Realistic LTE Performance
From Peak Rate to Subscriber Experience
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Introduction

Peak data rates are often perceived as actual data rates a subscriber will experience on a wireless network; this is however far from the reality. Peak data rates do not take into account factors like traffic load, fading, attenuation loss and the signal to noise ratio that have an impact on the end subscriber data rate in a fixed line environment, and an even greater impact in wireless networks. In wireless, additional factors such as the surrounding environment and atmospheric conditions also affect the achievable data rates. This results in a real world data rate that is well below the theoretical peak data rate obtained in laboratory environments.

There are many different ways to measure performance of wireless technologies; these include peak throughput, average sector throughput, cell edge throughput, subscriber data rate, etc., all of which take into account various conditions and scenarios. To accurately predict realistic live LTE network capacity and subscriber experience achievable, operators need to understand the different performance measurements.

In business case development and network modeling exercises, using realistic performance metrics like average sector and cell edge throughput deliver greater accuracy and drive more realistic expectations. For example, peak data rates are rarely used because they reflect theoretical rates that very few (if any) subscribers will actually experience in a commercial network.

As operators are evaluating where to invest in the next generation of wireless broadband technologies, it is important for them to get a realistic view of the true capabilities of the technology choices available to them.

This paper defines the most common throughput measures and provides insight into the associated variables, why considering peak rates for evaluating a business case is misleading, and why average sector throughputs are much more realistic when evaluating the business case for different technology options. Finally, we will look at the expected performance of LTE, supported applications, and how other factors such as latency and Quality of Service (QoS) set LTE apart from previous wireless technologies.
Radio Technology

Radio transmission vs. wired transmission

Radio transmission is broadcast via a radio base station, this equipment transmits the radio signals which are received by end user equipment (UE). Usually, the radio signal quality is affected by several factors, such as the signal path loss; this is essentially the reduction in power density of the signal as it moves through the environment in which it is traveling. Other factors that affect the signal strength include free space loss which affects the subscriber’s signal as he moves away from the transmitting base station. The signal also suffers if its path is obstructed by a factor known as diffraction or if the signal is reflected and reaches the receiver via a number of different paths. This results in performance degradation known as multipath. In effect, the less path loss and susceptibility to interference, the better the signal strength a UE experiences. The better the quality of signal received, the better the performance and throughput achieved by the subscriber.

This is very different from what we experience today with cable and other fixed connections. Fixed connections do not suffer as much from signal attenuation as the fixed connection signal travels in a confined and mostly shielded environment. An exception is xDSL as it uses very old “lossy” and unshielded copper cable, not originally designed to transport high throughputs of data. In comparison Ethernet cables or even fibre connections provide high bandwidth over fairly long distance; and as a result offer more predictable subscriber data rates that reflect its actual performance.

Figures 1 and 2 illustrate effects of signal path loss suffered by radio signals due to factors such as free space loss, multipath, building and vegetation, diffraction and the general atmosphere.

These factors affect the performance of radio transmission and have led the drive for the development of new adaptive modulation schemes and techniques which aim to compensate for these environmental factors, delivering more capacity and better range in an inherently noisy environment full of obstacles. One example of these sophisticated techniques is adaptive modulation. Adaptive modulation provides a tradeoff between delivered bit rate and the robustness of digital encoding, in order to balance throughput with error resilience. In areas where signal strength is good, the modulation switches to a higher bit rate with less robust encoding, while in areas where signal strength is poor or there are a lot of multi-path reflections, the modulation switches to a lower bit rate with more robust encoding to minimize errors. This is the reason that the highest throughput occurs closer to the tower.

Some technologies, like LTE, use additional techniques to extend the range of the performance benefit and maximize the user experience at the cell edge. Other technologies, like HSPA+, deliver increased data rates under strong signal conditions, typically near the center of a cell. Operators need to understand this when making their technology decisions, so they can make choices that will meet the long-term demands of the future.
Throughput Rates

End user expectations are often misguided because there are different methods and metrics for throughput measurement. Several factors such as those alluded to in the previous section impact the practical throughput in RF systems. The additional overhead added by adaptive modulation and error correction coding affect the actual data rate experienced by a user, significantly lowering the user experienced data rate compared to the physical layer peak data rates measured in the lab. The most significant throughput measurements are explained below, starting with the most theoretical measure and moving to measurements that better reflect actual performance in a commercial real life network.

**Physical Layer Peak Data Rate**

This is often the throughput measure highlighted in media and marketing materials. It is a fixed measure, based on the physical layer, and hence determines the actual capacity available per sector at the base station without any error coding. Physical layer peak data rate is useful in comparing laboratory performances against theoretical values, this measure does not consider any data correction techniques, signal quality, interference, scheduling, terminal performance, or mobility and hence is not a practical representation of the data performance.

**Application Layer Peak Data Rate**

The application layer represents the top of the Open System Interconnection (OSI) reference model layer. The OSI is a description for layered communication and network protocol design, it breaks up the network architecture into seven (7) unique layers, the application layer is where actual data is being sent to the subscribers. The application layer peak data rate achieved here assumes there is only a single subscriber on the network with the best possible atmospheric conditions; for example the subscriber is sitting directly under the base station. The rate is also dependent on the type of error rate coding type applied on the link. Error coding is a method of applying error control on a data transmission, where the system inserts additional data (redundant) to its messages, allowing the receiver to detect and correct errors without having to request a full retransmission of the affected data. The absence of error coding may lead to several retransmissions which will affect the size of the available bandwidth.

**Average Sector Throughput**

The Average sector throughput is the aggregate of the individual subscriber data rates in a sector; in other words, this is the ability to deliver the most number of bits to the most number of subscribers, hence allowing operators to maximize their revenue. Figure 4 illustrates several instant network access by various subscribers within a cell range. Throughput is often affected by a set of conditions such as distance from cell, number of concurrent subscribers, mobility, interference, indoor/outdoor coverage, tower heights, and the types of devices being used on the network. Average sector throughput is the measure that best represents the realistic capacity of a sector serving subscribers in a real world environment. This is why it is the most useful measurement when evaluating different technologies and developing detailed plans and business cases. It is important to note that variation in the average sector throughput will occur due to the various conditions listed above which are similar to what occurs in an everyday network.

The Next Generation Mobile Networks (NGMN) Alliance, a body aiming to create a coherent view beyond the standards of what mobile broadband will require beyond 2010, have created a number of baseline cases to assess the performance of different technologies under consistent scenarios that model different real life deployment conditions.
For this purpose, NGMN used average sector throughput to assess the real life performance measurement across the various technologies and eventually accepted, as a working assumption, that the 3GPP LTE project will be one of the most likely vehicle for the delivery of the NGMN radio design and similarly accepted 3GPP SAE as the prime system to deliver NGMN system architecture.

**Table 1a – LTE Peak Data Rates (Mbps) – no error rate coding**

<table>
<thead>
<tr>
<th>Antenna Technology</th>
<th>QTY</th>
<th>5MHz</th>
<th>10MHz</th>
<th>20MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIMO 2x2</td>
<td></td>
<td>43</td>
<td>86</td>
<td>173</td>
</tr>
<tr>
<td>MIMO 4x4</td>
<td></td>
<td>82</td>
<td>163</td>
<td>326</td>
</tr>
</tbody>
</table>

**Table 1b – LTE Peak Data Rates (Mbps) – 5/6 error rate coding**

<table>
<thead>
<tr>
<th>Antenna Technology</th>
<th>QTY</th>
<th>5MHz</th>
<th>10MHz</th>
<th>20MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIMO 2x2</td>
<td></td>
<td>29</td>
<td>59</td>
<td>117</td>
</tr>
<tr>
<td>MIMO 4x4</td>
<td></td>
<td>55</td>
<td>113</td>
<td>226</td>
</tr>
</tbody>
</table>

Subscriber data rate is often expressed as “up to” a peak, a range of min-max values, and average measurements. This is the view of a single subscriber’s data rate and can vary greatly depending on the conditions and the number of subscribers on a cell using the services, but it gives a realistic expectation of what subscribers are likely to experience on a real life network.

**LTE Sector Data Rate**

Sector peak data rates for LTE are listed in Table 1a below. The rates vary based on the channel bandwidth and antenna technology scheme used. Multiple-input and multiple-output (MIMO) is a smart antenna technology which allows the use of multiple antennas at both the transmitter and receiver to improve performance. It is important to remember that physical layer peak rate is a theoretical maximum and does not take into account error rate coding, which is essential in real life deployments. Without the application of error coding schemes in a real life environment, much of the bits will need to be resent several times reducing spectral efficiency to an extremely low level. Spectral efficiency refers to the rate at which information is transmitted over a given bandwidth.

LTE technology is spectrally efficient hence gets more bits per second over a fixed bandwidth than previous technologies and as a result, if you take into account a reasonable error rate coding, you reach a peak data rate (Table 1b) that is more realistic for commercial deployment.

**LTE Average Sector Throughput**

While peak data rates show the theoretical throughputs, the most significant figure that defines the typical subscriber experience, and more importantly network capacity is the average sector throughput. This throughput estimates how much bandwidth can be delivered within a sector under real world conditions. The aggregate throughput can then be used to estimate how many concurrent subscribers can be served in the sector. This average sector throughput rate helps operators have a better understanding of their deployment costs and operating costs, allowing for better dimensioning exercise and network profitability.
As described in the above figure, LTE provides a significant improvement in Average Sector Throughput capacity across all channel bandwidths when compared to other 3GPP technologies. These capacity improvements are a key to achieving the efficiencies necessary to reach the mass market and reducing the cost per bit for the operator.

Comparing Average Sector Throughput across Different Technologies

HSPA+ Release 8 radio improvements use 64QAM and MIMO; it places emphasis on peak rate. The improvement provided by 64QAM, MIMO and dual cell HSDPA will increase data rate all the way to the edge of the cell under lightly loaded conditions. Under heavily congested conditions, Dual Cell HSDPA performance is comparable to a single HSDPA carrier, limiting sector throughput improvements to the region of 10-20% of the total cell coverage area, leading to dense urban cells/indoor cells.

HSPA, like other W-CDMA technologies, experiences cell shrinkage or “breathing” issues. Because all signals share a single carrier, an increase in the number of subscribers on the network causes the interference to increase, leading to a shorter range to deliver the same data rate, ultimately resulting in a decrease of the cell radius.

While both LTE and HSPA+ use 64QAM and MIMO, LTE does not suffer cell breathing issues. In HSPA, subscribers share the same carrier separated only by mathematical algorithm. LTE, on the other hand, uses Orthogonal Frequency-Division Multiplexing (OFDM), uniquely assigning each subscriber an individual sub-carrier and hence is not impacted by more subscribers coming onto the cell. Other performance features which have significant impact on subscriber experience across the complete cell and at the edge of cell in LTE include:

- Multiple antenna techniques to increase overall data rate.
- Better multi-path signal handling capability than CDMA technologies.
- No intra-cell interference, as the sub-carriers are for a single subscriber in a time slot.
- Enhanced Interference cancellation is better for reduced inter-cell interference.
- No cell shrinkage with demand vs. loading phenomena of CDMA technologies.
- Lowered and more efficient control overhead.
- Frequency selective scheduling for additional flexibility and efficiency.

Figure 6 shows how LTE out performs previous technologies, the conditions below are identical and are based on the same tower height, path loss and in building penetration loss.

 Subscriber Peak and Expected Average Rate

Expected subscriber data rate is very hard to predict and will depend on many factors typical of radio technologies (distance to cell, cell loading, subscriber speed, indoor, outdoor, macro layer, or hotspot). These challenges have made average sector throughput a better measurement of what rates the subscriber can expect to experience from a technology. NGNM also adopted this measure to compare next generation technologies as it offers a more realistic expected rate.

Based on simulation and trials, LTE is capable of providing a true broadband experience with multi-megabit data rate in most of the cell even on a macro layer, and be more effective in delivering wireless broadband to mass markets.

In an indoor environment or “hot spot” areas with dedicated coverage, via pico and femto cells, subscribers can expect to reach speed near to the maximum rates listed below.

As described in the above figure, LTE provides a significant improvement in Average Sector Throughput capacity across all channel bandwidths when compared to other 3GPP technologies. These capacity improvements are a key to achieving the efficiencies necessary to reach the mass market and reducing the cost per bit for the operator.
Browsing the internet, streaming video, online gaming, uploading content on social networking site, or downloading large e-mail attachments all require high bandwidths and low latency to deliver great subscriber experiences. Below is a description of some of the capabilities that the LTE standard delivers in support of these popular services.

**Idle to Active State**

The number of connection states is dependent on the number of network elements involved in the access network path. The more elements, the longer it takes to establish a session. Fewer elements leads to a to a better system performance and a reduced transition mechanism, hence allowing for better subscriber experience.

LTE introduces a flat all IP architecture that reduces the time it takes to access the radio and core network resources. Flat IP architecture enables a simpler network structure and a reduction in number of elements involved in the network. The LTE standards body agreed to reduce the connection states in LTE to two states from the previous four states in HSPA to take advantage of LTE's network architecture.

Today, bandwidth is a challenge and in previous systems, it was impossible to maintain a constant connection. Each subscriber’s connection would be severed and placed in idle state when there was no longer a data transmission for a defined time period. For example, a browsing subscriber’s connection would be shifted to idle state on an HSPA network while a subscriber read a completely loaded page; when the subscriber clicked to request a new link, the connection would be re-established, resulting in delays.

The transition times between HSPA idle state to active state (Cell-DCH) can be as much as 1000ms. In LTE this is not the case; the connection remains constant thus eliminating the delay to re-establish each time a subscriber makes a request. This results in a user experience close to wired broadband’s “always-on” service.

**Latency**

Latency is the interval between the time a service request is made by a subscriber and the time the subscriber receives a response from the system. Latency can either be measured as one-way or round trip; round trip is the common measurement as it covers the time from the initiation of a service request on the subscriber device through the network and back down the network until it displays a response on the subscriber device – for example, the time between when a request to load a webpage is made to when that webpage begins to load. In addition to increased data rates, the latency enhancements of LTE provide a significant improvement in the subscriber experience. A number of user surveys have identified service response time as a critical factor in the take up of an application. With HSPA networks, a subscriber can expect a two-second or longer delay to set up the first connection, and then between 75 and 150 ms roundtrip latency afterwards. With LTE’s all IP, flat architecture, the initial data packet connection is much faster, typically 50 ms, and then between 12-15 ms roundtrip latency afterwards. The low latency of LTE, combined with its high average sector throughput, makes it an ideal platform for demanding services like video, gaming, and VoIP.

LTE’s roundtrip latency compares favorably to the typical latency on today’s fixed line broadband infrastructure, delivering an instantaneous response after pressing buttons on the browser or media player. This will have a significant impact on subscriber experience and satisfaction. Latency also has a significant impact for online application such as multimedia online gaming, where the gamer’s response and reaction affect the action on the game. This reaction time is linked to the latency experienced on the network. (Assuming insignificant delay on the server side)

With improvement in both data rate and latency, it is expected that applications on LTE will provide a subscriber experience very similar to that experienced at home with the wired broadband network providing the true realization of a broadband services that goes anywhere with the subscriber.

### Table 2- Realistic average subscriber data rate

<table>
<thead>
<tr>
<th>Throughput Measurement</th>
<th>LTE (20MHz 2 X 2 MIMO)</th>
<th>LTE (10MHz 2 X 2 MIMO)</th>
<th>LTE (5MHz 2 x 2 MIMO)</th>
<th>HSPA R8 (64QAM + MIMO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realistic Median Mini-Maxi Sub Data Rate (kbps)</td>
<td>2000-12500 (kbps)</td>
<td>2000-7500 (kbps)</td>
<td>500-4000 (Kbps)</td>
<td>300-3000 (Kbps)</td>
</tr>
</tbody>
</table>
Quality of Service (QoS)

Quality of service (QoS) in networks is the ability of the network to enforce different priorities for different application types, subscribers, or data sessions, while guaranteeing a certain level of performance to a data session. GSM, UMTS, and HSPA network today offer limited end-to-end QoS on the network. Very limited QoS is supported on the RAN and transmission nodes. This is because in previous 3GPP networks QoS classification was not available. LTE changes the game – as an all IP network, it defines QoS to not only guarantee the quality of a service but also support different level services for other latency or bit-rate sensitive applications. LTE has adopted a class-based Quality of Service model which is simple and provides operators with an effective and simple way to differentiate between services and support subscribers with varying levels of service quality allowing operators the opportunity to support premium services and more innovative billing and pricing models.

As IP becomes the de facto mode of transport, some data packets will be more critical than others. The various QoS classes ensure the network can prioritize certain types of packet with QoS for immediate and secured delivery; this is an extremely important feature and one which has a major impact on the subscriber experience and on service delivery. From an operators perspective this higher level of QoS control offers a chance to provide differentiated type of services, with potential for offering creative billing while offering subscribers a guaranteed service for the services that may matter to them.

The class of QoS and Guaranteed Bit Rate (GBR) are significantly dependent on the level of latency (delays in packet transmission), jitter (variation in latency), and dropped packets experienced. Without a QoS implementation on a loaded network, subscribers will experience choppy videos, and echoes and delays in voice resulting in poor audio quality on voice calls.
LTE as a Foundation for Mass Market Video Services

The demand for mobile video is growing exponentially. It is critical that investments made today will support video in the future. LTE’s high capacity and ability to deliver true broadband will help operators cost effectively deliver any applications used today on fixed line broadband networks anywhere. LTE will not only be able to deliver more simultaneous video streams but will also increase the quality of the video with higher resolution and better encoding to provide a more pleasurable video experience on any devices. Real-time online gaming, popular on the home PC today, will be a reality anywhere thanks to the low latency inherent in LTE. Subscribers with LTE will be able to keep all devices continually (and effortlessly) synchronized. So, for example, snapshots taken on an LTE enabled digital camera or mobile phone can automatically be synchronized with and backed up on a home computer and made available to view through an IPTV set top box.

The flat IP network architecture similar to the internet architecture drives lower cost application delivery and enables hand over between all IP access technologies. LTE will support unicast and multicast IP data flows for the delivery of high quality video and operators with already providing IPTV will be able to leverage video headend to deliver the same high quality video content to their LTE subscribers.
Conclusion

Mobile wireless broadband is more than just peak data rates. LTE technology combines innovations in its architectures and air interface to deliver fixed-like broadband experiences to customers on the go. LTE also offers operators a way of delivering services with end-to-end quality of service at the lowest possible CAPEX and OPEX costs when compared to currently available technologies.

Peak marketing has lead to a misaligned comparison of many wireless broadband technologies, leaving operators and subscribers confused about the actual performance of existing and future wireless broadband technologies. As seen in this paper, the true performance of wireless broadband network is reflected in more than just the Peak data rate number. In effect, this theoretical peak rate figure fails to give a fair picture of what users are likely to experience when using the technology in a real life situation.

Operators are aware that the growth in data are in double digits percentage growth and need to understand what factors in a wireless broadband technology will help them reduce the cost of delivering the ever increasing bits to its subscribers. Cell edge performance and cell site shrinkage are factors which will affect the number of sites operators deploy and how cost effective they can support a mass market broadband service.

Sector throughput offers the most realistic measure of real life network capacity and likely subscriber experience, hence giving operators a more accurate basis for business modeling and TCO but also a realistic performance for marketing LTE service to their end users. The quality of subscriber experience is a factor of data rate but also directly impacted by connection time and latency; for that reason LTE is the first technology that will provide subscriber with a true mobile broadband experience similar to wireless broadband services.

LTE is clearly positioned to address the challenges of next generation networks and with increased commitment from both vendors and operators, LTE commercial networks will be available in the next 12 months. LTE offers a true cost effective network that can offer the operators the ability to provide a wide range of services and delivering next generation performances.

Motorola has aligned its business units and roadmaps to provide a comprehensive, end-to-end solution covering all aspects of the LTE broadband wireless access deployment. With our leading contribution to the LTE standard, over a decade of R&D investment in OFDM and all IP wireless broadband solutions, and our industry leading commercial experience of wireless broadband OFDM access solutions, Motorola is primed to deliver best-of-breed LTE solutions.

Motorola has tremendous OFDM simulation and planning expertise following global deployments of commercial OFDM networks. Our state of the art simulation capabilities and LTE tools are demonstrating our leadership in the field with LTE trials performance results that most accurately match our simulation results.

Motorola is an industry leader in providing a robust suite of integrated network services including design, planning, installation, optimization, management, and support services. Our more than 8,500 professionals and next generation tools will ensure optimum and right 1st time network designs that are properly dimensioned to achieve KPI and eliminate LTE deployment risks.

Our experts are always available to help operators understand the true capabilities of their networks and potential networks. For more information on Motorola’s industry-leading wireless broadband and WiMAX capabilities, visit www.motorola.com/lte or contact your Motorola representative.