WHITE PAPER

Opportunity and impact of video on LTE Networks

Introduction

The world is becoming increasingly mobile, which is driving the demand for easier access to content and services from any location, with any device, at any time. The explosion of video and multimedia content that is available on the wired web has driven users to desire equivalent on-demand access to that content from a mobile device. Second and third generation public wireless technologies (2G & 3G) have not been able to support this need economically across a wide geographic area or with an acceptable user-experience. On the other hand, the new fourth generation (4G) wireless technologies such as Long Term Evolution (LTE) offer sufficient performance to support IP based streaming video and multimedia services to a large number of consumers simultaneously, with a quality that most will find attractive. LTE technology allows for significantly higher capacity at a lower cost per bit, leading to improved commercial viability of video services.

The Internet and wireline world is enabling a rapid convergence of IP video, audio, and data into completely new applications, while broadband wireless networks promise to provide access to these anytime, anywhere. Motorola is helping to bring these worlds together by providing a suite of solutions that leverage our leadership in video for wireline networks, coupled with our leadership in wireless broadband networks.

This paper begins with an overview of current wireless technologies and notable consumer trends that are relevant to video. Some background is given on the demands that transport of video content places on a network. Then the paper discusses a number of key technology factors that are advancing to allow LTE wireless networks to meet the needs of those consumer trends. The evolution of these technology factors are really allowing a revolution in new types of multimedia services that can be offered over wireless networks, which are personalized, predictive, and mobility aware. The paper concludes with some example network deployment alternatives for operators to consider and a discussion of the relative benefits they provide.

Current Wireless Technologies

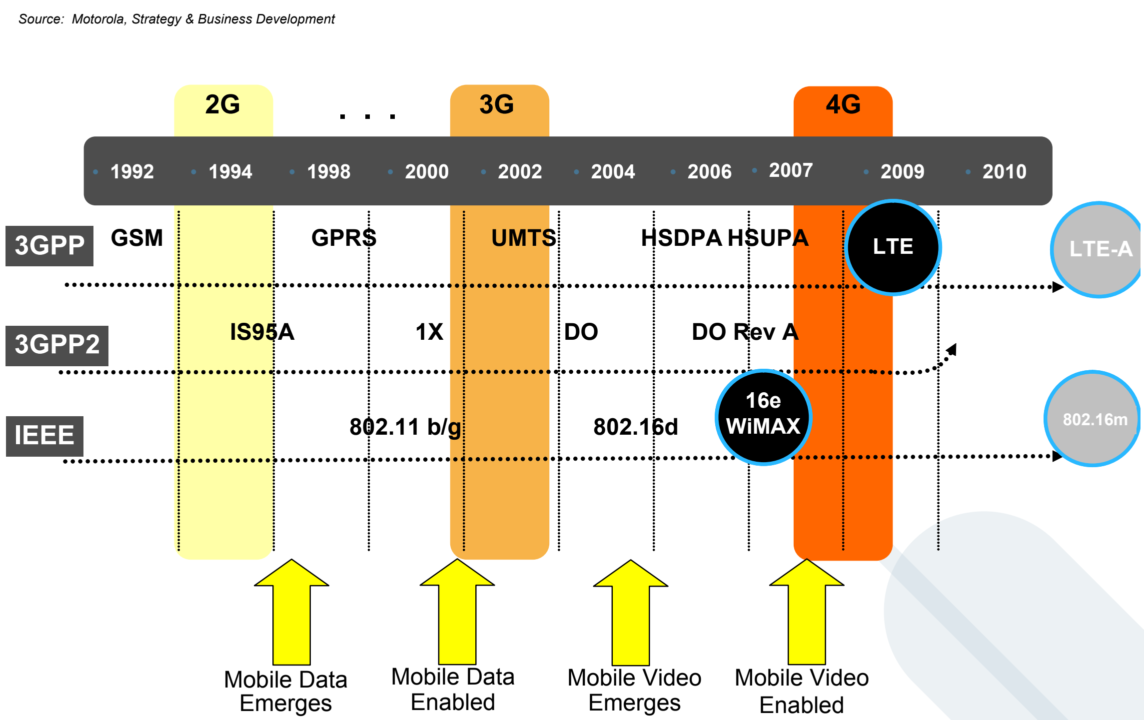

Figure 1. Evolution of the commercial wireless broadband standards

Figure 1 summarizes the evolution of commercial wireless broadband standards. The yellow arrows at the bottom highlight points in time where wireless data and video services first emerged, and when they enabled commercially viable service. With 2.5G technologies, such as GSM GPRS and CDMA 1xRTT, basic data services like email and web browsing were offered commercially and were somewhat successful. Simple video services were attempted on these technologies as well, with attention focused on video telephony and multimedia messaging. Technical feasibility was demonstrated, but undoubtedly the three most significant reasons for their commercial failure were high cost of data delivery, low bit rate performance, and limited mobile device functionality. The introduction of 3G and 3G+ technologies, UMTS, HSPA and EV-DO/A, during the middle of the current decade enabled a marked increase in wireless data capabilities, with typical data rates on the order of 0.5 to 1 Mbps achievable for HSPA and EV-DO. However, while these 3G technologies provide a dramatic decrease in the cost of delivering data services, they are still capacity limited and not able to economically support the huge mobile video demand that is emerging.

LTE and WiMAX are popularly called "4G" technologies, but they are actually considered 3.9G as strictly defined by the ITU. For simplicity this paper uses "LTE" and "4G" synonymously.

Key Consumer Trends for Video

Personalization or "Prime time to my time".

One clear world-wide trend is a shift from viewing linear broadcast TV to watching programming at a more convenient time, in other words shifting from "Prime Time" to "My Time" giving consumers more flexibility in when, what, and where they view content.

The bar graphs below in Figure 2 demonstrate the exponential growth of consumer demand for on-demand viewing. While the data shown is for Cable networks, this consumer trend is relevant to 4G LTE because it implies consumers will desire most wireless video content to be unicast to them upon request, with a corresponding lower demand for linear broadcast programming.

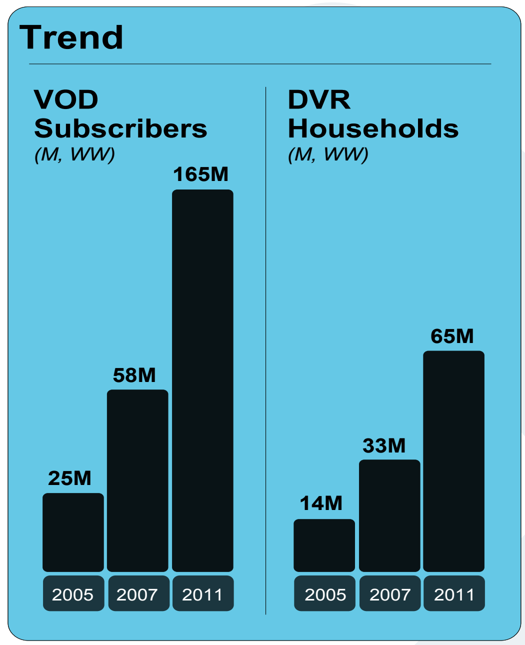

Figure 2. Shift from Prime Time to "My Time"

Explosion of content available.

More and more content is being made available for on-demand streaming. Additionally, there has been a large increase in the amount of user generated content. This includes TV network programming, movies [1], and services/sites like YouTube. YouTube alone represents 27% of the internet traffic with the average YouTube user streaming 50 videos per month. As of 2006, YouTube in the US alone consumed more traffic than the entire World Wide Web in 2000. Traditionally, services that appear in wireline networks (i.e. the Internet) tend to make their way to wireless, however the user experience is initially severely limited by the inherent nature of the wireless access. Access to this content in the Internet is enabled by its all-digital format, and its uniform transport over a data network. This directly leads to the desire to use a broadband wireless network, such as LTE, for doing the same thing anywhere.

By 2011, it is anticipated that the average mobile broadband subscriber will consume 1 - 5GB per month, with particular market segments using even more (i.e. Road Warriors may use 5GB, Urban Professionals 6GB, and College Students may use upwards of 10GB.)[2] These estimates include typical combinations of streaming video, emails, IM, web browsing, social networking, etc. Based on the growth of Internet traffic and mobile savvy users, combined with advanced devices, even this prediction could be pessimistic.

Emerging social features.

Beyond simply watching streaming programming, video will be used more and more as a means for enhancing social interactions and social networking. People have an increasing desire to easily create and share their experiences using video, either by itself or combined with other relevant supporting information. This will continue to drive up mobile network bandwidth needs, and in particular is likely to drive the uplink/downlink traffic towards a more symmetric mix. Fortunately, LTE is better suited at providing a more symmetric traffic mix than are existing wireless technologies. Some examples of these types of features are mobile video blogging and see-what-I-see, where users quickly create and share video related to their current activities. Peer-to-peer sharing of content will find many more legal applications, and will also drive traffic and up/down symmetry.

These consumer demands have been emerging in parallel with a number of important technology advancements over the past few years. Motorola has been a key participant in these technologies, with leadership in both video delivery and wireless networking solutions. The union of these two technology domains is what is creating the foundation for consumers to access web and operator provided content from anywhere at anytime.

Key Factors Converging

Figure 3 shows the key factors that are converging to meet those wireless video and multimedia consumer demands. The primary positive impacts of these factors have been continual improvement in quality of experience and reduction in cost of content delivery. As noted earlier, the current state of these is allowing significantly improved business viability of video services over broadband LTE, as compared to previous wireless technologies. Further, these improvements are projected to continue in the coming years.

The factors are grouped into four quadrants and include:

- Video Technology: Enhancements and Compression capabilities
- Air-Interface Improvements : LTE new and more efficient use of spectrum, improved capacity and higher bit rates
- Device Technology
- Network Architecture: Improved flexibility in Network Architecture and decreased costs.

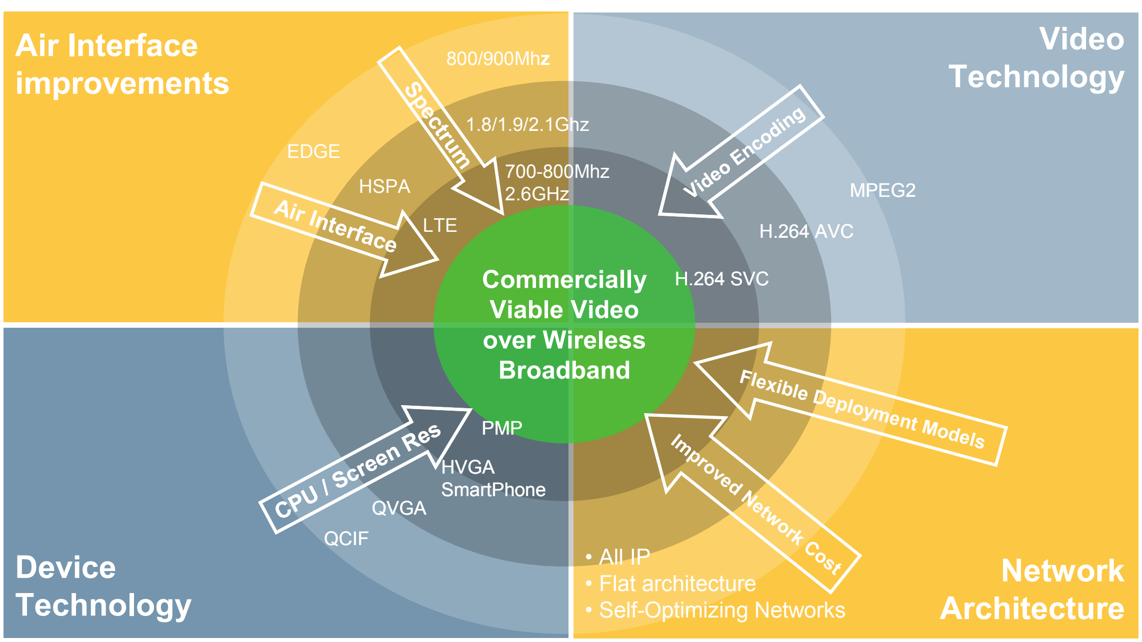

Figure 3. Convergence of Technologies for Improved Video Experience

The Video Encoding Technology quadrant describes the continuous improvement in efficiency of video encoding techniques as occurred over the past decade, from MPEG2 through MPEG4 Scalable Video Codec (SVC). It is envisioned that this trend will continue in the years to come, further decreasing the bandwidth requirement for video content. The Wireless Air Interface quadrant describes technology drivers that are evolving to support a "fatter bit-pipe", and additional QoS levels/control. The Device Technology quadrant represents technology drivers that make end user devices more capable for video based services. Devices continually incorporate more capable CPUs, larger memory sizes, and larger displays with higher resolution. The Network Architecture quadrant describes the trend toward lower costs per delivered bit, as a result of the flattening of current architectures and their migration to all IP.

In addition to the technology trends shown above, there are opposing trends that will require more rather than less bandwidth. These include user generated content, higher resolution Internet content, and new services (social networking, Peer-2-Peer, Media Mobility, etc.)

The remainder of this paper explores each of these factors in more detail.

Video Technology

Before discussing the capacity and bit rate capabilities of LTE, it's useful to have an understanding of the demands that video places on a wireless data network. As shown in "Today's Screen Resolution" column in Table 1, smartphones such as Motorola's Q support resolutions like QVGA and CIF, and make viewing video clips practical. Still larger handheld devices like the Apple iPhone, Motorola's DH02, and other Personal Media Players (PMP) support HVGA resolution, and in the LTE timeframe are moving to VGA. Higher resolutions, such as SD and HD which are used in the home may be less feasible on wireless, even on 4G, due to the much higher bit rates required.

Device type	Screen Size	Today's Screen Resolution		Typical Viewing Distance	Human Eye max dpi at Distance	Required Resolution for "HQ video"	Typical MPEG4 BitRate
Smartphones	2.5-3"	QVGA	320*240	Handheld 30-50cm	200	QVGA	192 to 500Kbps
Multimedia phones	3-3.5"	HVGA	480*320	Handheld 30-50cm	200	HVGA	500K to 1 Mbps
PMP	4-7"	WVGA	800*480	Handheld 30cm Table 80cm	120	VGA	800Kbps to 1.5
Ultra Mobile PC	7-9"	WVGA WSVGA	800*480 1024*600	Handheld 30cm Table 80cm	120	SD480/576i	1 to 2Mbps
Laptops	12-17"	WXVGA WUXGA	1280*800 1920x1200	Lap/Table 50-80cm	80	HD720i	3 to 4 Mbps
Small HD TV	<32"	HD720	HD720	2-3m	50	HD720p	6 - 8 Mbps
Large HD TV Projectors	>32"	HD1080	HD1080	3m +	30	HD1080p	12 - 16 Mbps

Table 1: Required Resolution for "HQ Video"

Device form factors and user interfaces have evolved to a point that it makes Internet access usable & video watching comfortable. The perceived quality of the video stream is dependent on a number of factors, such as the encoding technology used and its associated efficiency, the number of frames per second, the amount of scene dynamics in the content, buffer size and how they handle underflow. When running video over access technologies that have limited capacity, particularly wireless, the bit rates chosen for encoding the video streams is critical. In fact, encoding quality is often more important than the pure resolution. For example, given the same screen size, a QVGA encoder that is set to run at 500 Kbps will often produce higher perceived quality picture, at a better frame rate, than an SD encoder that is set to also run at 500 Kbps.

Another factor which affects the "perceived quality" of the video is the distance from the display to the viewer, represented in the "Human Eye Max DPI at distance" [3] column above in Table 1. The term "HQ video" used within this paper refers to the end users viewing experience, and is subjective. In essence, when the user views the content, there is a perceived quality that is affected by a number of variables including the screen resolution and the "screen to eyeball" distance. Users will typically hold a handheld device with smaller screens closer to their eyes. As an example from the table above, a Smartphone user holding his device 12 inches from his eye will experience video quality comparable to that of viewing the same content on a large screen HD TV in his home at a distance of 3m or ~10 feet. The goal is to provide a High Quality video viewing experience without consuming the bandwidth needed to send content at true Full-HD resolution. In effect, depending on screen size and distance from the screen, we can see that it is not necessary to send HD resolution to experience a quality close to HD. This concept is very advantageous to the LTE operator because it allows the HD content to be conveyed to smaller screen devices using a resolution that is less than HD, and therefore a lesser number of bits, while still allowing the user to experience a perceived High Quality video that is close to a HD experience watched at a normal viewing distance. What is also important to note is that based on the Human eye DPI capability, most screens today are already providing a dpi compatible for providing a "HQ video" experience for video streaming.

The "Typical MPEG4 Bitrate" column of Table 1 illustrates typical bandwidth demands for video services at those various screen resolutions assuming the latest generation of MPEG4 (H.264 Advanced Video Codec (AVC)) compression technology. The ranges are due to variability in scene content and motion, as well as some amount of provider adjustable quality. These rates include typical IP overhead, but do not include audio (which, depending on audio encoding, may add a few 10's of Kbps).

History has shown that technological evolution typically results in ~10% - 20% annual improvement in encoder efficiency, with the efficiency doubling every 6 – 8 years as a result of technological breakthroughs. These improvements enable more efficient use of the spectrum and therefore allow more video channels to be supported. Figure 4 below shows the efficiency progression of video compression technology over time. It is anticipated that further improvements to H.264 efficiency may soon reach a practical limit, and a new video encoding technology (hypothetically called H.265) will become available in the next few years. This would support the goal for LTE to support at least some SD video in the not distant future.

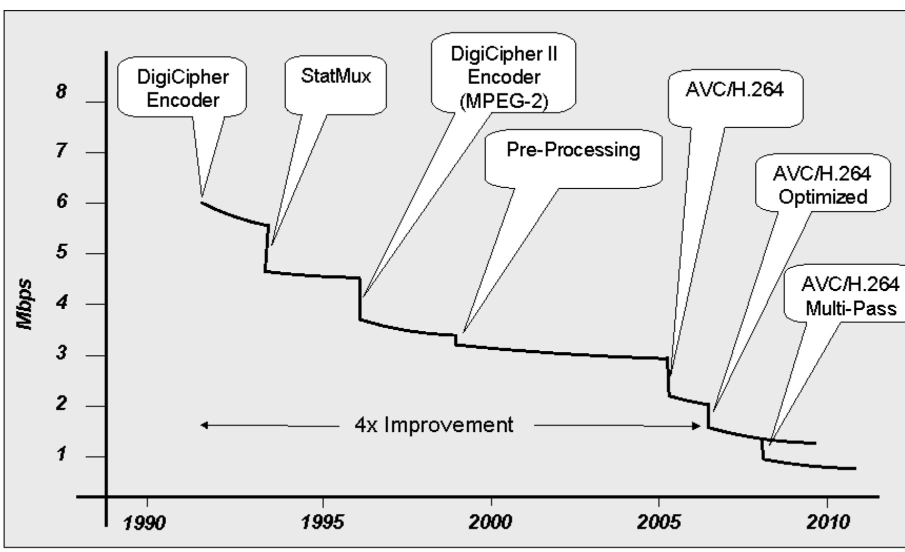

Figure 4: Encoder Technology Evolution

LTE may also be deployed using a Time Division Duplex mode, which supports various uplink/downlink ratios

5/6 error coding means one additional bit of error correction is added for every 5 bits of data. This is a typical example for illustration purposes, and is assumed to be independent of error coding on the air interface.

Our capacity estimates assume Next Generation Mobile Network (NGMN) Case 3 characteristics for the LTE wireless link. For more information on NGMN Case 3 see [4].

Air-Interface Improvements

Key technology developments in 4G networks are enabling wireless data rates to follow the same growth trend as wireline, while lagging wireline by approximately 5 years. The LTE standards and the technology allow LTE to be deployed in 1.4+1.4 all the way to 20+20 MHz channels , depending on the allocated spectrum to meet the desired mix of services. The sector throughput for each of these channel widths is a function of the attributes of the base site and the device, i.e. transmit power, antenna configuration and the environment (urban/rural).

4G wireless technologies are able to achieve higher spectral efficiency than was possible with 2G and 3G through the use of advanced transmitter and receiver designs, multi-antenna arrays, smart packet scheduling methods, and adaptive coding and modulation techniques. While earlier technologies possessed some of these methods they were not able to utilize them all in concert over a wider spectrum allocation to achieve the high data rates of LTE. The spectral efficiency of the proposed LTE-Advanced (LTE-A) standards is further improved with the use of adaptive antenna (up to 8 antennae), coordinated multipoint transmission and reception (COMP), ability to do channel-banding and inter-cell interference coordination (ICIC).

Table 2 shows the projected number of unicast video streams that can be supported per-sector at various MPEG4 data rates, which are dependent on screen resolution. This table assumes a 5/6 error coding is used on the video payload, and the total available bandwidth is being used exclusively for video . The "At Peak Data Rate" column shows the maximum possible number of video streams for a given screen resolution, while the "With Average Sector Throughput" column shows the more typical real-world expectation for the number of video streams that can be supported on the macro layer. Note that not all users in a sector will receive the same level of performance, since the air-interface delivered bit rate may vary from cell center to cell edge. The far right column summarizes that LTE is capable of supporting video at QVGA to SD resolution with full mobility using macro cells to a relatively large number of streams per sector. Support of HD720i is possible and economically viable for laptops in nomadic conditions in environments covered by LTE Pico/Micro cells and LTE-A focused improvements on nomadic performance will allow for more simultaneous HD720i channels per sector.

Referring back to Table 1, LTE at launch should be able to support "HQ video" streaming anywhere and on all LTE mobile devices, LTE enabled consumer electronics & laptops. In addition, the enhancements to the LTE air interface result in improved latency, an important parameter in the delivery of time-sensitive content like real-time streaming of video.

Device type	Screen Size	"HQ Video" Resolution	MPEG4 Datarate	Mobility	No of simulatneous video streams in 20MHz LTE Macro sector		LTE Capable
					Peak Datarate (5/6 error rate coding)	Sector Throughput (NGMN Case 3)	
Smartphones	2.5-3"	QVGA	240kbps	Full	507	116	Yes
Multimedia phones	3-3.5"	HVGA	750kbps	Full	163	38	Yes
PMP	4-7"	VGA	900kbps	Full	136	31	Yes
Ultra Mobile PC	7-9"	SD	1.5Mbps	Full	82	19	Yes
Laptops	12-17"	HD720i	3.5Mbps	Nomadic	35	8	Yes*
SD TV	<32"	SD	1.5Mbps	Fixed	82	19	Yes
Small HD TV	<32"	HD720p	7Mbps	Fixed	18	4	No
Large HD TV Projectors	>32"	HD1080p	14Mbps	Fixed	9	2	No

Table 2: Number of Video Streams Per Sector

Given the extrapolation of encoding efficiency improvements of 2X every 6-8 years as noted above, it is feasible to expect to support twice the number of devices at the same resolutions, or potentially the same number of devices at an improved resolution as well. Similarly, the number of supported streams can increase based on antenna gain and antenna location (i.e. antenna within mobile device, indoor CPE with indoor antenna, or CPE with outdoor antenna). Furthermore, with the advent of LTE-A, the number of supported streams would increase as well.

Multicast/Broadcast on LTE

\Use of unicast transmission for video allows for individualized streams to be sent to each user, as is required by video on demand, or any per-user access to media on the web for that matter. However, as noted above, video streams can be bandwidth intensive depending on the resolution. In an effort to alleviate the bandwidth impacts of unicast for at least some types of content, 3GPP is in the process of defining the Multicast Broadcast Multimedia Service (MBMS) for LTE. In principle, MBMS provides facilities in the network that define sets of base stations over which a given service (such as video or text streams) should be broadcast. There are provisions to control when a particular service is broadcast, including facilities to dynamically enable broadcast based upon user demand in a particular location.

The advantage of using broadcast transmission for video is that the same stream can be received over the air by as many users as can be supported in the sector. The contribution to bandwidth in this case is the number of simultaneous streams or "TV channels" that the operator wishes to broadcast in the sector, regardless of the number of users receiving them. The disadvantage of broadcast is that content must be pre-scheduled, so users are limited to viewing what the operator decides to broadcast.

Some types of content and services seem well suited to Broadcast/Multicast such as broadcast linear TV, group communications, and support of regulatory services like emergency alerts. However, given that consumers are switching from "prime time" (i.e. broadcast) to "my time" (i.e. video on demand), there is considerable question in the industry if the business case for broadcast video over LTE makes economic sense. This is a contributing factor to why specification of Multicast/Broadcast (MBMS) capability for LTE has been recently lowered in priority in the 3GPP standards groups.

Dedicated broadcast video systems such as DVB-H / DVB-SH and STIMI may be more economically suited to transmission of linear TV. Since LTE supports a mix of unicast and broadcast in the same sector, there is likely an opportunity to use its broadcast mode for specific purposes, such as free broadcast of advertisements and "teasers" for available VOD content, while primary revenue is derived from providing the unicast VOD itself.

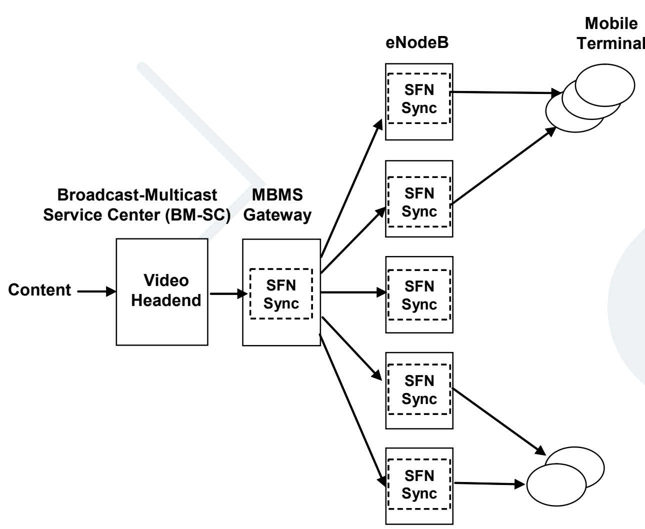

Figure 5: LTE Multicast Broadcast Multimedia Service (MBMS), with optional Single Frequency Network functionality

MBSFN (Multicast Broadcast Single Frequency Network) further optimizes the broadcast mode by bit-synchronizing transmission across multiple base stations so that media can be transmitted simultaneously, or 'simulcasted', by each station, as shown in Figure 5. This provides a much improved RF environment and corresponding signal/noise ratio by allowing the mobile terminal to combine reinforcing signals from multiple adjacent base stations.

Device Technology

The potential for new and expanded video services is also being impacted dramatically by technological advances in mobile devices. Processors used in mobile devices are following the same performance improvement curve as predicted by Moore's law, albeit occurring a few years later than desktop CPUs . Advances in materials and Micro Electro-Mechanical Systems (MEMS) technology are spawning a new generation of miniature advanced antenna systems that enable devices to fully exploit the capabilities of LTE. MEMS is also a key to new designs that leverage the DLP™ technology to provide high-quality, higher resolution reflective-light displays that are well suited for mobile applications. These new displays promise to provide improved visibility in high ambient light environments with extremely low power consumption, addressing two of the most serious challenges to supporting video applications in a truly mobile environment. 12 GB flash memory cards will be available for mobile devices this year. One card has enough storage to hold 1500 songs, 3600 photos and over 24 hours of video at the same time . By early 2009, wireless devices are expected to have built-in projectors. These devices have the potential to eliminate the most frequently cited inhibitor to video on mobile devices – their small screen. Finally, advances in lenses, flash lighting, memory cards, and other technologies are driving the need for bandwidth on the uplink as well as the downlink.

Network Architecture

The LTE network architecture was specifically created to support packet data services and is optimized for those services. In contrast, the 3G UMTS network has both a data architecture and a legacy circuit architecture. Since legacy circuit and packet data are dramatically different concepts, this combination architecture gives rise to complex, domain-specific components that limit network performance and drive up infrastructure costs. In contrast, the LTE architecture is flatter than the UMTS data architecture (i.e. more distributed, with fewer layers of system elements). In LTE there are two levels of components in the bearer path between the eNodeB and the application core network, while in UMTS there are three. The flatter architecture aids in simplifying network operations, as there are fewer different types of components to be managed.

Motorola has developed comprehensive cost modeling tools for LTE networks. These tools are being used to run a detailed analysis of deployment costs and total cost of ownership from initial system installation, through normal growth phases, and into system maturity. Variables such as the expected number of mobile or fixed CPE users, traffic expectations, spectrum, geography, backhaul type, and so on, are factored into the model. The expected average revenue per user can also be input. Each of these variables can be adjusted independently, allowing great flexibility for Motorola to assist an operator in testing various business scenarios.

As is becoming true in the Internet, transport of video content will likely become the single largest component of bandwidth used in an LTE network. Motorola has used these detailed models to explore the cost sensitivity of adding varying amounts of video traffic to an LTE network. Figure 6 shows an example of sensitivity to initial baseline LTE infrastructure deployment costs when supporting a handheld video load of between 1 minute and 60 minutes per user per busy hour . This hypothetical example assumed that

The Motorola Q9M smartphone, which contains a dual core ARM processor, has the equivalent processing power of a desktop PC circa 2003.

Approximation based on 4 minute songs using 128 kbps MP3, pictures taken with 2Mpixel camera and MPEG-4 video at 384 kbps. Pictures and video assume typical compression and resolution.

the network is sized to cover a city and surrounding area of about 3.5 million people, with a typical mobile broadband data user density. This analysis assumes the system is already supporting background data traffic of 1Mbps per user at a 30x oversubscription rate (i.e. 1 out of 30 users has an active data session). The video traffic is in addition to this data traffic.

In Figure 6, the oversubscription rate is shown on the x-axis, while the normalized deployment cost is shown on the y-axis. Note the infrastructure deployment cost is 'Year 1' CAPEX, and includes items such as base station equipment, site acquisition, IP core equipment, and backhaul. Results show that the infrastructure deployment cost is primarily driven by network geography, with minimal sensitivity to video traffic. Depending on the particular combination of market penetration rate (i.e. number of subscribers) and their additional video traffic load, costs are increased up to about 4% over the baseline 'no video' case at each market penetration level. For example, examination of the 8% penetration case (i.e. this operator serves 280,000 of total available market of 3.5 million subscribers), shows a jump in deployment cost of about 4% occurring at a video load of 30 minutes used during the busy hour. This is highlighted by the red circle on the figure. A relatively heavy oversubscription of 5x for video users is modeled here, which corresponds to 20% of this operator's 280,000 users, i.e. 56,000, streaming video at any given time. At this point, the operator's network becomes capacity limited, forcing additional sites to be deployed (site splitting) to support the increased traffic load due to video.

As shown by this example, cost sensitivity becomes most significant at each market penetration level only when the heaviest video usage of a full 30 to 60 minutes per user per busy hour is demanded. While every deployment scenario is different and has specifics that should be carefully analyzed, we conclude from this illustration that a typical handheld video load is absorbable by the LTE network, unlike what is being experienced today in many 2G and 3G networks.

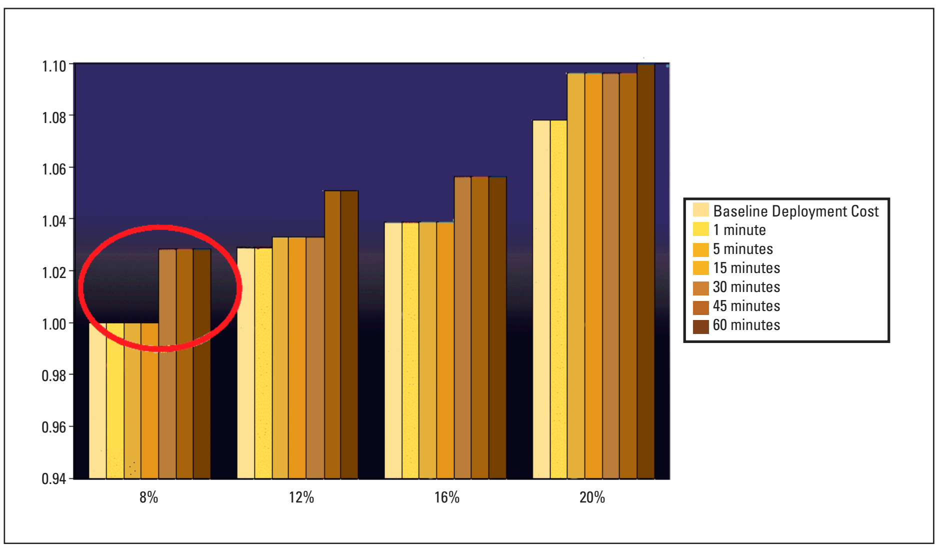

Figure 6: Deployment Cost and increase due to various amounts of video traffic

This example assumes an LTE network base of about 494 1:3:1 sites, 2.5 GHz band, 20/20 MHz uplink/downlink, 80% users in 50% (high capacity) sites; 50% in coverage limited sites. The baseline data model assumes 1Mbps /downlink, with a 30x oversubscription rate. Video model assumes handheld, unicast only, QVGA, H.264, about 240 Kbps/stream, with a 5x oversubscription rate for video.

Figure 7 shows the impact to the operator's Total Cost of Ownership (TCO) of adding video traffic. TCO includes the whole lifecycle of all the equipment costs, plus additional operational expenses such as recurring site rental and utilities, network and software maintenance, customer support, mobile device acquisition and subsidies, marketing, and so on. It's often useful to compare scenarios of TCO over a 10 year period, but examine them as a net-present value that is adjusted to today's values, in order to get an idea of the total multi-year costs. A typical market penetration is 16%, which translates to 560,000 subscribers of the total market of 3.5 M as used in this example. This figure compares the impact on TCO at that penetration due to video usage by a number of simultaneous video users ranging from 18,480 (i.e. 3.3% of the total user population of 560,000), to 112,000 (20%), as they increase their video usage from 1 to 60 minutes in a given hour. This increase corresponds to video usage of from about 0.27 GB/month to over 16 GB/month for a particular user. When this is averaged over the population of 560,000 subscribers and added to the baseline data that they are already doing, this is roughly equivalent to about a 130% increase in data traffic for the 3.3% simultaneous video subscribers case, or about 260% for the 20% simultaneous video subscribers case. The orange line on the graph is a useful guide to the total amount of traffic (in GB) expressed as an average per user. That line is showing the amount of traffic consumed by every subscriber (on average) for the 20% simultaneous usage case.

In this system example, the analysis shows that for the 3.3% of the 560K subscribers case, when their video usage increases from 1 to 60 minutes in a given hour (increasing overall average traffic by about 130%), TCO increases approximately 4%. Whereas, for the 20% case (which increases overall average traffic by about 260%), TCO increases approximately 29%. When compared to the increasing GB per user per month, this data indicate that the increase in TCO due to supporting video traffic on this example system correlates well with increased traffic demand. Summarizing, LTE provides good initial capacity for video and scales well with increased traffic, even with fairly heavy mobile video usage. Again, the higher levels of simultaneous usage (caused by either increased load per user and/or increased number of users), cause the system to become capacity limited and site splitting is required to add sites.

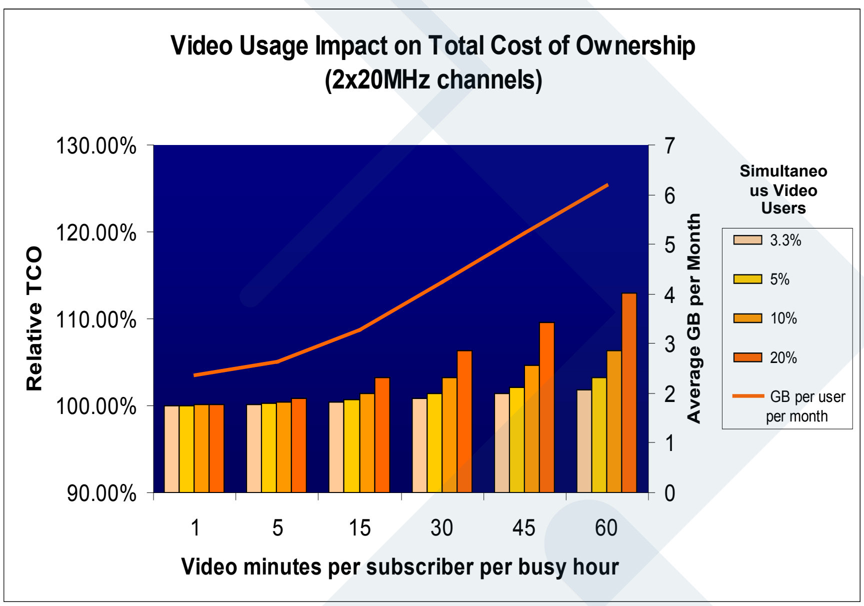

Figure 7: Total Cost of Ownership and increase due to various amounts of video traffic

For this illustration: a population density of 1000/km2 is assumed with a 15% subscriber penetration rate. The spectrum usage is normalized across the technologies.

LTE provides a substantial improvement in network price performance, especially as the amount of data consumption increases per device . A heavy mobile video user who averages an hour of QVGA resolution viewing per day would consume on the order of 4 Gbytes per month of data service. Examination of Figure 8 at the low population density side on the right indicates that it could cost 2 to 4 times as much to operate an HSPA or EVDO network when providing this level of per user capacity, as it would to operate an equivalent LTE network. At higher population densities, the improvement in network price performance becomes more pronounced at even lower per month usage rates.

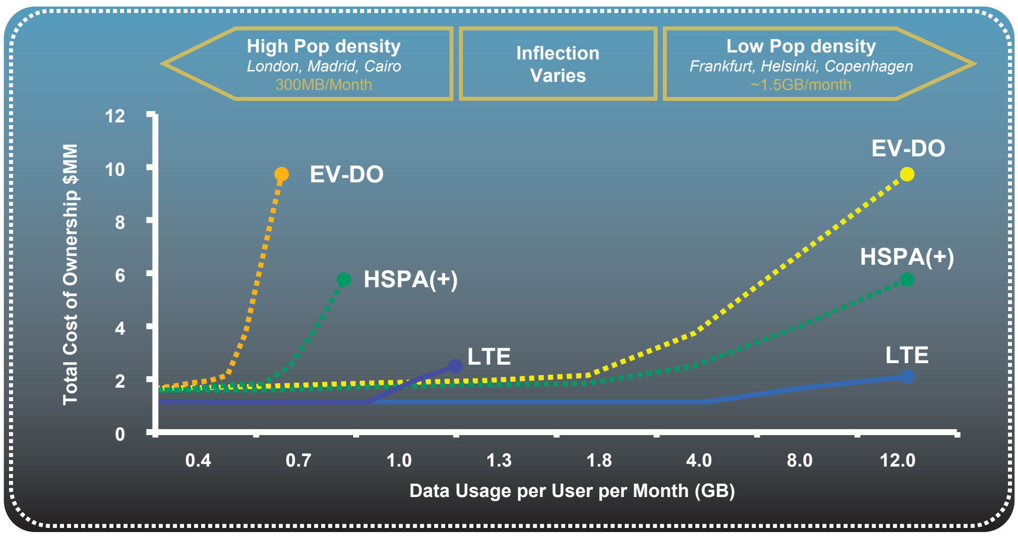

Figure 8: Relative Total Cost of Ownership for Broadband Data Delivery

Video & Applications Deployment

For a network operator to maximize revenue and profitability, it's desirable to participate in every way possible in the business of delivery of content and applications. There are several business models (i.e. network deployment models) the wireless operator may consider for video delivery, each requiring a varying degree of capital and operational investment vs. potential revenue generation capacity. Three of these scenarios are described here.

Model 1 – Operator owns the video headend

This model applies to incumbent operators that already own video ingestion, storage, and delivery equipment (such as wireline operators expanding into the wireless arena), and those operators that desire to offer video services to other access network providers. Though this model requires the highest capital and operational investment (CAPEX and OPEX) it offers the operator maximum flexibility, allowing complete control over the content offered, its aggregation and distribution. The key functionality offered by this model is:

- Management of the content offered from ingestion to delivery
- Flexibility of bundling offered content (video, music, etc.) and services (voice, video, data)
- Operator controlled content aggregation and distribution including aggregation of "over-the-top" content, offering a consistent look and feel for all content
- Present a unified portal to the users for selection, viewing and purchase of all content and services
- Augment content with operator-specific value added services to the user such as advanced search capabilities, location based content, application development portal/SDK, etc.
- Operator Control of advertising schemas such as user-specific/targeted advertising, location based advertising, context-sensitive advertising, portal-based advertising, etc.
- Operator control of a content stream delivery to a device or a specific user of the device to provide an optimized content experience based on preferences (operator, user, service, etc.)
- Policy enforcement (i.e. control rate and quality of the content streams)
- Operator leverages revenue opportunities from offered content, advertisements, value-added services, licensing of applications, development-kits, etc.

This model is depicted in Figure 9.

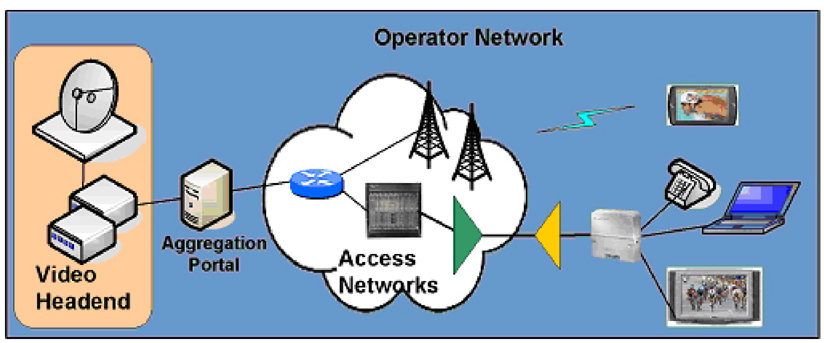

Figure 9: Model 1 - Operator Owns Video Headend Assets

Model 2 – Operator leases content aggregation services

The second model assumes the operator "leases" the content aggregation service from a content aggregation wholesaler (a video Mobile Virtual Network Operator (MVNO)). This model applies to operators who own the wireless Access Network, but have no desire to deploy and manage the video headend. While this model has a lower CAPEX and OPEX, the operator is dependent on a wholesaler for content aggregation. The key functionality offered by this model is:

- Partial control over the content offered, in concert with the video MVNO
- Limited flexibility of bundling offered content (video, music, etc.) and services (voice, video, data)
- Video MVNO controlled content aggregation, including aggregation of the "over-the-top" content
- Operator delivery of all content to end-users
- Video MVNO provides an operator branded unified portal to the users for selection, viewing and purchase of all content
- Value-added services per the video MVNO offering such as advanced search capabilities, etc.
- Video MVNO control of advertising schemas such as user-specific/targeted advertising, location based advertising, context-sensitive advertising, portal-based advertising, etc. with limited operator control of local advertising
- Video MVNO control of a content stream to a device or a specific user of the device to provide an optimized content experience,
- Operator control of policy enforcement (i.e. control rate and quality of the content streams).
- Operator leverages revenue opportunities from service subscription, and shared revenue for services and applications deployed in partnership with the video MVNO

This is depicted in Figure 10.

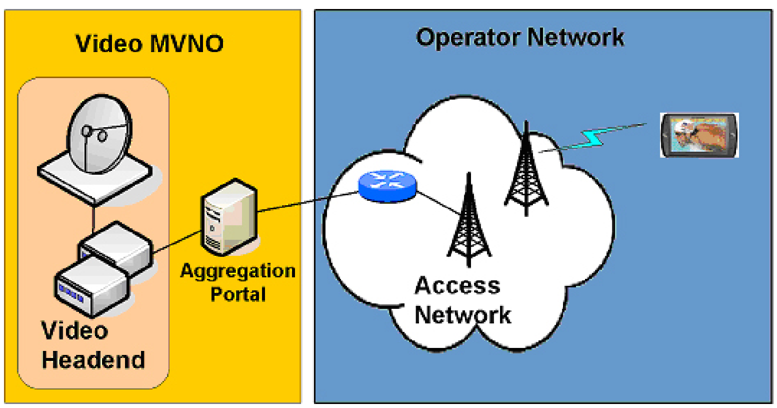

Figure 10: Deployment Model 2 - Operator Leases Video Headend Services

Model 3 – Operator owns the content aggregation and portal

In the third model, the operator provides a content aggregation function that consolidates only "over-the-top" content from numerous Internet sources together (such as YouTube, Hulu, BBC.com, etc.), and provides a unified look and feel to the user regardless of the source. Users interact with the aggregation function in the operators' infrastructure to access this content, rather than directly to the sources in the Internet. The key functionality offered by this model is:

- Operator offering is limited to delivery of only the "over-the-top" content
- Present a unified portal to the users for selection, viewing and purchase of the content.
- Augment content with operator-specific value added services to the user such as advanced search capabilities, etc.
- Policy enforcement (i.e. control rate and quality of the content streams).
- Operator leverages revenue opportunities from service subscription, and value-added services

This is depicted in Figure 11.

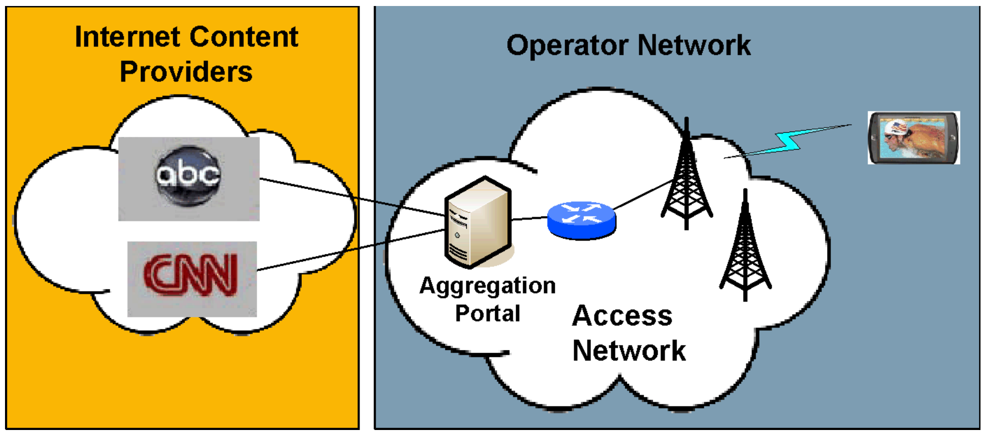

Figure 11: Deployment Model 3 - Operator provides Aggregation Portal and Transport

A fourth model also exists, but is not elaborated here. In this fourth model, the operator provides only the IP transport function. Users will use the operators' infrastructure as a "bit pipe" to access over-the-top content directly from providers in the Internet. In this model, the operator has virtually no control over the content (other than perhaps blocking or throttling it), and therefore the users will experience a different look and feel as presented by each content provider that is accessed. This model would look identical to the third model discussed above, except with the aggregation portal (and its potential as a value-added revenue source) removed. Even in a pure over-the-top situation like this, there is still the opportunity to offer improved performance of video stream delivery in the LTE network itself with some policy management and control. The revenue opportunity is limited to providing access to the subscriber.

Motorola's Solution for Improved User Experience

Motorola is building on our legacy in video delivery by developing complete end-to-end video solutions, like those that are implied in the models above, which can integrate advanced 'mobility-aware' applications and advertising into the video offering. This gives consumers access to advanced capabilities that can provide a personalized video experience, beyond simply enhancing their searches for content. Motorola also has technologies to provide closed loop client-server dynamic adjustment of video encoding to adjust to dynamic air-interface conditions, which is applicable to all models discussed above, including the over-the-top model.

As just one example of a mobility aware application, Motorola has developed a server which provides the ability to pause a video stream on one device and pick it up on another. This allows consumers to seamlessly move their video stream to wherever they choose to view it, whether it is a handheld device, PC/Laptop, or home TV. The flexibility of a converged applications architecture like this means that the underlying mechanisms that have been developed to allow video transfer among devices can be readily applied to other applications as well. Presence notifications, news feeds, home caller-ID, and many others are all examples of information that could easily have their target context changed from one device to another, as a user wishes, regardless of access network. Many other applications like this are being developed. While the details of these are outside the scope of this paper, Motorola would be pleased to discuss them further.

Benefits to the Operator

The ability for an operator to ubiquitously deliver converged video and multimedia content to their subscribers offers significant business advantages, such as:

Network efficiencies from a common video headend and converged session control - Operators with fixed and wireless networks can especially benefit from a converged architecture. For the operator owned and operator leased models like 1 & 2 above, a single video headend can deliver content independent of access technology. Significant savings in CAPEX and OPEX are realized by this approach, as opposed to deploying individual independent video delivery solutions for each.

Ubiquitous access - In a mobile environment, having 'always on' access regardless of location creates more opportunities for pay-per content access, or advertising 'eyeballs' reached. For all four models, additional ARPU should be possible simply by providing consistent service across multiple environments.

Taking advantage of location – Targeted advertising is possible based upon an individual's past behaviors as well as the content that is currently available (e.g., when a particular piece of media is about to be distributed by a MBMS broadcast, the user can be alerted). For the operator owned and operator leased models, feedback of current subscriber location information can be sent back into the video headend, making it possible to customize individual streams (VOD for example) based upon a particular user's location. This enables location based advertising with a fine degree of granularity (e.g., for individual shopping malls, restaurants, events, etc.)

Additional public services – Enhanced emergency communications services are also possible such as broadcast alerts and/or updates on surrounding context (e.g., traffic, etc.) based upon location. Many of these information services can be subscription based. It is also possible that public carriers may be able to "wholesale" selected broadband capabilities to public safety agencies.

Stickiness – Operator owned and operator leased models provide consistent access, management of preferences, a common look and feel (e.g., EPG, storefront) to the user in a mobile environment as well as the home/fixed locations increases the stickiness of the subscriber to the carrier.

The benefits of converged applications described above will require intelligence in the network to support applications interworking. For the operator owned model 1, the operator has complete control of the applications and their interworking. For the operator leased model 2, the operator must work with the content aggregator host to ensure proper functionality. For model 3, the operator must ensure their aggregation function provides convergence. For operators that provide IP transport only (the '4th model'), support of converged applications would be dependent on the interworking of the over-the-top Internet hosted applications outside of the network, which is not likely to be supported.

Conclusion

With the advent of 4G wireless technologies, operators will have the needed building blocks and network flexibility to economically deliver a truly mobile video and multimedia experience. LTE offers significant performance and economic advances over its 2G and 3G predecessors via an all IP based flat architecture. Additionally LTE is expected to offer economically viable delivery of "HQ video" streaming anywhere and on all LTE mobile devices, LTE enabled consumer electronics and laptops. Video encoding and mobile device technologies have advanced commensurately, and will continue to do so, to provide a reasonable platform for mobile multimedia applications and services. Availability of new spectrum makes LTE a logical choice for providing broadband wireless services.

Motorola LTE solutions accelerate the delivery of Personal Media experiences that enable service providers to create customer-centric tiered video services and ensure the right level of quality. As an expert in both video delivery and wireless broadband technologies, Motorola has proven capability to deliver an end to end LTE network that is optimized for video services. No matter which of the 3 deployment models described above are most applicable in a customer's environment, we can provide full solutions, subsystems, or components from video headend to LTE access and devices. This includes an integrated, well-engineered Video Headend (BM-SC), Data Center, Service Edge, Applications, Wired Access, CPE, set-top boxes, and of course, LTE Access.

Additionally, Motorola's planning tools, deployment and integration services, and cost modeling, have all been specifically tailored to video to assist a network operator in maximizing the opportunity for profitability.

For more information on video applications for LTE & how Motorola can help you leverage innovative video services to improve ARPU, please talk to your Motorola representative.

References

[1] John Jurgensen, "Indie Films Hit the Web", Wall Street Journal, October 18, 2008
[2] ComScore, Inc. and Motorola http://www.comscore.com
[3] Perception of Print quality, http://www.diax.nl/pages/perception_printquality_uk.html
[4] NGMN Case 3, 3GPP TSG-RAN WG1 #54bis R1-083807, September 29 – October 3, 2008