station) and strong interference may be able to support only about 1 Mbps.[10] If there are multiple active users with guaranteed bit rate (GBR) requirements, other users involved in non-GBR services such as email and web browsing will experience much lower average throughput. As noted above, the numerous variables inherent to a wireless network may mean that during times of congestion, heavy users may have to be treated differently to ensure proper throughput for all users. Should the FCC mandate the suspension of such network management practices in the name of "neutrality," significant negative consequences could result.

The throughput experienced by a user would also depend on the service (or application) being received by the user. A seemingly low instantaneous data rate of about 300 kbps would be more than adequate for a VoIP call, while a much higher instantaneous data rate (e.g., few Mbps) would be needed for video streaming or a file download to provide satisfactory user experience. In the absence of the context of the specific service or application and their related QoS requirement, a given value of data rate, or any other metric, such as latency, is not a reliable indicator of the user performance or experience.

The available amount of spectrum directly affects the achievable performance. If a service provider has a 10 MHz LTE channel in one market but only a 5 MHz LTE channel in another market, the achievable throughput can easily differ by a factor of more than two. The larger the channel bandwidth, the higher the achievable throughput. Frequency selective scheduling could provide larger gains in case of larger channel bandwidths.

The impact of user mobility on achievable performance is also significant. In general, a higher velocity of the user equipment results in a larger Doppler shift and typically implies frequent and more severe short-term fades. In contrast, a slowly-moving device (e.g., pedestrian speed) has a smaller Doppler shift and experiences fewer varying signal fades, but the time period for the fade may be much longer and more impactful, as the user may remain within a performance null area for a longer period of time. The signal-to-interference plus noise ratio required to achieve a target throughput (or error rate) can vary significantly due to the impact of the user mobility and the distance from the serving cell.

The network performance and the user performance are affected by the capabilities of the user equipment and the eNodeB. All the eNodeBs do not have support for all the configurations defined by the standard. For example, Release 8 LTE supports parallel transmission of data from four antennas. However, commercial Release 8 LTE deployments typically have two transmit antennas for parallel data transmission. Similarly, not all devices have these same capabilities. Five categories of user equipment are defined for release 8 LTE, and, Category 3 devices are widely used in current commercial deployments in the U.S. and around the globe. Category 3 devices receive signals on two antennas. Furthermore, Category 3 equipment supports QPSK and 16-QAM modulation schemes to transmit data in the uplink. In contrast, Category 5 devices have four antennas to receive the downlink signals and support QPSK, 16-QAM, and 64-QAM to transmit data in the uplink. Such differences in equipment categories are a key reason why the downlink peak data rate is around 300 Mbps for a Category 5 device and around 100 Mbps for a Category 3 device and the uplink peak data rate is around 75 Mbps for a Category 5 device and around 50 Mbps for a Category 3 device [3GPP_TS36.306].

[10] These calculations assume that a (2x2) MIMO (Multiple Input Multiple Output) technique is used when the channel conditions are excellent (i.e., with CQI=15) and a non-MIMO technique at CQI=1 is used.

The generation and the revision within the generation of the wireless standards also have a significant influence on the achievable performance. For example, Release 8 LTE supports theoretical peak data rates of 300 Mbps downlink and 75 Mbps uplink. In contrast, Release 10 LTE-Advanced supports a theoretical peak data rate of 3 Gbps downlink and 1.5 Gbps uplink. Again, defining one set of reasonable metrics is impossible in the face of different generations of handsets.

In summary, mobile broadband providers are committed to complying with the existing transparency rule but, recognizing that the specifics of network and handset performance will vary constantly, the granularity contemplated by the proposed expanded transparency rule would be infeasible. There are simply too many factors (most of which are highly dynamic or variable) that influence network and user performance, making it impractical to predict, guarantee, and/or verify user performance in the context of the expanded transparency rule.

4.1.3 Congestion

The 2014 NPRM envisions disclosure of congestion-related statistics such as speed (i.e., throughput) and packet loss. In the context of mobile wireless networks, such disclosure requirements are unhelpful for several reasons explained below.

First, the dynamic nature of mobile wireless networks leads to wide variations of throughput as discussed in Section 4.1.2 above. For data-centric systems, packet loss is reflected in the overall throughput. Furthermore, some throughput degradation and/or packet loss may not be due to congestion at all; it may simply be due to changes in channel conditions, user mobility, and/or service change. The packet loss rate may not really reflect any congestion.

Separating congestion issues from non-congestion issues through analysis and storing and maintaining such data for the sole purpose of compliance with the transparency rule would need significant investment of resources without any tangible benefit to consumers. As mentioned in Section 3, the eNodeB scheduler operates as fast as every millisecond, and the number of active users can change within a few seconds due to transitions between the idle and connected modes. So-called congestion can widely fluctuate in matter of few seconds. Network optimization processes aimed at addressing congestion can respond to these temporary congestion issues just as quickly. As a result, real-time disclosure of network congestion would be problematic to implement and confusing for consumers, as the network is constantly responding to ever-fluctuating levels of traffic. Section 2 illustrated the LTE network architecture. The complexity of the overall architecture means that network upgrades due to revisions or new feature implementations would almost certainly need extensive troubleshooting efforts which would likely lead to temporary congestion issues. Engineers seeking to comply with such a rule would face an unnecessary burden that could delay solutions to real problems, and cause harm to the subscribers instead of helping users (which is the real goal of the transparency rule). The key to keeping overall network capacity high is to adapt to the traffic over time using sophisticated and proprietary scheduling algorithms. Network neutrality rules which place strict demands on traffic handling and may restrict or prevent certain schedule techniques, would require infrastructure and capacity to be over-engineered to handle otherwise manageable peaks, and hence result in higher costs for consumers.

Since network optimization is an ongoing and iterative process, it is quite likely that some congestion issues that are reported will have been remedied long before they could be incorporated into any required disclosure. Mobile wireless networks have numerous challenges on the radio channel, and,

service providers need to invest heavily in ongoing technology upgrades, network RF planning, design, and optimization activities. The technology for wireless is changing very quickly and will continue to change quickly for the foreseeable future. Service providers will have a learning curve to understand how to deploy this technology and realistically, regulatory policy will (and perhaps must) adjust more slowly to these technology developments. Undue regulation at this point will stifle technology deployment that could increase bandwidth availability and lower costs for the consumer.

4.1.4 Peak Load Management

There are many legitimate reasons why a wireless network operator needs to manage data traffic on its network. In such cases, reporting of such peak load management would have little benefit. Recall from Section 2 that the Policy and Charging Control network works with the Evolved Packet Core to ensure suitable QoS. Such interworking between the Policy and Charging Control network and the Evolved Packet Core means that peak load management of traffic may be carried out such that the QoS for a given Evolved Packet System bearer is met. Each Evolved Packet System bearer has QoS parameters such as the maximum data rate. If the incoming data rate exceeds the subscribed data rate, the Packet Data Network Gateway manages the data to meet the data rate constraint toward the Serving Gateway. Such peak load management is carried out as part of the 3GPP standard's QoS characteristics [3GPP_TS23.203]. The network needs to manage the traffic so that all users can satisfactorily receive services instead of just few users consuming disproportionate amounts of resources. If excessive amount of traffic is received at the eNodeB, the eNodeB may have to buffer the packets, delaying the packets and potentially causing packet loss if the device-specific buffer overflows. Hence, even for the user with higher data rate needs, suitable peak load management is needed.

The resources in mobile wireless networks are scarce, and these scarce resources must be shared among numerous users. If suitable optimization is not carried out, some applications could flood the network with excessive amounts of data traffic (and even signaling traffic), causing degradation to many users in the network. In general, higher data rates result in the consumption of more resources, and, concentration of radio resources among only few subscribers would be unfair to other users. Hence, network optimization could be viewed as a network management mechanism to provide some level of fairness among the uses and users of radio resources. Network operators need the flexibility of such legitimate management to strike a balance among fairness, network performance, and aggregate user performance. The network management in mobile wireless networks must have at its disposal all means, including optimization, to safeguard the interests of all subscribers and to provide the best possible experience to all subscribers instead of just a select few subscribers. This balancing is dynamic and load dependent, so again, one set of uniform metrics cannot meaningfully capture overall performance.

4.1.5 Parameters of Best-Effort Service

The NPRM asks if any parameters can be specified to quantify the best-effort service. Numerical parameter settings that quantify the best-effort service and that are reliable are difficult to guarantee in mobile wireless networks. First of all, commercial mobile wireless networks have a mix of radio access technologies, mobile devices with different capabilities, and eNodeBs with different capabilities. Hence, the achievable performance varies depending upon the specific combination of the technology, the mobile devices, and the eNodeB for a given channel condition.

Even within the narrow scope of a given standard such as LTE and ignoring differences among technologies, compliance with the NPRM-proposed transparency rule in the form of target parameters would be quite challenging. LTE defines nine levels of QoS in terms of QoS Class Indicators (QCIs) [3GPP_TS23.203]. A QoS Class Indicator (QCI) specifies the QoS class. Defining different data rates for these services offers operators additional flexibility. An operator could also define proprietary QCIs. For example, QCI = 1 is suitable for applications such as VoIP. Its priority is 2, and it seeks to provide a minimum data rate, e.g., around 12 kbps. (Of course, keep in mind that a wireless network cannot provide an absolute guarantee. "Guarantee" here means that if the network agrees to grant service with QCI = 1 for a user, it will try its best to honor the granted GBR (Guaranteed Bit Rate). In the worst-case, the call may drop due to a hostile radio environment.[11])

Now, let's contrast QCI = 1 with QCI = 8. An application such as email might fall into QCI = 8. Since VoIP has more stringent delay requirements than email (e.g., 100 ms for VoIP vs. 300 ms for email), its priority is higher than email's. Also, the target error rate for email is lower than that for VoIP because the integrity of email bits is much more critical than the integrity of VoIP bits. So our goal is to lose no more than one of one million IP packets for email.

A web browsing session typically uses QCI = 8 or 9, which corresponds to so-called best-effort service. However, according to the 3GPP recommendations, the Evolved Packet System bearer with QCI = 8 or 9 is a non-guaranteed bit rate (non-GBR) bearer and therefore has absolutely no guarantee of any minimum data rate. The maximum data rate for such Evolved Packet System bearer is operator-configurable. Commercial LTE networks determine the maximum data rate as a function of the mobile device category. Since there is no guarantee of any minimum data rate for the best-effort service, the most critical parameter (i.e., throughput or data rate) cannot be specified for the best-effort service. Furthermore, the priority of traffic associated with the best-effort bearer is the lowest among all types of Evolved Packet System bearers. Hence, when the eNodeB scheduler becomes busy serving higher-priority bearers, the average throughput can be expected to be impacted for the best-effort bearers.

In summary, the absence of the specification within wireless standards of even the minimum data rate for a best-effort service is a hurdle that cannot be overcome by the transparency rule.

In light of the practical issues described above in Sections 4.1.1 through 4.1.5, applying an enhanced transparency rule to mobile wireless networks is impractical, would stifle innovations, and (most importantly) would not benefit users at all. Even if some information about network management practices were to be disclosed to comply with the transparency rule, such information would most likely be too vague. Metrics for gauging network neutrality do not exist and if they did they would likely become obsolete quickly with the rapid development of technology and new applications. Enforceability of such a rule would be highly questionable and this rule would, in practice, reduce network performance.

[11] The packet delay is the one-way time between the device and the edge of the operator's network. QCI = 1 aims for a delay of less than 100 ms. (The lower the number for priority is, the higher the actual priority.) The packet loss rate of 10^{-2} = 0.01 or 1% means that an application with QCI = 1 can tolerate the loss of one of 100 packets.

4.2 No-Blocking Rule and Mobile Wireless Networks

The *no-blocking rule* specifies that mobile broadband service cannot prevent consumers from accessing lawful websites and cannot prevent users from using voice or video telephony applications that compete with the mobile broadband service provider's services, subject to reasonable network management. The NPRM further clarifies that mobile broadband service providers would not be violating the rule if they do not degrade a lawful service or content below the minimum level of service. The NPRM is seeking a definition for such minimum level of service and exploring the feasibility of using measurements such as speed, packet loss, and latency delay to quantify the minimum level of service.

Application of the no-blocking rule has several unique challenges in mobile wireless networks. To begin with, the definition of the minimum level of service is not feasible for mobile wireless networks. Throughput is the most important performance metric for data-centric mobile broadband systems, and, as explained in Section 4.1.5 on the best-effort service, LTE does not define any minimum data rate guarantee for such service. Note that non-IMS applications such as consumer-chosen voice and video applications do not travel through the IMS network and are typically placed onto the Evolved Packet System bearer with QCI = 8 or QCI = 9. Recall from Section 2 that signaling for IMS applications such as operator-aware VoIP (e.g., Voice over LTE or VoLTE) travel through the IMS network and that the IMS and Policy and Charging Control networks work with the Evolved Packet Core to provide target QoS, which would include guaranteed bit rate (GBR) for QCI = 1 Evolved Packet System bearer. Hence, any non-IMS user application such as voice and video cannot be expected to have the IMS application-like QoS.

The issues associated with expansion of the no-blocking requirements for mobile wireless networks are similar to those addressed in Sections 4.1.1-4.1.5, above, for implementation of an enhanced transparency requirement. When a single user or single application could overwhelm the limited resources provided to wireless providers, such a provider must be able to block this interfering use to ensure the quality of service expected for many other users. As has been discussed throughout this paper, unlike wireline networks, mobile wireless networks have scarce spectral resources (capacity) that are affected by interference, multipath, blockage, clutter and other conditions which require active management, including blocking of particular applications or users. Without the ability to manage blocking effectively, a wireless provider would be faced with situations where a single user or application could occupy all the radio resources associated with a particular eNodeB – leaving any other subscriber seeking access to that eNodeB without the ability to connect and receive the service expected. Therefore, the current no-blocking regulation continues to be the most appropriate technical path forward. Attempting to apply a broader no blocking rule—even with a safe harbor set of guidelines or other means to cabin off "reasonableness" – is extremely impractical, as discussed in more detail below.

In case of resource crunch, the eNodeB gives higher priority to Evolved Packet System bearers carrying IMS signaling and guaranteed bit rate traffic (e.g., VoIP traffic). Furthermore, according to the Quality of Service Class Indicator characteristics defined in [3GPP_TS23.203], Evolved Packet System bearers are set with a certain Allocation and Retention Priority (ARP), and, by design, best-effort bearers have a lower Allocation and Retention Priority compared to other higher-priority bearers. The best-effort Evolved Packet System bearers carrying email, web browsing, and consumer-installed non-IMS voice and

video applications could potentially be affected adversely as part of routine and legitimate network management.

Without the differentiation capabilities described above, the LTE network will simply not function reliably for some services, or will function in a very inefficient manner. Standards organizations such as 3GPP have spent years working out the details of these capabilities and how they will interoperate, and they should not be modified without thorough technical analysis.

The NPRM is seeking comment on the feasibility of using the following methods to define a *minimum level of service*: a best-effort standard, a minimum quantitative performance standard, and a reasonable person standard. As discussed in Section 4.1.5, a best-effort standard cannot be really quantified for mobile wireless networks. The minimum quantitative performance standard would also be impractical. Finally, the main problem with the reasonable person standard is that a typical end user cannot be expected to be knowledgeable about how mobile wireless networks operate and different people would have different expectations from their networks. The absence of reliable and quantifiable estimates of "reasonableness" makes the reasonable person standard highly subjective and non-enforceable. Wireless providers, based on network management requirements developed within industry standards, should have the right to block any use or application on their wireless network if such use would preclude other subscribers from accessing service. Attempting to limit wireless providers' ability to block (such as attempting to define "reasonableness") would not allow the scarce spectral resources available to wireless providers to be used in the most effective and efficient manner.

4.3 Unreasonable Discrimination Rule and Anti-Discrimination/Commercial Reasonableness Rule, and Mobile Wireless Networks

The FCC has stated that the newly-proposed anti-discrimination/commercial reasonableness rule, just like the original 2010 rule, is not intended to be applicable to mobile broadband service. Our view concurs with the FCC view that different treatment for mobile broadband should be continued because differentiation among users and user services is required to provide a satisfactory quality of service to consumers.

As discussed in detail in Section 3.1 above, wireless networks are characterized by: (1) scarce radio resources; (2) radio resource sharing; (3) dynamic channel conditions and varying performance; (4) varying resource consumption; (5) ever-evolving networks and (6) the need to integrate differing devices and infrastructure. Because of these factors, user differentiation due to the dynamic nature of the radio environment is fundamental to the operation of any good scheduling algorithm design for a wireless network. A good scheduling algorithm maximizes network performance while providing good user-perceived experience, not necessarily by treating all users or all applications identically. If the scheduler treats two users with two different channel conditions (e.g., one excellent channel and one poor/noisy channel) in the same manner, the overall network performance would certainly degrade and the average user experience would also deteriorate. Consider Figure 5, where two users are downloading an email with a huge attachment and their channel conditions are constantly changing. Good channel conditions can support a higher data rate, and poor channel conditions support a lower rate as illustrated in Scenario 1 and Scenario 2.

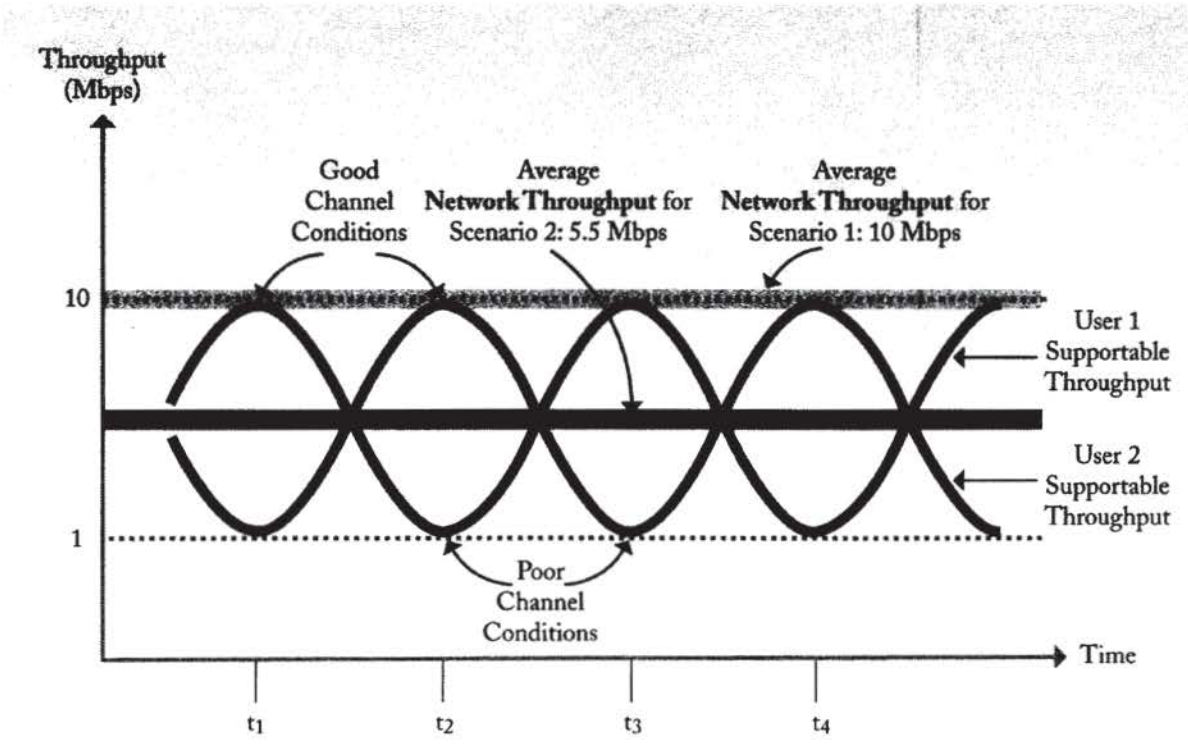

Figure 5. Necessity of User Discrimination Due to Dynamic Radio Environment

Figure 5 shows the user supportable throughput when all the available resources are allocated to the users. In Scenario 1, a high-performance scheduler allocates all the available resources to a user with the best channel conditions and transmits packets to such user. Observe that at time t_1, User 1 has the best channel conditions and can support 10 Mbps if allocated all resources. The scheduler dedicates the entire 100% of network resources to User 1 and sends a packet to User 1 at 10 Mbps at time t_1. At time t_2, User 2 has better channel conditions, and the scheduler allocates all network resources to User 2 and sends a packet to User 2 at 10 Mbps. The average network throughput is 10 Mbps as the network is always sending the packets at 10 Mbps. Sometimes the network sends packets to User 1, while other times, the network sends packets to User 2. The average user throughput that User 1 experiences is 50% of 10 Mbps = 5 Mbps, and the average throughput User 2 experiences is also 50% of 10 Mbps = 5 Mbps because these users are scheduled 50% of the time.

In Scenario 2, an equal-opportunity scheduler equally distributes the network resources at all times. At time t_1, the network allocates 50% of resources to User 1, leading to User 1 throughput of (50% of 10 Mbps = 5 Mbps). Note that User 1 throughput is 5 Mbps and not 10 Mbps because User 1 is allocated just 50% (and not all 100%) of resources. Similarly, at time t_1, the network allocates 50% of resources to User 2, leading to User 2 throughput of (50% of 1 Mbps = 0.5 Mbps). The network throughput at t_1 is 5.5 Mbps (User 1 throughput + User 2 throughput = 5 Mbps + 0.5 Mbps = 5.5 Mbps). Now, consider time t_2, where the allocation of 50% of resources to User 1 results in User 1 throughput of (50% of 1 Mbps = 0.5 Mbps) and the allocation of remaining 50% of resources to User 2 results in User 2 throughput of (50% of 10 Mbps = 5 Mbps). Again, note that the users experience only 50% of the throughput values shown

in Figure 5 because the throughput values correspond to a hypothetical case where all of the network resources are allocated to a single user. The network throughout at t_2 is (User 1 throughput + User 2 throughput = 0.5 Mbps + 5 Mbps = 5.5 Mbps). The average network throughput is then 5.5Mbps. Let's calculate average user throughput. User 1 experiences 5 Mbps 50% of the time and 0.5 Mbps remaining 50% of the time, leading to the average user throughput of 2.75 Mbps (0.5*5 Mbps + 0.5* 0.5 Mbps = 2.75 Mbps). Similarly, the average user throughput for User 2 is also 2.75 Mbps. In other words, since the network equally distributes resources between the two users, the network throughput of 5.5 Mbps is equally divided between the two users as (5.5 Mbps/2 = 2.75 Mbps).

In our simple example, the network throughput is reduced by almost 50% (i.e., from 10 Mbps to 5.5 Mbps) in Scenario 2 compared to Scenario 1. Just imagine what would happen to the business models of service operators if the cost of supporting their customers doubles overnight? While the scheduler has optimized network performance in Scenario 1, User 1's throughput and User 2's throughput are also better in Scenario 1 compared to Scenario 2 (e.g., 5 Mbps in Scenario 1 compared to 2.75 Mbps in Scenario 2). Better network performance enables the service operator to cost-effectively provide services to many users simultaneously. Subscription plans for users can then be relatively inexpensive, promoting growth of cellular subscribers and services. The comparison of network performance in Scenarios 1 and 2 shows that differentiation is best for the aggregate network and for all users. Treating all users the same all the time appears more fair at first, but adapting to the radio channel by having the scheduler weight the service schedule against predicted data delivery performance results in better performance for everyone, even though at any moment, not all users are treated the same.

Combined service and user differentiation is also quite important. Assume that User 1 has an ongoing email application and has in the past been promised a maximum data rate of 10 Mbps, and assume further that all the network resources are being consumed by such a user. Suddenly, ten users start making voice calls. The network simply lacks the resources to simultaneously support ten voice users and an email user with a 10 Mbps data rate. If the network's resource management algorithms downgrade the email data rate to perhaps 9 Mbps, then the network can accommodate both the email user and all ten voice calls. If the network fails to differentiate between the voice users and the email user, all ten voice calls would be blocked. In summary, user and service differentiation is essential to aggregate service fairness for the average consumer. Here again, the scheduler is not treating every application identically ('fairly'), but the net aggregate result benefits more users. What set of metrics would represent this fairness? These considerations evolve as the applications mix changes.

Differentiation based on resource consumption is also inherent in a wireless network and facilitates network efficiency and fairness. The network management algorithms must differentiate between users based on the amounts of network resources each user is consuming. For example, current mobile wireless networks commonly limit the amount of resources a single user can consume. If one user consumes an excessive amount of network resources due to a hostile radio environment and/or such user is using bandwidth-intensive data applications, that user may dominate the network so much that no other user can get any service in the absence of pro-active network management.

There are several situations where it is legitimate and beneficial for wireless network operators to differentiate traffic. For example, Wireless technologies are increasingly being used for machine-to-machine services and public welfare systems. It is critical that these systems – such as, for example, wireless monitoring of bridges – be fully functional at all times, and this may require prioritization. In

addition, public safety personnel clearly should have higher priority than regular users. More "ordinary" services, such as voice call, email, and streaming video, all require different quality of service levels, and wireless network operators should be allowed the flexibility to prioritize these diverse services in a manner that ensures that an end user experiences the quality of service necessary for these services to function. User and service differentiation is also essential to service fairness – one user should not be permitted to monopolize network resources at the expense of others.

In summary, the dynamic nature of mobile wireless networks requires a reasonable, necessary, and *dynamic*differentiation among users by the network management to ensure an acceptable aggregate quality of service for all wireless subscribers. To subject mobile broadband providers to claims that such non-uniform network management techniques are 'unfair' and violate commercial practices, particularly when combined with the prospect of regulatory rebuke, would significantly impair the ability of providers to experiment with new and innovative network management tools designed to improve consumers' experiences. Any rule that would prohibit discrimination on mobile wireless networks would be impractical and would actually work against the FCC's goals of promoting innovation and benefiting consumers.

5. Mobile Wireless Broadband Internet Access: An Integrated Information Service

Mobile broadband service is an integrated service that enables the wireless subscriber to access a variety of services in a wireless fashion. The subscriber's device communicates with the mobile broadband service provider's network via complex interactions. The nodes of the entire wireless network infrastructure work together to present a single unified view of the network to the subscriber's device and to provide service-specific QoS for a user's services according to the 3GPP LTE framework. All the network components need to do specific processing, which often needs to be customized for a given service, to provide seamless and satisfactory experience of a variety of services for the user. All the complexities associated with subscriber's experience of wireless services are handled by the subscriber's device and the broadband service provider's network without the active involvement of the subscriber.

When the FCC classified wireless broadband Internet access service as an "information service," it did so based on the correct finding that this service "offers a single, integrated service to end users, Internet access, that inextricably combines the transmission of data with computer processing, information provision, and computer interactivity, for the purpose of enabling end users to run a variety of applications."[12] This statement, which was made by the FCC in 2007, has only become more emblematic of the wireless ecosystem. As technologies and networks have evolved, subscribers are increasingly using advanced networks for multiple simultaneous data services, such as email, web browsing, and various other applications. Extensive and complex processing in the mobile broadband network allows customers to seamlessly navigate among multiple mobile broadband applications and services at the same time, enjoying a good experience of various applications.

The mobile broadband network consists of numerous network nodes that interact among themselves in different and complex ways and that do custom processing depending upon the type of service or application. Such interactions and custom processing enable the wireless subscriber to obtain an

[12] *Appropriate Regulatory Treatment for Broadband Access to the Internet Over Wireless Networks,* Declaratory Ruling, 22 FCC Rcd 5901, 5911 ¶ 26 (2007).

integrated information service that integrates different types of information to provide a unified service experience (user experience) and that meets specific requirements of applications (e.g., guaranteed data rate or very low packet error rate or very low latency). *Indeed, the mobile broadband service is an integrated information service that requires (i) tight coupling between the mobile device and the network,*[13] *(ii) numerous complex interactions*[14] *between the mobile device and the network and among the network components, and (iii) service-specific custom processing at different network nodes.*[15] Let's take a closer look at these three areas.

Tight coupling between the mobile device and the network is essential in providing seamless and satisfactory services to the subscriber. For example, each service requires a certain quality of service, and, the network properly configures the mobile device and the network nodes so that the user has satisfactory experience. According to the 3GPP LTE standard, the overall packet error rate cannot be greater than 0.0001% for services such as email and web browsing (see Table 6.1.7 in 3GPP TS 23.203). However, the raw packet error rate on the LTE air interface is 10%.[16] Hence, the network configures a suitable number of packet retransmissions to reduce the effective packet error rate from 10% to 0.0001%. Furthermore, the mobile device provides feedback on the prevailing downlink radio channel conditions so that the network can use suitable transmission parameters (e.g., the modulation scheme, the amount of redundancy, the type of multiple antenna technique, and the number of Physical Resource Blocks) to provide a satisfactory downlink data rate and hence a satisfactory user experience. Similarly, the mobile device informs the network about the amount and type of data it has in its uplink buffers and the available transmit power. The network allocates a suitable amount of uplink radio resources based on such information and the subscriber can send the data traffic (e.g., email) within acceptable delay limits (e.g., less than 0.3 second). This tight coupling enables end users to receive email, for example, at a data rate that would be expected with very limited errors. Without this network management, the quality of service would deteriorate and be unacceptable to subscribers.

Complex interactions between the mobile device and the network and among the network components take place before the subscriber can obtain even basic wireless services. Mobile devices typically do not have pre-assigned fixed IP addresses, and, the devices cannot obtain any IP-based services such as email and web browsing without IP addresses. Hence, the network *must* allocate an IP address to the mobile device. To provide security over the wireless interface, the network and the device first perform mutual authentication and then locally generate security keys. For example, LTE can secure the wireless interface by encrypting user traffic. The network also sets up several logical connections called Evolved Packet System bearers that help carry user traffic such as email and streaming video. The network

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[13] Such tight coupling is exemplified by packet retransmissions occurring between the user device and the radio network to provide essentially error-free information to the applications such as e-mail and web browsing.

[14] An example of such interaction is the invocation of a Domain Name System (DNS) server by the user device so that the name of a web site (e.g., www.cnn.com) can be translated into an IP address of the server that is in charge of the web site.

[15] An example of such custom processing include fast packet forwarding of delay-sensitive traffic by an IP router and delayed packet forwarding of delay-tolerant traffic by an IP router. The operator's network utilizes multiple IP routers within the network (e.g., between the Serving Gateway and the Packet Data Network Gateway in the LTE network).

[16] The LTE air interface uses the instantaneous target block error rate (BLER) of 10% to improve efficiency of precious radio resources. A suitable combination of the modulation scheme and Turbo coding is used to meet such target BLER for a given radio channel condition.

nodes interact among themselves and the network interacts with the mobile device so that the bearers can be set up. Selected information about the mobile device is stored at different nodes so that packets can reach the correct user via the bearers. Without all these integrated actions, the user would not be able to obtain the Internet services expected (i.e., would not be able to access the desired web site). The wireless provider must manage these complex interactions to provide the seamless experience expected by consumers.

Service-specific custom processing is carried out at different network nodes. Depending upon the policies of the service provider, different types of IP addresses could be allocated to the mobile device for different packet data networks. For example, for the packet data network of the Internet, an IPv4 address could be allocated to the mobile device because of prevalence of IPv4 addresses. In contrast, for IMS-based applications, an IPv6 address could be allocated to the mobile device to benefit from the abundance of IPv6 addresses. Quality of Service (QoS) in an IP network can be provided by an Integrated Services or Differentiated Services framework. The network node provides different QoS to different services to meet the service requirements and user expectations. When a Differentiated Services framework is used, Differentiated Services Code Point (DSCP) is used to mark each IP packet. IP routers use correct packet forwarding treatment to an incoming IP packet. For example, assume that two IP packets arrive at a Packet Data Network Gateway: a delay-sensitive IP packet carrying a streaming video and a delay-tolerant IP packet carrying email. The delay-sensitive IP packet carrying a streaming video can be marked with the DSCP value of 30 and the delay-tolerant IP packet can be marked with the DSCP value of 0. In case of heavy traffic, the IP routers between the Packet Data Network Gateway and the Serving Gateway would quickly forward the delay-sensitive packets (i.e., video streaming packets) and would delay the forwarding of the delay-tolerant packets (i.e., email packets). The IMS and the PCC network nodes also work with one another such that the bearers can help meet different QoS requirements for different services. This in turn allows the wireless provider to ensure that subscribers that are not affected adversely by latency to be delayed, while those applications that are latency sensitive are not delayed. For example, video streaming would not be delayed so that playback is acceptable for a subscriber, while email packets could be marginally delayed but consumers would not be affected by this delay. This network management allows the provider to manage the scarce spectrum resources in an efficient, effective manner, without degrading the subscriber experience.

Close cooperation between the mobile device and the network is needed for cohesive and seamless integrated service experience for the wireless subscriber.

Examples of Integrated Wireless Broadband Services

The tight integration needed to provide wireless broadband services is demonstrated below by how a consumer obtains two services, web browsing and video conferencing. For both of these cases, the mobile device and the broadband network must work together to provide a seamless and integrated service experience for the consumer. Before any services are rendered to the consumer, the mobile device synchronizes with the radio network and performs an attach operation with the network. As part of the attach operation, mutual authentication occurs, and security between the mobile device and the network is established. Furthermore, two default bearers are established, one for the Internet packet data network and one for the IMS Packet Data Network. The Packet Data Network Gateway allocates to the mobile device an IP address for the Internet Packet Data Network and a separate IP address for the IMS Packet Data Network. Additionally, IP addresses of the DNS server and the IMS server are conveyed

to the mobile device. When the consumer initiates video conferencing, additional bearers[17] are established to carry voice and video through numerous interactions among the mobile device, the radio network, the core network, the IMS network and the PCC network. Now that all the groundwork for data traffic has been completed, the IP packets for the email and video conferencing packets start flowing through the network and the consumer reaps the benefits of all the hard work that the mobile device and network nodes have been doing.

Web Browsing on Mobile Broadband Networks

Let's summarize the *major steps involved when the consumer is browsing the web* as illustrated in Figure 6.[18]

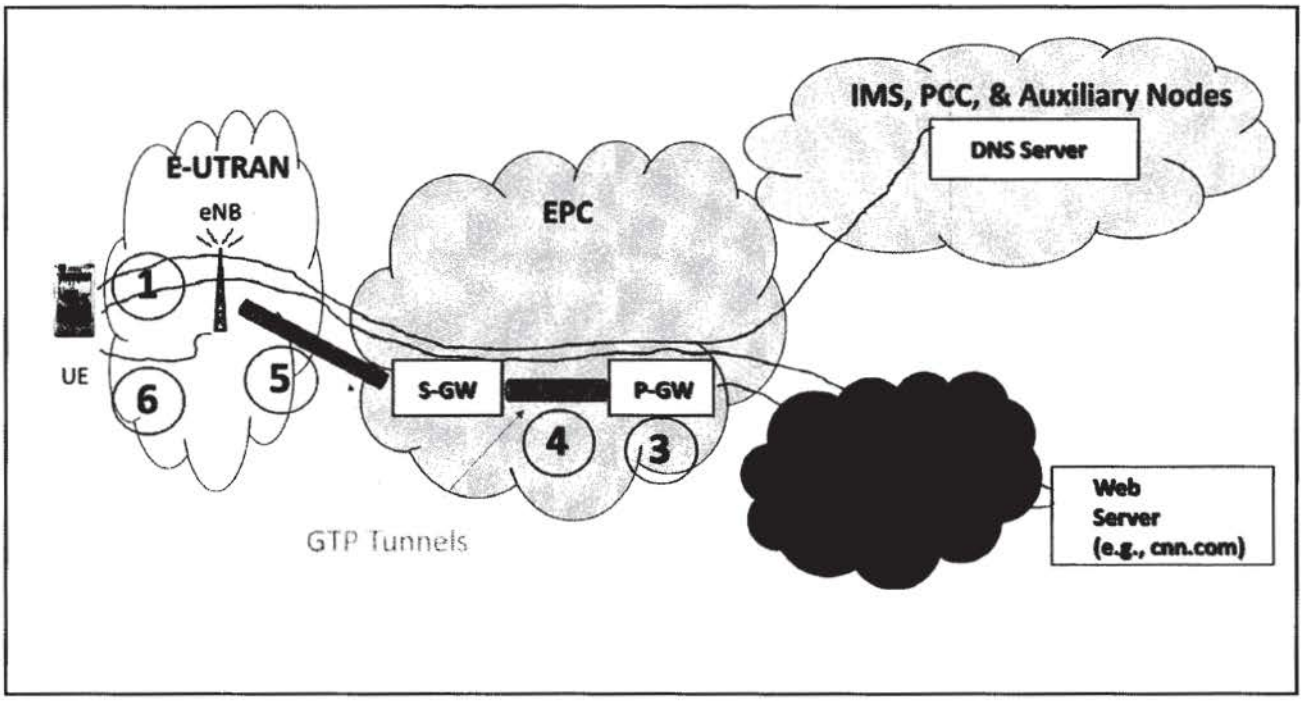

Figure 6. Major Communication Steps for Web Browsing

When the consumer selects www.cnn.com as the web site for browsing in Step 1, the mobile device communicates with the DNS server to find the IP address of the web server in charge of www.cnn.com and then communicates with the web server to set up an end-to-end connection with the web server. In Step 2, the web page from the web server passes through the IP routers of the Internet and arrives at the Packet Data Network Gateway. The Packet Data Network performs translation between the public IP address and the private IP address (if needed) in Step 3. In Step 4, the Packet Data Network

[17] LTE controls QoS at the levels of the EPS bearers. Hence, two bearers are required for two services that need two different QoS levels.

[18] The simplified description here represents one possible approach for providing web browsing and video conferencing services. The LTE standard is quite flexible and operators can choose a variation of the approach described here to offer services to the user. In the interest of simplicity, only selected nodes and connections are shown in the figure.

determines the correct bearer for the incoming IP packet containing the web page and places the IP packet inside a tunnel (representing part of the bearer) toward the Serving Gateway using a protocol called GTP.[19] The Serving Gateway extracts the IP packet and places it inside another tunnel toward the eNodeB using GTP protocol in Step 5. The eNodeB uses several protocols of the air interface protocol stack to format the original IP packet for air interface delivery (including encryption for security) in Step 6 and then transmits the web page packet over the air to the mobile device. In Step 7, the mobile device also uses the protocols of the air interface protocol stack to extract the original IP packet from the air interface (including decryption) and then presents the web page to the consumer. *As is evident from these steps, the mobile broadband network nodes and the mobile device work closely together to present web browsing to the consumer as an integrated information service.*

Video Conferencing on Mobile Broadband Networks

Figure 7 summarizes the main steps involved when the consumer is participating in video conferencing [Radisys_October2012] [Ericsson_ Feb2012].

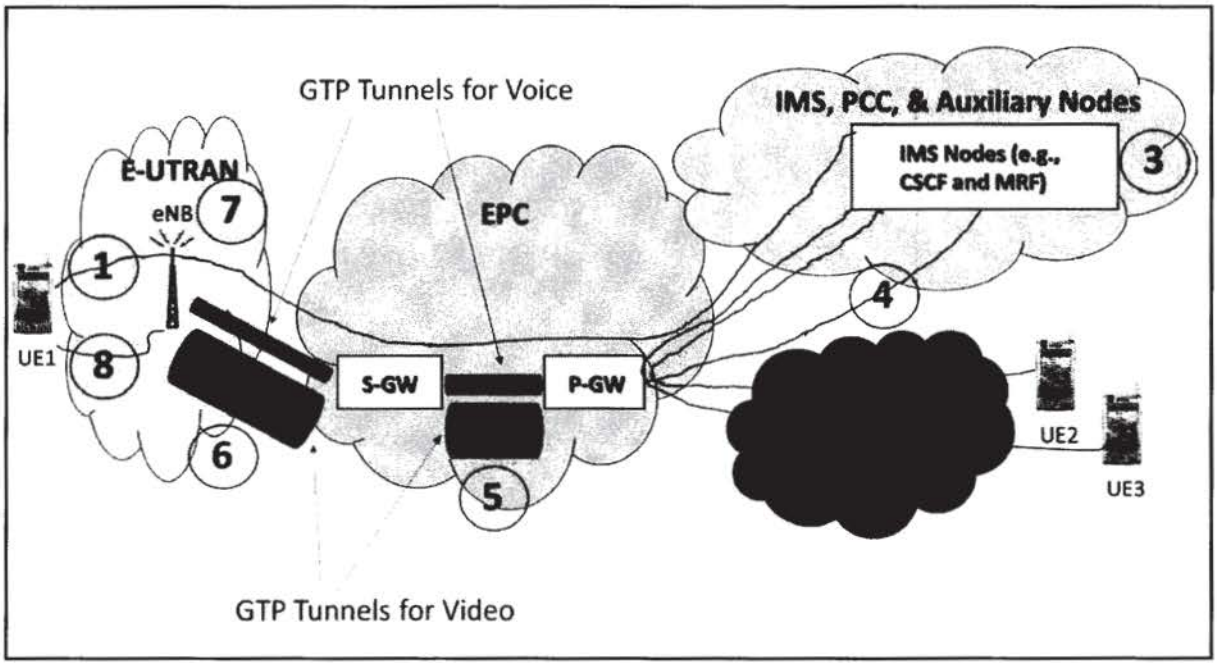

Figure 7. Major Communication Steps for Video Conferencing

[19] GTP stands for GPRS Tunneling Protocol, where GPRS is General Packet Radio Service. GTP enables LTE to support IP mobility, where the user can move from one geographic location to another while maintaining the same IP address. IP mobility is one of key elements of a mobile broadband service.

When the consumer chooses a video conferencing application in Step 1, the mobile device 1 communicates with the IMS network to create communication paths among the participating devices. In Step 2, the voice and video media from other devices such as mobile device 2 and mobile device 3 arrive at the Media Resource Function in the IMS network. The Media Resource Function properly mixes the voice and video media streams (and performs media codec conversion if needed) in Step 3. In Step 4, the Media Resource Function sends the IP packets containing voice and video to the Packet Data Network Gateway. The Packet Data Network Gateway in Step 5 determines the correct bearers for the incoming IP packets, places the voice packets inside one tunnel toward the Serving Gateway using GTP, and places the video packets inside another tunnel toward the Serving Gateway using GTP. The Serving Gateway extracts the IP packets and places them inside other tunnels toward the eNodeB using GTP in Step 6. The eNodeB uses several protocols of the air interface protocol stack to format the original voice and video IP packets for air interface delivery in Step 7 and then sends these IP packets over the air to the mobile device in Step 8. In Step 9, the mobile device 1 uses the help of the air interface protocols to extract the original voice and video packets from the air interface and then plays voice and video to the consumer in the video conferencing application. *As is evident from these main steps, the mobile broadband network nodes and the mobile device work very closely together to offer video conferencing to the consumer as an integrated information service.*

See Appendix I for a more detailed discussion of how the mobile broadband network provides an integrated information service to subscribers.

6. Recommendations

Mobile wireless broadband networks face unique challenges such as the scarcity of spectrum and other radio resources, dynamic radio environment, varied and changing technologies for devices, base stations, and networks, differentiated and evolving services and applications, and exponentially-rising data traffic. Based on the in-depth analysis of the modern mobile wireless networks, we respectfully recommend the following to the FCC.

- ✓ Mobile wireless broadband networks must be treated differently from other communications networks such as fixed wireless networks and wireline networks.
- ✓ Aim for minimal regulations for mobile wireless networks to promote innovations and thereby facilitate achieving the ultimate goals of superior network and spectral efficiency and excellent user experience.
- ✓ Give maximum flexibility to the design and optimization of complex and distributed wireless network management so that the networks operate with maximum possible efficiency under the constraint of limited spectrum.
- ✓ Refrain from establishing any minimum performance standards, because these standards are simply impractical to define or enforce in mobile wireless networks.
- ✓ Ensure that proprietary and competitive management processes are respected and encouraged to motivate continuing innovation and differentiation.

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Appendix I

A Closer Look at the Mobile Broadband Internet Access Service as an Integrated Information Service

Let's dive into the details of how the mobile broadband network provides an integrated information service to the subscriber.[20] Consider Figure 8, where the wireless subscriber is using an LTE network for three simultaneous services- web browsing, email, and video conferencing.[21]

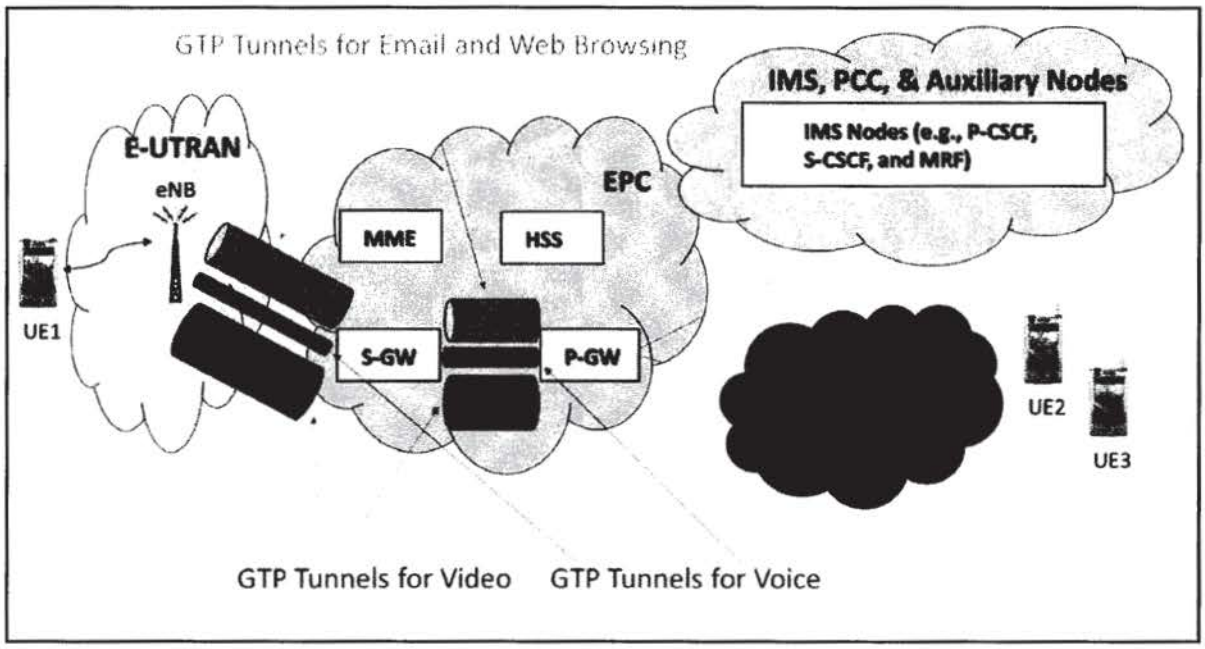

Figure 8. Integrated Information Service Offered by the Mobile Broadband Network

Different network nodes process different aspects of signaling and/or traffic. The following steps are executed to provide the integrated information service to the wireless subscriber: (I) initial attach and default EPS bearer setup toward the IMS network, (II) default EPS bearer setup toward the Internet, (III) dedicated EPS bearer setup toward the IMS network, and (IV) data transfer. Let's take a closer look at these steps below. *These steps show that complex interactions and node-specific custom processing are instrumental in providing an integrated information service experience to the wireless subscriber.*

Initial Attach and Setting up of the Default EPS Bearer Setup toward the IMS Network

As summarized in Section 2.2, the UE carries out the initial attach procedure upon power-up. The UE synchronizes with the eNB and establishes an RRC (Radio Resource Control) signaling connection with a cell. This RRC connection helps the UE and the eNB exchange signaling messages such as the messages

[20] The description given here is one possible implementation. The LTE standard is quite flexible and the operator can choose a variation of the approach

[21] This figure is based on the information given in [Ericsson_February2012] and [Radisys_October2012].

related to handover and EPS bearer setup. The UE and the MME perform mutual authentication. The HSS helps the MME in the authentication process. The signaling connection between the UE and the MME is a NAS (Non-Access Stratum) connection, which can be used for messages such as EPS bearer setup messages. Security is activated for the RRC connection and the NAS connection. The responsibility of securing the air interface between the UE and the eNB lies with the UE and the eNB. The responsibility of securing the NAS signaling connection between the UE and the MME lies with the UE and the MME. The service provider determines which packet data network should be used as the default packet data network. In Figure 6, the Internet and the IMS network are potential candidates as the default network. In our scenario, the network establishes a default EPS bearer with QCI = 5 (which is recommended by the 3GPP [3GPP_TS23.203]) that has the highest priority among the QCIs. During the default EPS bearer setup, the P-GW allocates an IP address to the UE, and, this address is conveyed to the UE by the MME. The MME also conveys to the UE IP addresses of the P-CSCF (Proxy- Call Session Control Function) and the Domain Name System (DNS) server. The P-CSCF is the first point of contact of the UE with the IMS network and performs various functions such as compression of SIP signaling messages and interactions with the PCC to provide end-to-end QoS for IMS-based services. The DNS server is used by the UE to resolve the website names to the IP addresses so that the UE can exchange IP packets with websites. The default EPS bearer toward the IMS network helps the UE and the network exchange SIP signaling messages.

Setting up of the Default EPS Bearer Setup toward the Internet

After the default EPS bearer with the default packet data network (e.g., the IMS network in our scenario) is set up, a different default EPS bearer with QCI-8 or 9 toward the Internet is established. The P-GW allocates an IP address to the UE for the Internet access. This default EPS bearer helps carry traffic corresponding to applications such as email and web browsing.

Setting up of the Dedicated EPS Bearers toward the IMS Network

As discussed earlier in Section 3, LTE controls the QoS at the level of EPS bearer. Although a default EPS bearer toward the IMS network has already been established, the QoS of this EPS bearer is inadequate to carry voice and video traffic. The QCI = 5 EPS bearer is a non-GBR bearer, while the voice and video need data rate guarantees for satisfactory user experience. When a user initiates video conferencing, SIP signaling messages are exchanged between the UE and the IMS network. The P-CSCF observes such signaling messages and conveys the information about the QoS requirements of the call to the Policy and Charging Rules Function (PCRF). The PCRF consults Subscription Profile Repository to check if the QoS requested by the video conferencing application can be accepted. The PCRF translates the generic QoS description extracted from SIP signaling messages into the LTE-specific QoS parameters (e.g., a numerical values for QCI and determination of the GBR) and conveys the LTE-specific QoS to the Policy and Charging Function (PCEF). According to 3GPP, P-GW acts as the PCEF. The P-GW initiates the setup of (i) the dedicated EPS bearer that can carry the voice traffic with suitable QoS and (ii) the dedicated EPS bearer that can carry the video traffic with suitable QoS. The S-GW conveys the dedicated EPS bearer requests to the MME. The MME works with the eNB and the S-GW to set up network resources for the new dedicated EPS bearers. The eNB accepts the dedicated EPS bearer requests if it has adequate radio resources to support the QoS required for the video conferencing service.

The IMS network, and in particular, the Media Resource Function (MRF) plays an important role in supporting the video conferencing service. The MRF consists of the signaling entity called Media Resource Function Controller (MRFC) and the user traffic entity called Media Resource Function Processor (MRFP). The MRFC works with other IMS entities and facilitates the establishment of communication paths among the devices that are participants of video conferencing. The MRFP is responsible for mixing voice streams and video streams so that the mobile device can receive audio and video from all other participants.

Data Transfer

Consider the web browsing service. When the subscriber enters the website name in the browser (e.g., Internet Explorer or Chrome), the mobile device contacts the DNS server to receive the IP address of the website. The mobile device and the web server can now exchange IP traffic such as web pages and acknowledgements to the received IP packets. The IP packets containing the web page from the web server pass through the Internet routers and arrive at the P-GW that gave the UE the IP address associated with the Internet. In case a private IP address had been assigned to the UE, the P-GW translates the public IP address into a private IP address for the journey of the IP packet within the operator's LTE network. The P-GW places the IP packet on the GTP tunnel (associated with the default EPS bearer for the Internet) toward the S-GW. The S-GW removes the IP packet from the P-GW side of the GTP tunnel and places the IP packet on the GTP tunnel toward the eNodeB. The eNodeB extracts the IP packet and passes it through these protocols of the air interface protocol stack so that IP packet is in the format that can survive the hostile and dynamic radio environment- Packet Data Convergence Protocol,[22] Radio Link Control,[23] Medium Access Control,[24] and Physical Layer.[25] The eNodeB then transmits the formatted IP packet over the air. The mobile device acquires the formatted IP packet from the air interface and recovers the original IP packet by using the air interface protocols. Finally, the IP packet is made available to the web browser that displays the actual content to the subscriber.

Let's focus on the video streaming service now. After the video conferencing service has been initiated and the IMS network has helped establish communication paths among the participants, the voice and video traffic can start flowing. Voice and video streams from the participants of the video conferencing arrive at the MRF. The MRF mixes the audio and video streams of the participants and sends the IP packets carrying voice and video to the P-GW. The P-GW has two dedicated bearers with the UE in support of video conferencing, one for voice traffic and one for video traffic. The IP packets containing voice are placed onto the tunnel associated with the voice traffic and the IP packets containing the video are placed onto the tunnel associated with the video traffic. Once the S-GW retrieves the IP packets from the P-GW side of the tunnels, it removes the IP packets from the P-GW side of the GTP tunnels and places the IP packets on the GTP tunnels toward the eNodeB. The eNodeB extracts the IP packets and passes them through the layers of the air interface protocol stack mentioned above. The eNodeB then transmits the formatted IP packets over the air. The mobile device retrieves the formatted IP packets from the air interface and recovers the original IP packets carrying voice and video by using the air

[22] Example functions of Packet Data Convergence Protocol are encryption and header compression.

[23] Example functions of Radio Link Control are in-sequence delivery of packets and retransmissions of erroneous packets.

[24] Example functions of Medium Access Control are scheduling and management of radio resources and control of physical layer retransmissions.

[25] Physical Layer takes care of functions such as modulation, coding, power control, and multiple access.

interface protocols. Finally, the IP packets are sent to the video conferencing application that plays the voice and video content for the subscriber.

The transport network that carries the traffic between eNB and the S-GW and between S-GW and the P-GW also needs to provide different QoS treatments to best-effort traffic such as email and web browsing and delay-sensitive traffic such as voice and video packets. The mechanism such as Differentiated Services (DiffServ) is widely used for QoS in an IP network. DiffServ involves marking of the IP packet by a code called DiffServ Code Point (DSCP). Different values of DSCP are defined for different services so that the IP router that forwards the IP packet containing a given service (e.g., email, web page, voice, or video) toward the destination gives a suitable priority to the incoming IP packet. For example, DSCP=0 means that the service is a delay-tolerant and the IP router could let this IP packet wait in the buffer for some time when it is busy with IP packets carrying other higher priority services. In contrast, DSCP=30 means that the IP packet is carrying a video streaming packet and hence warrants faster packet forwarding from the IP router.

As discussed in the paragraphs above, numerous and complex interactions among the mobile device, the radio network, the core network, the IMS network, and the PCC network are required so that the subscriber can access a variety of Internet access services. *Multiple services are offered to the consumer as a single integrated information service with the mobile device and the network working closely together and carrying out complex, intense, and custom processing.*

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CTIA Perspective on Preserving an Open Internet

Net Neutrality and Mobile Broadband Networks

Key Points

- Competition in the U.S. mobile broadband market is delivering an open mobile Internet, providing world-leading mobile broadband networks, and creating an innovative mobile ecosystem that benefits U.S. consumers and businesses. Internet openness is essential for any carrier seeking to win and keep customers.

- Technical, operational, economic, developmental and other factors continue to make mobile wireless services different and warrant a mobile-specific regulatory approach.

- Invitations to apply backward-looking Title II public utility regulation are barred by statute, would undercut investment, stifle innovation, and give rise to great uncertainty, all of which would harm consumers.

The U.S. Mobile Wireless Ecosystem Has Thrived Since 2010

- **LTE Deployment**: The U.S. is the global leader in 4G deployment: with just 5 percent of the world's wireless connections, we have almost half of all LTE connections worldwide.
- **Investment**: Wireless network providers have invested over $90 billion in advanced wireless networks since 2010.
- **Apps Economy**: Analysts expect mobile app downloads worldwide to exceed 139 billion this year.

Mobile Trends in the United States, 2010–2013

	2010	2013	Increase
Apps	800 thousand	3.6 million (5.5 million as of May)	+347%
Cumulative Capex	$310 billion	$398 billion	+29%
LTE Subscribers	215,000	95.2 million	+44,168%
Data Traffic	388 billion MB	3.23 trillion MB	+732%
Video Traffic	24 PB a month	200 PB a month	+733%
Minutes of Use	2.24 trillion	2.62 trillion	+17%
Cell Sites	253,000	304,000	+20%
Smartphones	78 million	175 million	+124%
Tablets *(CMRS only, not Wi-Fi)*	13.5 million	25.2 million	+86%
Total Handset Models Available	630	790	+25%

CTIA, Press Release, CTIA's Annual Survey Says US Wireless Providers Handled 3.2 Trillion Megabytes of Data Traffic in 2013 for a 120 Percent Increase Over 2012 (June 17, 2014), available at http://www.ctia.org/resource-library/press-releases/archive/ctia-annual-survey-2013; Cisco, VNI Mobile Forecast Highlights 2013–2018, http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/index.html#~Country (last visited July 13, 2014) (accessed by selecting United States, Mobile Applications); Informa Telecoms & Media Group, WCIS+ Database (last visited September 15, 2014).

Mobile Wireless Networks and Their Unique Technical Characteristics

- Scarcity of spectrum
- Dynamic radio channel conditions
- Need to share radio resources with varying quality of service (QoS) requirements
- Mobility
- Slower process of network capacity and growth
- Coexistence of devices and network technologies with widely different capabilities

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Characteristics of Wireless Networks

Change is Constant…multiple generations, revisions of a generation, & upgrades in a revision → Impractical to track network management mechanisms in a timely fashion for regulatory needs

Network Characteristics & Policy Implications

Complex & Dynamic Radio Channel, Mobility, and Quality of Service [illegible] discrimination and fair allocation by network management

Dynamic Radio Channel, Ever-Changing Networks, Variety of Apps, & Shared Radio Resources → Impractical to quantify any truly verifiable performance guarantees

Inherent Differences between Wireline and Wireless Networks

Characteristic	Wireline	Wireless
Communications Channel	Relatively clean with signal regeneration	Impaired with noise, interference, multipath, and blockage
Bandwidth	No spectrum limitations	Severe Spectrum limitations
Mobility	None	Constant, complex, often unpredictable, and often consuming extensive resources
Security	A lesser concern due to the physical path between the provider and the user (buried or on aerial infrastructure).	A greater challenge due to the possibility of tracking a user and variety of interfaces
Response to Capacity Demand	Capacity increases may be feasible, although soaring demand and increasing congestion issues may call for additional pricing, bandwidth limitations, and prioritization mechanisms	Primarily managed dynamically through prioritization, scheduling, and power allocation.
Network Complexity	Relatively simple	Extremely complex
Network Stability, Deployment, and Maintenance	Comparative stable platform and systems, although high growth in demand and new applications are issues	Extremely dynamic platforms and systems; Deployment and maintenance require constantly dealing with real estate acquisition and zoning issues; Planning and maintenance are more difficult, and continuous maintenance and frequent resetting of network parameters required; Infrastructure changes to address localized capacity issues have ripple effects through adjacent cells.
Quality of Service	Easier to implement due to availability of higher capacity and predictability of resource requirements	Quite difficult to implement due to variable capacity, unpredictability of resource requirements, and existence of proprietary mechanisms; Industry moving towards IMS and PCC.