capacity where needed, is well understood. So are the challenges and solutions for managing the interference. Enhancements such as "Range Expansion," introduced in LTE Advanced, increase the overall network capacity much more than what can be got by merely adding small cells. The interference management techniques of LTE Advanced make adding more small cells possible without affecting the overall network performance.

To reach the 1000x capacity goal, we will need many more small cells. We will need them everywhere (indoors and outdoors), at all possible venues (residences and enterprises), and capable of managing all technologies (3G, 4G, Wi-Fi). Furthermore, the "small cells" will be all types, including femtos, picos, metros, relays, remote radio heads, distributed antenna systems, etc. As shown in Fig. 3.1, all of these small cells will complement the traditional macro networks, and allow denser use of spectrum, making the network completely heterogeneous, often referred to as hetnets.

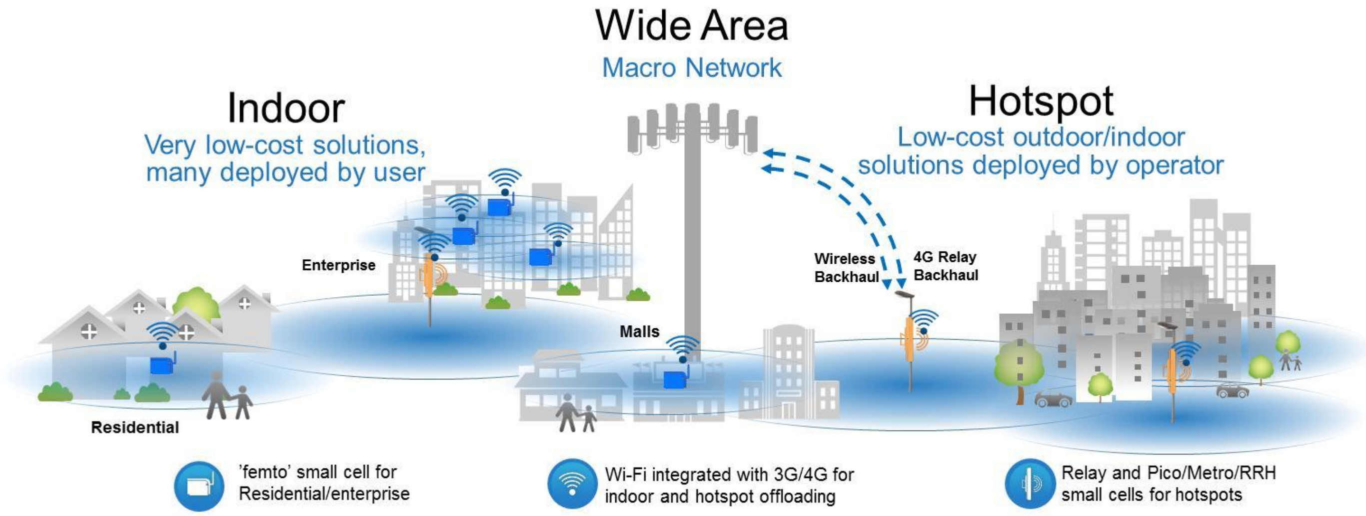
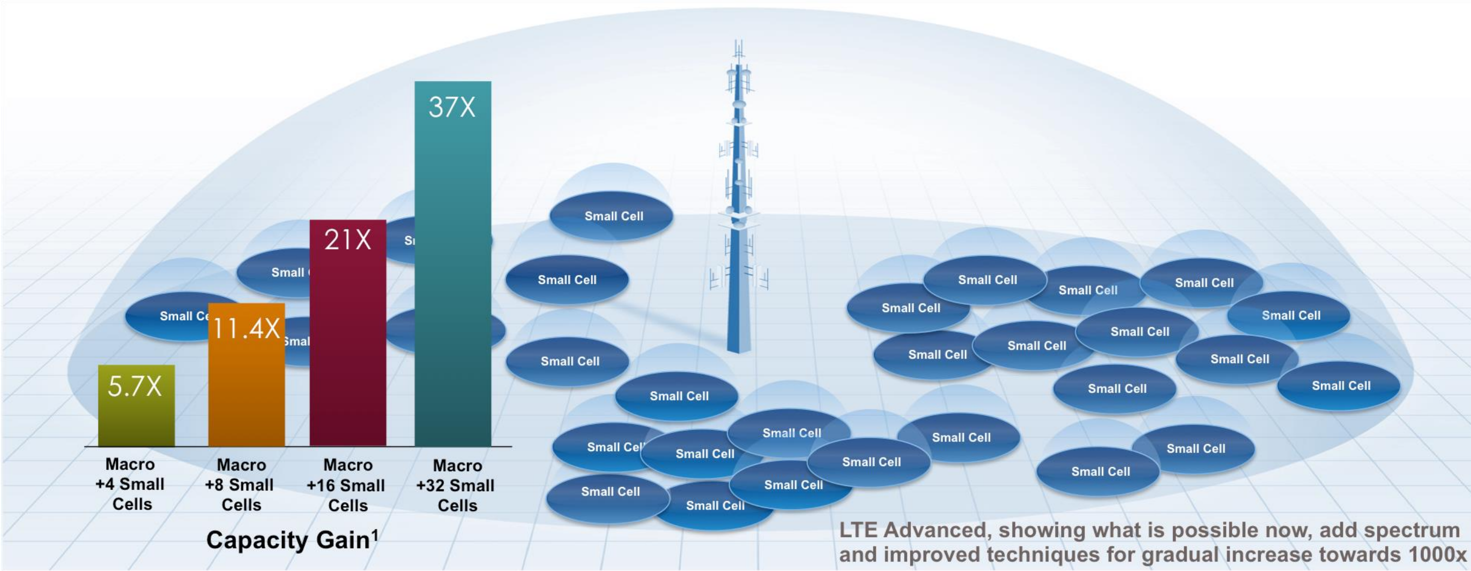


Fig. 3.1 – Small cells allow denser use of spectrum

Extremely low-cost indoor small cell solutions can be used at homes, offices, enterprises, shopping malls, etc., and for the most part, can be installed by users themselves. Small cells can also be deployed by operators as hotspots, cost-effectively serving highly concentrated indoor/outdoor traffic. Relays are an ideal solution for backhaul-challenged areas, as they use part of their capacity for backhaul. No matter what kinds of 3G/4G small cells are deployed, integrating Wi-Fi into all of them makes perfect sense. Wi-Fi can opportunistically offload a substantial amount of data traffic from 3G/4G, whether it's an indoor or outdoor deployment, or a hotspot.

Our initial studies have shown that the overall capacity of these hetnets scales with the degree of densification of small cells, thanks to advanced interference management techniques. Fig. 3.2 clearly illustrates this by showing the relative capacity increase with the increasing penetration of small cells in a LTE Advanced network. For example, if there are 32 outdoor picocells for every macrocell in the network, then the overall capacity will be a staggering 37x (approx.) capacity gain over a macro-only network.



Assumptions: Pico small cell, 10 MHz@2 GHz + 10MHz@3.6 GHz,D1 scenario macro 500m ISD, uniform user distribution scenario. Gain is median throughput improvement, from baseline with macro only on 10 MHz@2 GH, part of gain is addition of 10 MHz spectrum. Users uniformly distributed—a hotspot scenario could provide higher gains. Macro and outdoor small cells sharing spectrum (co-channel).

Fig 3.2 – Hetnet capacity scales with small cell densification

Obviously, 37x is not even close to 1000x. But the point is, we can reach 37x with technologies that have been already developed. And more importantly, it proves that capacity can scale with the densification, without any negative effects. Adding more spectrum, as well as employing more advanced techniques that are being developed by Qualcomm (and possibly others) can move the capacity increase toward the magical 1000x mark. Some of the enhancements being considered (3GPP R12 and beyond) include: 1) opportunistically switching small cells “ON” when and where needed, to minimize interference; 2) more sophisticated interference coordination between small cells themselves and macros; 3) next-gen advanced receivers with more improved interference cancellation, and 4) possibly adding the ability to simultaneously receive data from multiple cells and many more. Small cells are one of the main research areas for Qualcomm. We are intensely focused on developing end-to-end small cell technologies to make the 1000x increase in mobile data usage possible.

We have an over-the-air LTE Advanced small cell test network in San Diego, and have used it to demonstrate the performance of hetnets at many global trade shows, and similarly plan to showcase the future enhancements as well.

3.1 Wireless Backhaul and Relays

With small cells going everywhere, providing high capacity backhaul is a looming challenge. Backhaul for the indoor residential and enterprise deployments could be a lesser issue, as users are expected to bring their own backhaul, be it DSL, cable or fiber. A large portion of the outdoor deployments could also be backhauled by fixed network.

But for many outdoor, and some indoor deployments, bringing in wired backhaul could be expensive, time consuming and, in some cases, impossible. An example of this is developing countries, where fixed infrastructure is either sparse or non-existent. In such environments, wireless backhaul is useful. It is relatively easy to install, requires less time to deploy, and is very flexible and scalable. Microwave-based LoS (Line of Site) wireless backhauls have been used for macrocells for a long time now. But now, the same concept is being extended to small cells, and also being expanded to include non-LoS solutions, and to the spectrum beyond microwave (e.g. sub 6 GHz).

Relays take the wireless backhaul concept even further, using part of their capacity for backhaul and the remaining for user traffic. In essence, they are a small cell and backhaul solution woven into one. There are different deployment options for relays; for example, they could use one carrier (spectrum) for the backhaul and the other for user traffic, or use the same carrier for both.

A special case of relays is the concept of “Velcro-Relays.” These tie together a LTE small cell for backhaul with other access such as HSPA+/EV-DO small cell for user traffic. These can be very helpful in leveraging LTE spectrum to rapidly increase the network capacity, even when there is no substantial penetration of LTE devices in the market. For example, in markets such as India, where the fixed backhaul infrastructure is limited, LTE spectrum is already licensed, and the penetration of HSPA/HSPA+/EV-DO devices is growing at an enormous pace. In such a scenario, Velcro-Relays can use LTE spectrum to rapidly expand the coverage of HSPA/HSPA+/EV-DO across the country.

4 More Indoor Deployments – Evolve from Outside to Inside

The magnitude of the 1000x challenge requires a new level of thinking as well as a new approach: capacity from indoor small cells, in addition to macros and outdoor hotspots. The huge increase in indoor data usage combined with the relatively small size and cost of small cells is fueling the move toward complementing traditional macro networks with indoor deployments of 3G/4G femtocells and Wi-Fi.

There are multiple deployment models for indoor small cells. One promising example of this indoor focus—and one that Qualcomm is pioneering—is a concept called “Open Neighborhood Small Cells.” Imagine a neighborhood with sizable penetration of user-deployed indoor small cells, providing huge amounts of data capacity that can not only support all the indoor usage but also the outdoor usage in the entire neighborhood, including people walking by on the sidewalk, people in the park, people passing by in slow-moving vehicles, etc. At the same time, these small cells provide good contiguous outdoor coverage all around the neighborhood, supporting seamless handovers between themselves as well as with the macro network. Is that possible? Our simulations, prototyping and testing suggest that this indeed is possible, provided the network is configured and managed intelligently. Fig. 4.1 paints the landscape of such a network.

Fig. 4.1 – The "Open Small Cell Neighborhood Network"

So what are the configurations? They are pretty simple and straight forward. As the name suggests, all of these small cells are open, which means any authorized user of the larger 3G/4G network should be able to access them. The small cells use Self Optimized Network (SON) enhancements, including advanced interference and mobility management techniques to maximize their coverage and capacity and support seamless handoffs. There should be sufficient coverage and capacity from the macro network to support any fast moving transient users as well as outdoor users that don't have good small-cell coverage.

Our initial studies, which used dedicated spectrum for the small-cell network (different than the spectrum used by macro network), showed a huge potential for such a model. We could get up to a 500x capacity increase by deploying 65 small cells for every macro cell, and potentially up to 1000x using 144 small cells for every macro cell. These in turn represent a mere 9% and 20% penetration of households, respectively. Both these scenarios utilized 10x more spectrum than the macro-only deployment model. Further studies are focused on making the neighborhood small-cell network model work more efficiently for shared spectrum (i.e., using the same spectrum for both macro and small-cell networks).

Then the question is, where do we find this 10x more spectrum? The answer is higher bands. Bands such as 3.4 – 3.8 GHz were previously not mainstream bands for mobile networks, mainly because of their small coverage. But for small cells they are most suited, as by design small cells have smaller coverage footprints. In fact, smaller coverage is beneficial in reducing interference. Some parts of this spectrum can be licensed in many countries and the other parts can be made available through LSA. So, no wonder this band is fast emerging as the spectrum of choice for small cells, and proving to be a worthy, globally harmonized band. In the same manner, we envision leveraging even higher bands as well, for small cells.

Neighborhood network obviously has many benefits:1) ease of deployment as these are plug-and-play, enabled by SON, without requiring any detailed network planning, deployment or maintenance; 2) lower cost because of the easy deployment and, in many cases, users provide their own backhaul; 3) guaranteed Quality of Service (QoS) as these small cells use licensed spectrum.

Another question that always arises is: isn't Wi-Fi already partially doing this and won't it continue to do so in the future? Yes, of course. Wi-Fi is one of the major solutions for offloading traffic from 3G/4G. But, one differentiator for 3G/4G small cells is the guaranteed QoS, mainly because they operate in licensed spectrum whereas Wi-Fi uses unlicensed spectrum. Moreover, the trend is toward integrating Wi-Fi into all 3G/4G small cells. So, in the future there will be both Wi-Fi and 3G/4G available, and devices will decide which air interface to access based on the type of application, available capacity, coverage, possible interference, etc.

Qualcomm currently has an over-the-air "Open Neighborhood Small Cell" test network in San Diego and we have demonstrated its performance at many major international exhibitions. In the future, we plan to show further enhancements.

5 Higher Efficiency – Across Networks, Devices and Applications/Services

When looking to offer this huge increase in capacity, the critical nature of lining up more resources is obvious. Equally important, if not more, is ensuring that all of the resources not only operate at their peak performance point, but also work intelligently with the other constituents of the network to offer the best possible overall network performance and an outstanding user experience. To achieve this, many aspects must be taken care of, as shown in Fig. 5.1.

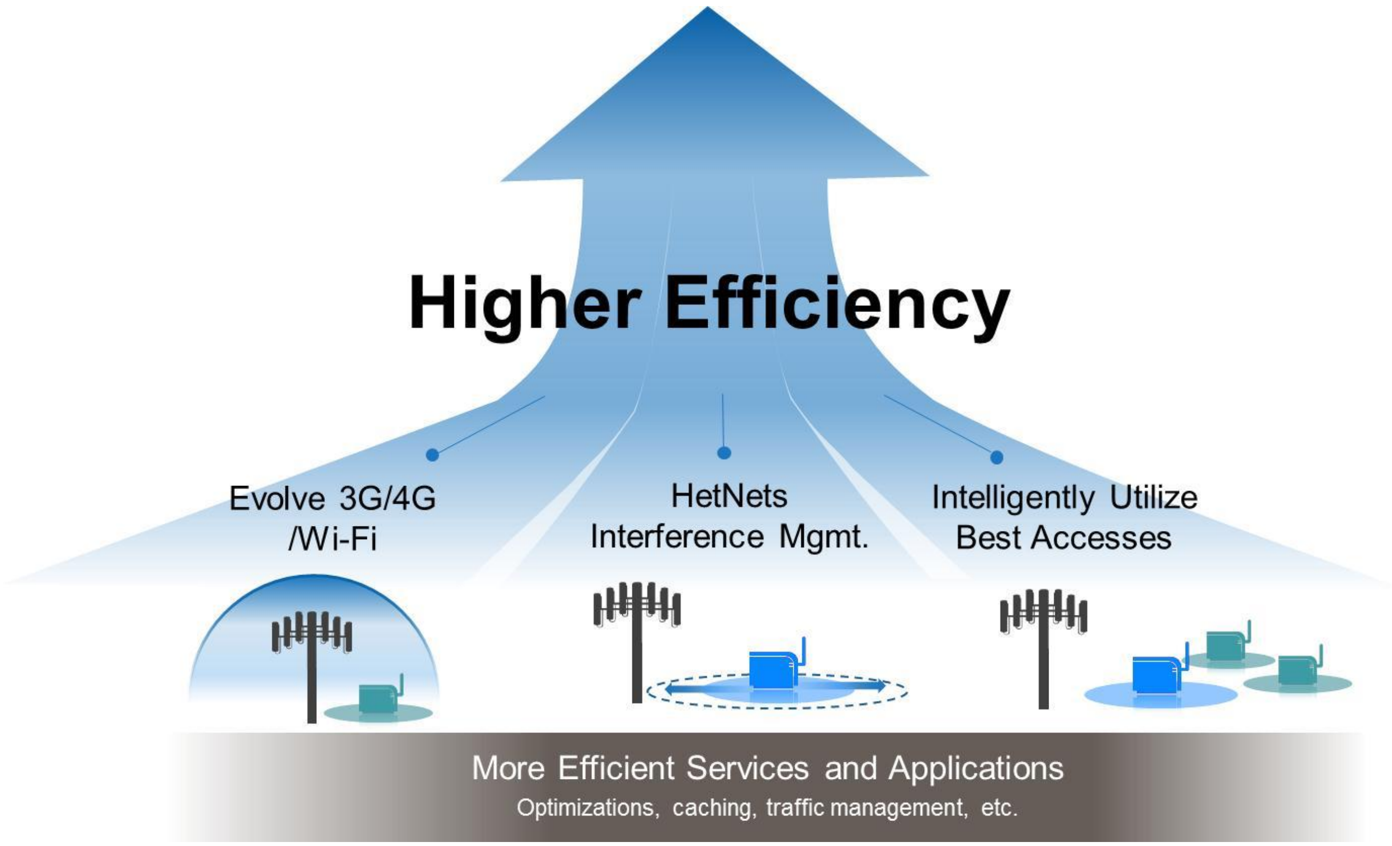


Fig. 5.1 Various aspects of the networks to increase overall efficiency

The first and most straight forward step is to evolve the existing 3G/4G/Wi-Fi networks. This means upgrading LTE to LTE Advanced, HSPA+ to HSPA+ Advanced, EV-DO to DO Advanced, CDMA 1X to 1X Advanced, WCDMA to WCDMA+, Wi-Fi to 11ac, etc. These evolutions improve capacity, data rates, and elevate the user experience.

Heterogeneous networks (hetnets) with small cells will play a major role in meeting the 1000x challenge. To increase their efficiency, it will be critical to manage the interference among the small cells and between the macro networks. This, combined with the next generation of advanced receivers, will take hetnet performance to the next level.

There are also some specific enhancements that address the changing landscape of mobile broadband usage. For starters, HSPA+ Advanced has mechanisms that can achieve more than a 10x increase in capacity for bursty applications such as web browsing, machine-to-machine, etc. And eMBMS, a broadcast/multicast technology standardized in LTE, can offer enormous amounts of capacity for mass consumption of multimedia. It provides substantial gains as compared to unicast (normal video streaming) for even just a few users in the cell. For a higher concentration of users, the efficiency will be even higher. Moreover, the eMBMS can be dynamically turned "ON" and "OFF" based on the concentration of users accessing the same content.

LTE-Direct is an innovative high-efficiency technology for direct device-to-device (peer-to-peer) services. It allows efficient discovery and communication among peer-to-peer users/services. There are many more such tailor-made enhancements that vastly increase capacity and performance for specific services.

Wi-Fi has been the most successful offload strategy thus far for operators, and Wi-Fi's next generation—802.11ac—should be a cornerstone of any operator's future game plan. 11ac is finally making the dream of realistically breaking the 1 Gbps user rate a reality. It's also making HD-quality wireless video streaming across the entire home, not just next to the router, possible. There are many more enhancements in the works to make the interoperability between 3G/4G and Wi-Fi robust and seamless.

Finally, smart devices, applications and services will play a significant role in helping meet the 1000x challenge. For example, when all sorts of connectivity options are available for the device (3G, 4G, Wi-Fi, Bluetooth, small cells, macro network, etc.), selecting the best possible access method, based on the performance of each of those options, the type of application or service being used, and then *intelligently* and seamlessly switching between them, takes the overall network performance, and ultimately, the overall user experience, to a whole new level!

6 Conclusion

Mobile data traffic has seen impressive growth in the last few years, approximately doubling every year. The growth is going to continue and the industry is now preparing for an astounding 1000x increase. The mobile industry and the latest wireless technologies have the answers to effectively counter this formidable challenge, some of which are already developed, and there is a clear roadmap for more solutions to come.

Without a doubt, new resources are required, but adopting radically different approach in acquiring, deploying and managing these resources is of paramount importance. Our vision to address the 1000x challenge is comprised mainly of three components:

1) More spectrum – traditional licensed and unlicensed approaches, as well as innovative approaches such as LSA.

2) More small cells – extreme densification of small cells, indoor and outdoor, user and operator deployed, including all technologies (3G,4G,Wi-Fi) all enabled by innovative interference management techniques.

3) Higher efficiency – bringing in enhancements that not only provide excellent performance of all components of the system but also enable intelligent interplay between each other and provide the best possible overall efficiency and user experience.

Obviously, there is no single solution that is perfect for all the players. Operators, based on their market conditions, business model, and assets, will have to devise a strategy with a mix of these solutions that suit their needs. However, the bottom line is no matter how extraordinary the 1000x challenge appears, based on our initial studies (simulations and prototyping), it is clear that that it is indeed possible to successfully address a 1000x capacity increase. Many of the technologies needed are already developed and there is an intense focus to bring in new enhancements to make the 1000x increase a reality.

In closing, while the "1000x Challenge" may be a subjective forecast, it is an indisputable fact that demand for mobile data is growing at an explosive rate. The effort in this paper has been to focus on what we are best at — coming up with technology solutions to address wireless challenges.

To follow the evolving 1000x story, visit www.qualcomm.com/1000x for the most updated and detailed information.

