October 3, 2014

VIA ELECTRONIC FILING

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: ***Protecting and Promoting the Open Internet*, GN Docket No. 14-28; *Framework for Broadband Internet Service*, GN Docket No. 10-127**

Dear Ms. Dortch:

On October 1, 2014, Christopher Guttman-McCabe, Scott Bergmann and Krista Witanowski of CTIA – The Wireless Association® ("CTIA"); together with Dr. Jeffrey Reed, Willis G. Worcester Professor in Electrical and Computer Engineering and Director, Wireless@Virginia Tech, at Virginia Tech University met with David Goldman and Priscilla Argeris (Office of FCC Commissioner Jessica Rosenworcel) of the Federal Communications Commission ("Commission").

CTIA explained to staff that the Commission's tentative conclusion to extend a mobile-specific Open Internet framework is grounded in three aspects of the mobile marketplace: mobile broadband faces unique technical and operational constraints; mobile broadband technologies are rapidly evolving; and the "generally greater amount of consumer choice" for mobile broadband services than for fixed.[1] Dr. Reed reviewed with staff the attached technical paper he co-authored, *Net Neutrality and Technical Challenges of Mobile Broadband Networks*, and the attached presentation to help detail the operational constraints in these ever-evolving mobile networks, the complexity of mobile network management, why flexibility is needed, and how prescriptive regulation would undermine mobile broadband operators' ability to provide consumers with the level of service they have come to expect.

We explained the primary technical factors affecting mobile network management; how mobile broadband providers apply differential treatment to different traffic streams on a real-time, dynamic basis; the stark technological differences between wireless and wireline networks and network management; and the problems that would arise from imposing prescriptive Open Internet regulation on mobile providers. The technical factors they highlight include the following:

[1] Protecting and Promoting the Open Internet, *Notice of Proposed Rulemaking*, GN Docket No. 14-28, FCC 14-61, ¶ 91 (rel. May, 15, 2014); *see also id.* ¶ 62.

- ***Scarcity of radio resources.*** With the explosion in the amount of mobile data traffic, spectrum resources have not kept pace. Mobile broadband operators are thus constrained, necessitating aggressive and efficient management of limited radio resources.

- ***Radio resource sharing.*** As the number of users being served by the same base station fluctuates, the challenge of providing high-quality service to each of them also grows, requiring providers to make choices regarding how to manage network resources.

- ***Dynamic channel conditions.*** The allocation of radio resources constantly changes due to changing channel conditions and the interference environment, as often as every millisecond.

- ***Varying resource consumption.*** For a given channel condition, different services consume different amounts of resources. Thus, resource allocations change as users shift among different uses – often many times during a given session.

- ***Integration of devices and the network.*** Even when two devices experience identical channel conditions and allocation of radio resources, their design characteristics may dictate widely different throughput, further complicating network management.

- ***Ever-evolving network.*** Mobile broadband providers constantly manage user mobility across various technology generations and revisions across the network, offering differing levels of achievable network performance.

- ***Challenges of network capacity additions***. The intricacies of capacity growth (adding spectrum and wireless infrastructure deployment), along with ever-rising user traffic, make efficient utilization of the existing radio resources extremely critical to the user experience and network efficiency.

We also explained that mobile and fixed networks face vastly different technical challenges, as compared with fixed broadband offerings. Fixed networks have significantly higher capacity and predictability of resource requirements, whereas mobile networks are far more capacity constrained, with constantly changing user requirements and operating environments. Fixed networks involve channels that are relatively clean with signal regeneration, while mobile channels are impaired with interference, multipath and blockage, varying by location and from one millisecond to the next.

We noted that mobile broadband providers need more flexibility to manage their networks and to ensure that their customers have the service they have come to expect. That flexibility must include the ability to manage applications to avoid harm to the network and to maintain reliable and efficient service for the aggregate user experience. Similarly, mobile operators should be free from any anti-discrimination or commercial reasonableness requirement that would restrict their ability to innovate, optimize, and differentiate service to deliver a high quality product. In addition, expanded transparency requirements are infeasible in the context of dynamic, ever-changing mobile network operations. We explained that more prescriptive mobile rules would only stifle innovation and competition, to the detriment of the user-experience and system capacity, and would severely limit the ability of mobile wireless networks to meet the unique challenges faced by modern wireless networks.

Dr. Reed detailed the difficulties that would be created by the application of an overly broad or overly prescriptive set of rules on mobile broadband and the inability to remedy overbroad rules through the application of a reasonable network management exception. As his paper explains, "subjecting this type of network and network management to broad prophylactic rules with a vague 'exception' standard would provide no clarity to carriers, edge providers, or consumers as to how these networks will be managed. The exception would either simply subsume any rules (e.g., blocking or non-discrimination) or providers would be stripped of their ability to evolve and manage networks for the betterment of the entire subscriber base."

Pursuant to Section 1.1206 of the Commission's rules, 47 C.F.R. § 1.1206, this letter is being electronically filed via ECFS with your office. Please direct any questions to the undersigned.

Sincerely,

/s/ *Scott Bergmann*

Scott Bergmann
Vice President – Regulatory Affairs
CTIA – The Wireless Association®

cc: David Goldman
Priscilla Argeris

Attachments

Net Neutrality and Technical Challenges of Mobile Broadband Networks

Dr. Jeffrey H. Reed and Dr. Nishith D. Tripathi

September 4, 2014

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Abstract

As this paper describes in detail, the management of mobile broadband networks is a constantly evolving task. From millisecond to millisecond, handsets with differing capabilities, consumers with different usage patterns, applications that utilize different aspects and capabilities of both the handset and the network, and content consumption, including video, must be integrated with the network and managed adroitly to deliver a world-class broadband experience for the customer. Now imagine that millisecond to millisecond process happening while the consumer is in motion, while the handsets vary in capability (think flip-phone to smartphone), while the available network changes from 3G to 4G and from one available spectrum band to another, while traffic moves into and out of a cell sector, and while spectrum capacity is limited. **This entire process – the integration of all of these different variables – is unique to mobile broadband.** This paper is designed to illustrate and explain this extremely complex, very dynamic process in the context of the FCC's 2014 Notice of Proposed Rulemaking ("NPRM") on net neutrality.

The NPRM seeks comment on several proposed rules and associated mechanisms. In particular, the NPRM seeks comment on three rules that impact the management of mobile broadband networks. First the "transparency rule" requires mobile broadband providers to publically disclose accurate information regarding network management practices, performance, and commercial terms of their broadband Internet access service. Second, the "no-blocking rule," which was vacated by the D.C. Circuit, prohibited mobile broadband providers from blocking consumers from accessing lawful websites, as well as prohibited blocking applications that compete with the provider's voice or video telephony services, subject to "reasonable network management." The Commission is now exploring modifications to these rules. And third, though it tentatively concludes that such a rule should not be imposed on mobile broadband providers, noting its previous findings distinguishing mobile broadband in the context of net neutrality regulation, the Commission also seeks comment on whether it should apply to mobile broadband networks an "anti-discrimination/commercial reasonableness" rule, that would enforce a "commercially reasonable" standard of conduct for broadband provider practices.

This paper demonstrates that any extensions of, or additions to, the FCC's 2010 rules would be unwieldy and over-inclusive when applied to the complex and constantly-evolving management of mobile broadband networks. In fact, with the introduction of LTE, networks are managed and operated in a far more complicated and complex manner than the networks in place in 2010 when the Open Internet Order was adopted. As more of the LTE standard's advanced functionalities are incorporated into wireless networks, the complexity and prioritization in the networks will only grow, as will the benefits to consumers.

This paper addresses, based on the complexity and constantly-evolving management of mobile networks, why several of the proposals could be disruptive to a robust consumer broadband experience, and why some of the Commission's tentative conclusions should be maintained. For example, requiring mobile broadband providers to develop and/or report metrics regarding network management would be extremely difficult from a technical perspective and is unlikely to be useful due to the millisecond-to-millisecond adjustments that are inherent to a mobile broadband network. As described throughout, ever-increasing usage and scarcity of spectrum resources requires active management of the network to address capacity issues in a rapid fashion at the cell (or sector) level based on the demands placed on

the network. Similarly, while the competitive pressures on wireless carriers make imposition of a no-blocking rule unnecessary, broad application of a rule could have a significant negative technical impact on wireless broadband networks.

This paper explains how wireless applications can consume very large quantities of bandwidth, potentially causing problems for the end user or for others nearby. Third-party mobile apps and services can also interfere with and undermine network performance, and wireless network operators must be permitted the flexibility to manage their networks to prevent these negative effects. The NPRM also seeks comment on the feasibility of defining a minimum level of service that broadband networks must provide, proposing several possible standards that could be used. As discussed, such standards cannot be readily quantified for mobile wireless networks given the millisecond-to-millisecond adjustments in the network and would prevent wireless network operators from using techniques critical to ensuring a robust user experience. Also, as handset technology, base station technology, network technology and application technology rapidly change, it is unclear what metrics and standards would apply universally over time to fairly judge capabilities or performance.

The paper also demonstrates that the NPRM's tentative conclusion that an "anti-discrimination/commercial reasonableness" rule need not apply to wireless is the correct one. Differentiation among users and user services is required to provide a satisfactory quality of service to consumers. This is due to the dynamic nature of the radio environment and the need to operate good scheduling algorithm designs in a wireless network that maximize network performance while providing a good user-perceived experience. It is also due to product differentiation within a competitive marketplace in terms of what devices, features, and services might be offered as part of a carrier's service plan.

Finally, the paper explains that without today's real-time sophisticated scheduling algorithms that support network management that enables the service operator to cost-effectively provide services to many users simultaneously, overall user experience and network throughput will suffer. Treating all users alike at all times will degrade network performance by driving delivery to the lowest common denominator, and make the network less efficient. Adapting delivery to the predicted data delivery performance based on dynamic radio channel assessments promotes more efficient performance overall, across all users, even though at any single moment a network's site will distinguish between users based on channel quality.

The paper concludes that if adopted or expanded, several of the rules proposed in the NPRM would place constraints on mobile wireless networks that would stifle innovation and competition, negatively impact the user-experience and system capacity, and severely limit the ability of mobile wireless networks to meet the unique challenges faced by modern wireless networks. The result, in turn, would be harm to wireless users – the very outcome the Commission seeks to prevent.

From an engineering perspective, the concept that a network management exception to Open Internet rules is sufficient to allow wireless networks to evolve and operate is nonsensical. A modern wireless network must be managed aggressively. It is not an exception, it is a daily reality. Subjecting this type of network and network management to broad prophylactic rules with a vague "exception" standard would provide no clarity to carriers, edge providers, or consumers as to how these networks will be managed. The exception would either simply subsume any rules (e.g., blocking or non-discrimination) or providers would be stripped of their ability to evolve and manage networks for the betterment of the entire subscriber base.

This paper demonstrates the following:

- *Minimal regulatory constraints for mobile broadband networks would facilitate achieving higher spectral efficiency and improved user experience.*
- *Network Management is practiced extensively in mobile broadband networks and is critical for wireless operations.*
- *Preserving the ability for wireless carriers to block websites or applications as necessary for reasonable network management is important to avoid harm to the network or degradation and is critical to maintaining reliable and efficient service.*
- *Application of an anti-discrimination/commercial reasonableness rule to mobile broadband providers would hamper their ability to innovate, optimize, differentiate, and deliver high quality products and services.*
- *Expanding the transparency rule would increase costs and negatively impact network management option, but will not provide any meaningful benefit to consumers.*
- *Mobile broadband Internet Access service is an integrated information service due to the tight coupling between the device and the many network elements, needed for customized processing of different types of information, and the distributed nature of the complex wireless network.*

1. Overview

This technical paper demonstrates the unique technical aspects of wireless broadband networks that make the imposition of prescriptive net neutrality regulations highly problematic. Mobile broadband networks are highly dynamic, with constant changes in network standards, technology, and capacity needs. Mobile broadband operators are also managing their networks with limited spectrum resources, which must be managed actively and quickly to provide a high quality of service to consumers. As a result, wireless network management practices are necessarily complex. Further, congestion-related metrics are highly variable both temporally and spatially, and also change by the millisecond, making meaningful reporting impractical.

The 2014 Net Neutrality NPRM. With respect to mobile broadband service, the NPRM discusses the transparency rule, the no-blocking rule, and a revised anti-discrimination/commercial reasonableness rule. The existing transparency rule requires the service provider to disclose items such as network management practices and performance, though the FCC now seeks comment on whether and how to expand the transparency requirements for mobile wireless providers. The proposed no-blocking rule would prohibit mobile broadband service providers from blocking consumer's access to lawful websites and from blocking consumer's voice or video telephony applications that compete with mobile broadband service provider's services, though the NPRM seeks comment on whether to apply this rule more broadly to mobile wireless services. The NPRM proposes an anti-discrimination/commercial reasonableness rule that prohibits commercially unreasonable practices based on the totality of circumstances. The NPRM tentatively concludes that this rule should not be applied to mobile broadband service, but it seeks comment on whether to reverse that finding. Comments filed in response to the NPRM affirm the technical findings explained in this paper.

Mobile Wireless Networks Undergo Constant Technical Evolutions. Mobile wireless networks have evolved from first-generation analog systems to fourth-generation high-performance digital systems with multiple revisions within a given generation. These generations and revisions have widely different capabilities for both the networks and the mobile devices. Commercial mobile providers typically have multiple generations and revisions of generations simultaneously operating to serve legacy and new devices. Each time a new revision is introduced network management practices must change. The mobile broadband network and the mobile device perform numerous operations and interact with each other so that the end users have anytime and anywhere seamless communications experience. And the wireless industry has not reached the end of the road on innovation – the industry is already turning to the development of 5G technologies, injecting further complexity in the design and management of mobile wireless networks.

Mobile Wireless Networks Have Unique Technical Characteristics. The difficulty of quantifying guaranteed network performance and user experience is increased further due to the unique characteristics of mobile wireless networks. Examples of such characteristics include:

- scarcity of spectrum,
- dynamic radio channel conditions,
- the need to share radio resources among numerous users and user services with different Quality of Service (QoS) requirements,
- mobility,
- vast variability in loading due to both variations in user density per area and variations in usage and data rates,
- inherently complex process of network capacity growth, and
- integration of devices and network technologies with widely different data use and application capabilities.

These characteristics pose significant challenges to mobile wireless networks and make the imposition of the prescriptive net neutrality rules infeasible. In particular, determination of any reliable universal thresholds or metrics to quantify user experience or network performance is infeasible. Further, imposing such specific metrics would then distort optimization and would impose conditions that would degrade consumers' mobile experiences. Furthermore, mobile broadband providers need a high degree of flexibility to efficiently and effectively manage precious radio resources to ensure the best possible aggregate service experience for all subscribers.

QoS and the ability to treat different types of traffic differently based on their service needs are essential in a mobile network. In a mobile network, where the connectivity performance is not as stable as with a wired network, some services will simply not work well if they are not subjected to differentiated treatment. VoLTE is one example – it is meant to replace the traditional, circuit-switched phone service available on cellphones. Without prioritization of this traffic, the quality and reliability of the phone service would be severely impacted. Other future services such as LTE multicast have similar requirements. As new services are layered onto the networks, and historical separation of data and voice services vanishes the need to address QoS issues will only increase.

Wireless Operators Engage in Numerous Network Management Techniques. The network management practices in mobile wireless networks are extremely complex and consist of numerous mechanisms that are distributed among various components (or nodes) throughout the wireless and core network. Examples of network management mechanisms include the scheduling algorithm for downlink and uplink resource allocation, the handover algorithm, the load balancing algorithm, handling of the connected mode-idle mode transitions, adaptation to the changing channel conditions, power control, and interference coordination. These network management mechanisms are proprietary and are key competitive differentiators. Providers continually refine their network management practices to dynamically reflect changes in network equipment, application demands, and consumer usage patterns. Indeed, the rapid evaluation of these practices may well mean that by the time a given practice is challenged and adjudicated the practice may no longer be in use. Hence, a mandate to fully disclose these mechanisms, or to impose sweeping no-blocking or anti-discrimination rules, would discourage innovations, violate intellectual property rights, and harm consumers.

Wireless Network Operators Make the Most of Scarce Spectrum Resources. Wireless providers need maximum flexibility in the management of their networks to make the best use of the *scarce radio spectrum* in the presence of exponentially rising data traffic. Due to the scarcity of spectrum, innovative, high-performance, and ever-evolving network management mechanisms are absolutely essential to the overall network performance and user experience. For example, wireless providers must take steps to contain data-intensive applications from flooding the network with excessive amounts of traffic that would degrade service for many users. Wireless network operators require the flexibility to fairly balance network performance and user performance among users, devices, user services, and overall services on the network.

Net Neutrality Regulation Imposes Numerous Unique Challenges on Wireless Networks. As this paper demonstrates, application of the 2014 NPRM's proposed enhanced transparency rule to mobile wireless networks is nearly impossible, as network management practices are highly complex and are constantly changing. Furthermore, flexibility with respect to network management is essential to enable continued innovation in this area and these characteristics counsel strongly against far-reaching no blocking or anti-discrimination rules. Indeed, application of the no-blocking rule, meanwhile, is infeasible as the Commission has defined a "minimum level of service" that is not possible to guarantee for mobile wireless networks. The revised anti-discrimination rule is not intended to be applicable to mobile broadband service, and the findings of this technical paper strongly support this FCC conclusion. The FCC should continue to distinguish between mobile and fixed broadband with respect to the "no discrimination rule" and "anti-discrimination/commercial reasonableness rule." The dynamic and resource constrained (and at times, congested) nature of mobile wireless networks requires differentiation among users and user services to ensure a high quality of network performance and a satisfactory user experience.

Mobile Broadband Internet Access is an Integrated Information Service. Mobile broadband service is a highly integrated service that enables a subscriber to access a variety of services at once. The Commission itself observed that wireless broadband Internet access service offers a single, integrated service to end users that inextricably combines the transmission of data with computer processing, information provision, and computer interactivity. This level of integration requires cross-layer optimization in the network to ensure optimal network performance. Without the flexibility to actively manage their networks, mobile broadband providers will not be able to deliver integrated services at the level of quality that consumers have come to expect.

Recommendations. Due to the challenges faced by mobile network operators, which are outlined below, this paper recommends that the Commission:

- recognize that mobile wireless networks must be treated differently from other communications networks,
- strive for minimal regulation of mobile wireless networks to promote continued innovation, and refrain from applying far-reaching no blocking rules or an anti-discrimination/commercially reasonable rule,
- grant to network providers maximum flexibility regarding the design, management, and optimization of networks to serve consumers,
- refrain from establishing minimum performance standards (or metrics) for wireless networks, as these are impractical to define or enforce in the face of spectrum scarcity and variability, and
- ensure that proprietary and competitive network optimization and management processes are respected, which will ensure continued innovation and differentiation.

Flexibility in tuning and adapting the network management mechanisms to the fast-paced technology evolution, implementation of new features and uncertainty regarding the requirements of emerging applications or services urge that the network management mechanisms in mobile wireless networks should not be subject to broad disclosure, sweeping no-blocking, or anti-discrimination requirements. In other words, these network management mechanisms are intended, by their very nature, to optimize the aggregate performance for the benefit of all users. A focus on specific metrics may work to the detriment of the aggregate network performance and user experience. Conversely, reporting aggregate metrics will not reveal meaningful insights into specific instances.

2. Mobile Wireless Networks: Evolution, Network Architecture, and Operations

In order to fully appreciate the complexities associated with managing a wireless network and the difficulty of imposing an inflexible net neutrality framework, it is helpful to have an understanding of the rapid evolution of wireless networks and technology as well as the underlying architecture. In the more than 30 years that the wireless service has been provided to consumers, there has been a near-constant evolution of the underlying network. Section 2.1 summarizes this evolution of commercial mobile wireless networks. Section 2.2 illustrates the network architecture for the most popular 4G standard – Long Term Evolution (LTE). The wireless network and the mobile station (referred to as the user equipment or UE, mobile device, or handset device) perform numerous operations and interact with each other so that end users have anytime and anywhere seamless communications experience, processes which are quite different from wireline systems. Section 2.3 provides a glimpse of such operations and interactions.

2.1 Evolution of Mobile Wireless Networks

Mobile wireless networks have evolved from the first generation (1G) to the fourth-generation (4G) in just about three decades. Numerous 1G systems were used throughout the globe. Advanced Mobile Phone System (AMPS) is an example of the 1G system in the U.S. First generation systems were analog (radio air interface) in nature and offered primarily voice services. First generation systems evolved to second-generation (2G) digital systems. The 2G systems provided better voice quality and higher capacity compared to the 1G systems. Global System for Mobile communications (GSM), Interim

Standard-54 (TDMA), and later Interim Standard- 95 (IS-95 or CDMAOne) are examples of 2G digital systems engineered primarily for voice services used in the U.S. These digital systems evolved to '2.5 G' systems to better support low data rate uses, including GPRS for GSM, IS-136/EDGE for TDMA, and CDMA 2000 1X for CDMA. Due to expanding needs for wireless data at higher rates, third generation standards for mobile wireless networks focused on supporting data services more efficiently separated from voice channels. The 3G systems include a packet-switched core network to facilitate Internet access. Universal Mobile Telecommunication System (UMTS), High Speed Packet Access (HSPA), and 1xEvolution-Data Optimized (1xEV-DO as a CDMA derivative) are examples of true 3G cellular systems. The 3G systems support peak user data rates on the order of few megabits per second (Mbps). Finally, fourth generation systems such as Long Term Evolution (LTE) were developed to provide higher data rates (e.g., many megabits per seconds) and higher spectral efficiency. In addition, LTE would allow both data and voice to be provided in an integrated fashion using Internet Protocol (IP) for transport, also known as VoIP (Voice over IP). LTE is currently being deployed in the U.S. and around the globe and is expected to be the most dominant wireless standard for the near term. Mobile wireless networks will continue to evolve—indeed providers are already working on 5G—with future generations of technologies bringing new capabilities and challenges. It is key that this evolution and innovation be able to progress unfettered by restrictive regulation. Figure 1 depicts the evolution of mobile wireless networks.

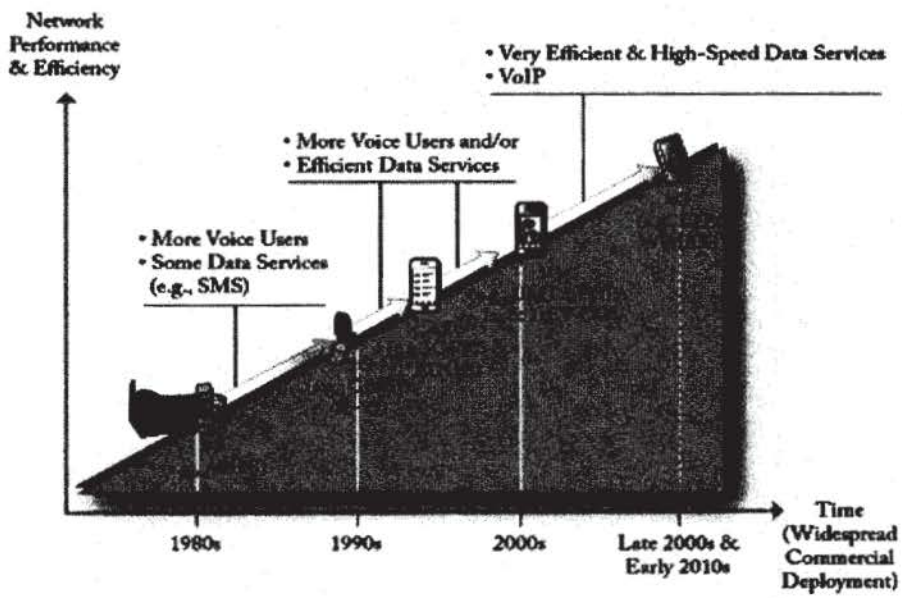

Figure 1. Ever-Changing Mobile Wireless Networks

Even for a given generation of wireless standards, multiple in-generation revisions that offer different features and capabilities exist. For example, 3G UMTS Release 99 supports a peak data rate of 2 Mbps in the downlink, while the 3G UMTS Release 5 feature called High-Speed Downlink Packet Access (HSDPA) supports a peak data rate of 14 Mbps in the downlink. The UMTS Release 7 feature called HSPA+ supports 21 or 42 Mbps in the downlink.

A mobile broadband provider typically has multiple revisions of multiple generations of technologies simultaneously operating. For example, in a given wireless service provider's network, some mobile devices may support GSM, some may support revisions up to HSDPA, some may support revisions up to HSPA+, and some may support revisions up to LTE. As the user switches from one generation of technology to another or from one revision to another, the performance can vary quite significantly. User mobility across different technologies needs to be properly managed by the mobile service provider. This involves complex network management.

The mobile service provider's network is never static. The network needs to be upgraded from one revision to another revision of a given generation technology and from one generation to another generation. Furthermore, once the network is upgraded with new features and capabilities, troubleshooting and then on-going optimization are carried out. The achievable peak performance keeps changing as the network undergoes never-ending upgrades. Even though LTE provides superior performance compared to prior generations of mobile wireless networks, LTE networks are currently undergoing upgrades with new features such as carrier aggregation and Voice over LTE (VoLTE), with each upgrade requiring changes to network management.

2.2 Network Architecture

The network architecture is different for 2G, 3G, and 4G (e.g., LTE) systems. This paper focuses on the network architecture for LTE due to its current dominance; however we will briefly describe simplified 3G and 4G network architectures below. In this section, we will describe the complex and decentralized nature of the wireless network and why application of net neutrality principles in this environment is so difficult. Moreover, with the move to an all IP-based infrastructure, the core wireless infrastructure is more intrinsically integrated into the radio network which in turn requires the wireless provider to calibrate and manage the radio resources and the core resources more carefully to ensure that subscribers are receiving an appropriate level of service.

LTE is defined by an organization or a standards body called the Third Generation Partnership Project (3GPP). 3GPP has defined a radio network called the Evolved-Universal Terrestrial Radio Access Network (E-UTRAN) and a core network called the Evolved Packet Core (EPC). The combination of the E-UTRAN and the EPC is termed Evolved Packet System (EPS) that can be viewed as the end-to-end LTE network. The LTE EPS uses the help of auxiliary networks such as IP Multimedia Subsystem (IMS) and the Policy and Charging Control (PCC) to provide a variety of services to end users. We will look at the main functions of the E-UTRAN, EPC, IMS, and PCC after a brief discussion of the simplified network architectures of 3G (e.g., UMTS) and 4G (e.g., LTE) network architectures illustrated in Figure 2.

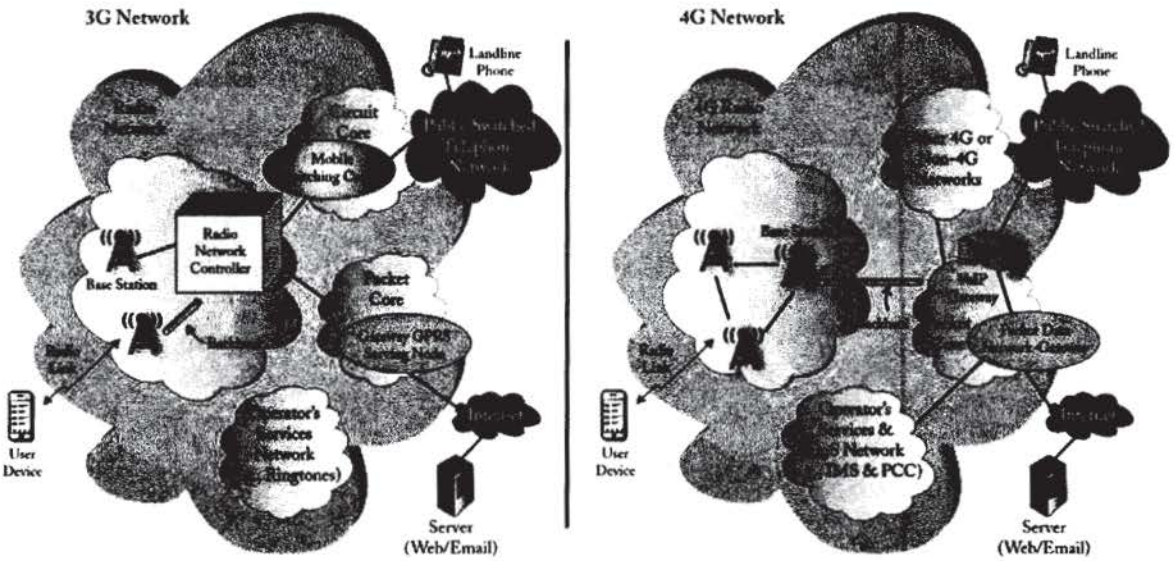

Figure 2. Simplified 3G and 4G Network Architectures

A 3G network consists of a radio network, a circuit-switched core network, a packet switched core network, and a services network. The radio network includes multiple Radio Network Controllers with each Radio Network Controller controlling hundreds of Base Stations. The Base Station communicates with the mobile device (referred to as the user device) via the air interface. The circuit-switched core network interfaces with the Public Switched Telephone Network so that the mobile device can communicate with a landline phone. The packet-switched core network enables the mobile device to access web and email servers via the Internet. The Mobile Switching Center is one of the nodes residing in the circuit-switched core network and controls the voice calls. The Gateway GPRS (General Packet Radio Service) Serving Node is an example of the packet-switched core network node and is in charge of assigning an IP address to the mobile device.

A generic 4G network consists of a radio network, a packet-switched core network, and a services and Quality of Service (QoS) network. The radio network includes the base stations. The packet switched network interfaces with the Internet using the help of a node such as the Packet Data Network Gateway. The packet-switched core network also interfaces with other 4G or non-4G networks. Since there is no circuit-switched core network in a typical 4G network, special nodes such as a VoIP gateway are needed to support calls between the 4G mobile device and the Public Switched Telephone Network. Auxiliary networks such as IP Multimedia Subsystem (IMS) and Policy and Charging Control (PCC) can be viewed as part of the operator's services and QoS network; these networks enable the service provider to offer to its subscribers a variety of IP-based services that have different QoS requirements. *We take a closer look at the LTE-specific 4G network architecture next.*

Wireless Radio Networks are Complex and Decentralized. The E-UTRAN has a decentralized and flat architecture. The E-UTRAN consists of the Evolved Node B (eNodeB or base station). The eNodeB communicates with mobiles over the wireless interface. The eNodeB makes the network management decisions related to the radio resource utilization. For example, the eNodeB evaluates the availability of the radio resources to determine if the subscriber can be offered services or not. The eNodeB implements a scheduling algorithm that allocates radio resources (radio bands and within one band, Resource Blocks (RBs)) to the active users based on numerous factors including the target quality of service (QoS) of the applications of users, the amount of data, the number of users and the types of the user applications vying for resources, the radio channel conditions of users, the capabilities of the eNodeB and the mobiles, and the available spectrum. The eNodeB executes the scheduling algorithm as often as every 1 millisecond (ms). The eNodeB also determines the type of multiple antenna technique and the combination of the modulation and coding scheme for a given mobile device to reflect the prevailing radio channel conditions for the mobile. The eNodeB also carries out load balancing and interference coordination with the neighboring eNodeBs. The eNodeB implements a handover algorithm that utilizes the measurement reports of the radio environment received from the user equipments (UEs) and makes a handover decision if appropriate.

The Core Network is Tightly Integrated with the Radio Network. The Evolved Packet Core includes several entities such as the Mobility Management Entity (MME), Serving Gateway (S-GW), Packet Data Network Gateway (P-GW), and Home Subscriber Server (HSS) with specific responsibilities assigned to these entities. The Mobile Management Entity authenticates the LTE subscriber by working with the Home Subscriber Server. The Home Subscriber Server stores the subscriber database including the authentication related information. The Mobile Management Entity keeps track of the mobile device location when the mobile is in the idle mode so that a page can be sent to the mobile device to bring it out of the idle mode. The Mobile Management Entity coordinates the setup of Evolved Packet System bearers[1] for a mobile device; the Evolved Packet System bearers help carry the user traffic between the mobile and the Packet Data Network Gateway. The Packet Data Network Gateway allocates one or more IP addresses to the mobile device. The Packet Data Network Gateway is a mobile's gateway to the outside world such as the Internet. The Serving Gateway helps move the traffic between the eNodeB and the Packet Data Network Gateway. When the mobile goes from one eNodeB area to another eNodeB area, the Serving Gateway learns about such user mobility from the Mobile Management Entity and is able to forward the traffic between the Packet Data Network Gateway and the correct eNodeB. When the user is receiving information from a web server, the IP packets from the web server pass through the routers in the Internet and arrive at the Packet Data Network Gateway. The Packet Data Network Gateway forwards the user traffic to the correct Serving Gateway. The Serving Gateway forwards the IP traffic to the eNodeB that is currently serving the UE. The eNodeB allocates suitable radio resources to the mobile device and sends the IP packets to the mobile over the air interface.

The End-to-End LTE Network is Carefully Calibrated to Provide Quality of Service to Consumers. The Evolved Packet System works with the IP Multimedia Subsystem (IMS) and the Policy and Charging Control so that subscribers can be offered a variety of IP Multimedia Subsystem-based services with suitable QoS. The QoS benchmarks are derived from the standards work in 3GPP and are not set by the individual wireless provider. Examples of IMS-based services include Voice over IP (VoIP), Short Message Service (SMS), and Instant Messaging (IM). The wireless service provider is aware of the IMS-based services of the subscriber and the signaling associated with the IMS-based services passes through the Evolved Packet System and the IMS network. The IMS network performs its own service authentication for the cellular subscribers to allow the subscribed IMS services. The IMS network processes the signaling messages and extracts QoS for a given IMS service. The IMS network specifies

[1] A bearer in this context refers to a "pipeline" connecting two or more points in the communication system in which data traffic flows. An "EPS Bearer" would be the pipeline through which data traffic flows within the Evolved Packet System.

such QoS to the Policy and Charging Control network, which compares the service-requested QoS with the subscribed QoS and determines the QoS and charging rules based on operator policies and user subscriptions. The Policy and Charging Control network uses the help of the Packet Data Network Gateway to initiate the setup of an Evolved Packet System bearer[2] to meet the QoS requirements of the subscribed IMS service. Non-IMS services such as regular email and web browsing use the best-effort Evolved Packet System bearer toward the Internet, and signaling and traffic for such non-IMS services do not pass through the IMS network. Once a suitable Evolved Packet System bearer is in place, the Policy and Charging Control and the Packet Data Network Gateway implement the negotiated service-specific QoS. Although the resource bottleneck is usually radio resources at the eNodeB, the QoS control is needed on the link between the eNodeB and the Serving Gateway and the link between the Serving Gateway and the Packet Data Network Gateway.

2.3 Typical Wireless Network Operations

The 3G and 4G mobile wireless networks are quite complex, with various mobile device and network operations combining to support high data speeds and ever-improving quality of service. Figure 3 provides examples of such operations of mobile devices and the network for LTE.

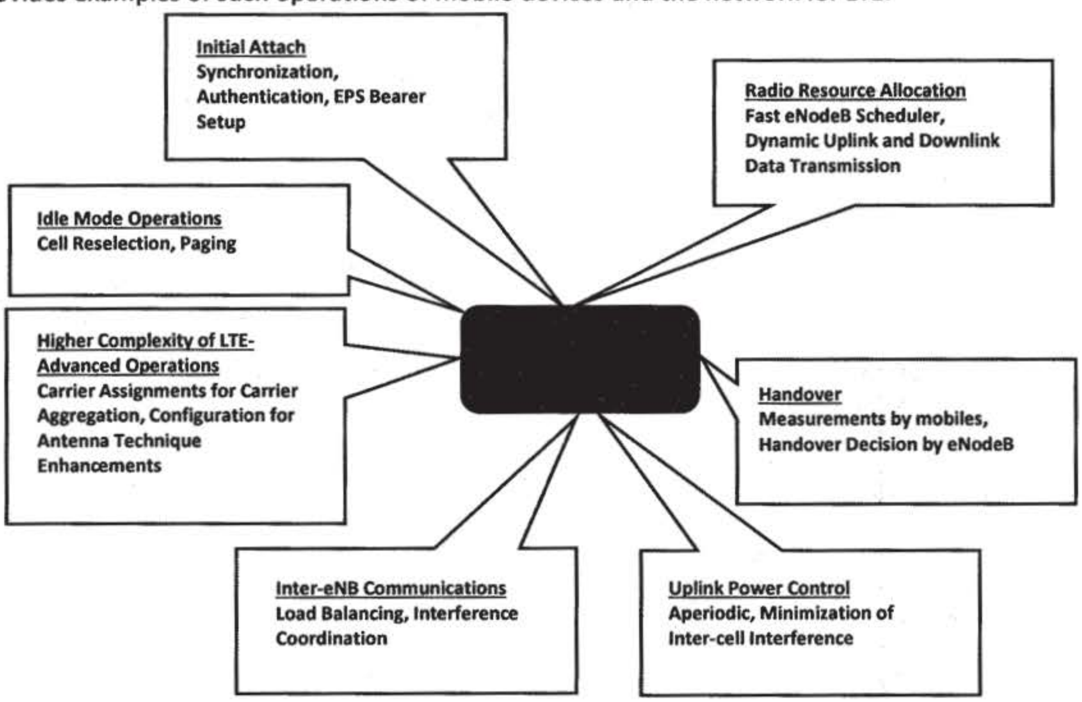

Figure 3. Operations of the Wireless Mobile Device and the Network

The mobile device carries out an initial attach procedure after power-up. During the attach procedure, the mobile achieves downlink and uplink synchronization with the eNodeB. The mobile and the network authenticate each other, and security is established. A default Evolved Packet System bearer with best-effort service is established toward a default packet data network to carry information without any

[2] End-to-end QoS is controlled at the EPS bearer level in LTE. Hence, if two applications need two different levels of QoS, two different EPS bearers with distinct QoS characteristics are needed. Furthermore, two applications with same QoS needs can be placed onto the same EPS bearer.

guaranteed data rate but with the target delay of 300 ms between the mobile and the Packet Data Network Gateway. The mobile is typically allocated an IP address during the default Evolved Packet System bearer setup.

Active mobiles have one or more Evolved Packet System bearers, and, the eNodeB scheduler dynamically allocates radio resources to the mobile for the downlink data transmission and the uplink data transmission. The eNodeB scheduler executes as fast as every millisecond to adapt to the radio channel conditions and to modify the allocated downlink and uplink resources.

The serving eNodeB configures the active mobile with measurements of neighboring cells that can be on the same carrier frequency as the serving cell or a different carrier frequency, or a different radio access technology (e.g., UMTS). The mobile device provides measurement reports when configured measurement events occur. The serving eNodeB makes a handover decision (if appropriate) and works with the target eNodeB to obtain resources for the mobile. Handover may occur without the movement of a user if the handover would balance traffic between eNodeBs.

In addition to allocating spectrum resources to the mobile, the eNodeB also controls the transmit power of the mobile by sending power control commands. Power control in LTE may be implemented as aperiodic and multiple power step-up and step-down sizes can be used. Power control helps minimize inter-cell interference in the uplink.

The eNodeB may communicate with the neighboring eNodeBs to carry out load balancing and to coordinate interference. Minimizing interference improves the achievable user throughput and cell throughput. Scheduling provides a compromise between fairness in serving all users and throughput for the overall network.

Complexity of the LTE network increases further with LTE-Advanced. The eNodeB scheduler needs to decide when to use multiple carrier frequencies simultaneously for a given mobile to improve throughput as part of the carrier aggregation feature of LTE-Advanced. More antenna technique enhancements are available in LTE-Advanced compared to LTE, and, the eNodeB dynamically needs to determine the type and configuration of the multiple antenna technique.

In the absence of data activity for a configurable time period, the eNodeB asks the mobile to enter the idle mode. The network needs to keep track of mobiles in the idle mode so that the network can page the mobile in the correct geographic region for incoming voice or data traffic. Even though the mobile in the idle mode does not consume any radio resources, it performs cell reselection to observe the strongest cell so that it is in the best possible cell when it needs to exit the idle mode to do some activity such as signaling exchange or data transfer.

3. Characteristics of Mobile Wireless Networks and Differences Between Wireless Networks and Wireline Networks

In Section 3.1, the characteristics of mobile wireless networks are discussed in detail. These characteristics dictate the complexity of network management and the need for flexibility for wireless providers to respond to changing circumstances within the network. Section 3.2 describes the significant differences between wireless and wireline network architectures that warrant differences in how mobile wireless networks are managed.

3.1 Characteristics of Mobile Wireless Networks and Resulting Implications

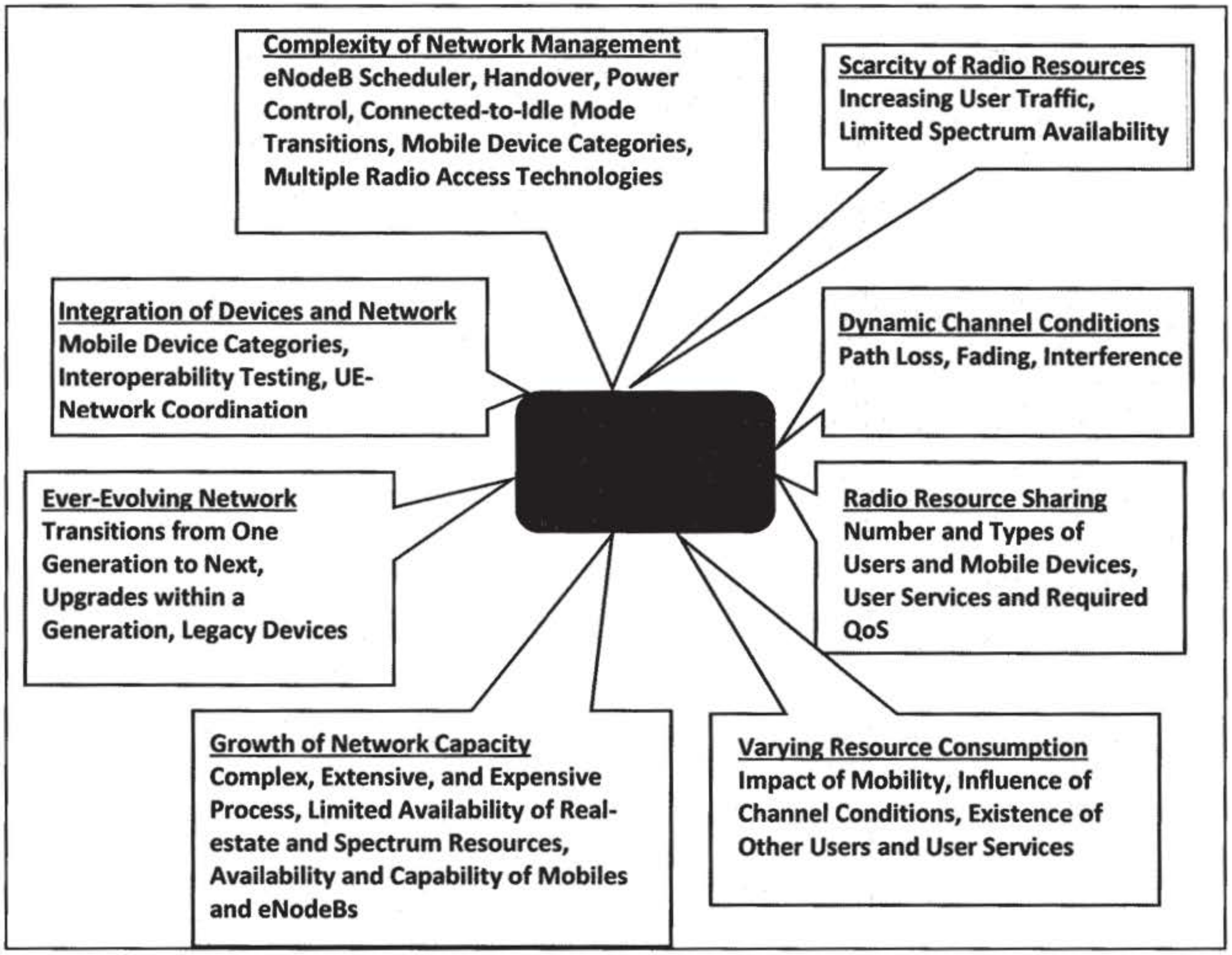

Figure 4. Characteristics of Mobile Wireless Networks

Figure 4 summarizes the characteristics of mobile wireless networks. These characteristics as a whole pose significant challenges to mobile wireless networks and make the application of prescriptive net neutrality principles to mobile wireless networks practically infeasible. In particular, determination of any reliable thresholds to quantify user or network performance is impossible. Furthermore, service providers need a high degree of flexibility to efficiently and effectively manage precious radio resources to ensure the best possible service experience for all subscribers.

Scarcity of Radio Resources. The popularity of the Internet and IP-based services such as video streaming have contributed to the explosion in the amount of data traffic traveling through the mobile broadband network. 4G services such as LTE bring with them higher data speed and greater video quality. The result has been more intensive use of 4G devices for bandwidth-heavy services, such as streaming video. Globally, in 2013 a 4G connection generated 14.5 times more traffic on average than a non-4G connection.[3] Although 4G connections represent only 2.9 percent of worldwide mobile connections today, they already account for 30 percent of mobile data traffic worldwide.[4] In the United States, the average 4G smartphone generated 1,739 MB of traffic per month in 2013, compared to 906 MB for non-4G smartphones.[5] Cisco estimates that "In the United States, mobile data traffic by 2018 will be equivalent to 383xthe volume of U.S. mobile traffic ten years earlier (in 2008)."[6] However, spectrum does not become available with the same growth rate as data traffic. Mobile broadband operators are constrained by the amount of spectrum available and the growth rate of new spectrum availability will not keep up with constant increases in user demand. This is exacerbated by the rapid rate of data intensive applications, now enabled by mass adoption of screen based smartphones and tablets that encourage use of pictures, graphics and video, and hence drive data demand as well as driving requirements for lower latency (real time response). Scarcity of radio resources, such as spectrum, necessitates efficient management of aggregate radio resources that needs to strike a balance among numerous competing factors such as the number of active users, target QoS of user services, and prevailing radio channel conditions.

Radio Resource Sharing. Limited radio resources must be shared among the active users in a given geographic area. Basically all of the channel capacity is divided among the various users and the speed for every user will go down as more users are added. A small number of very heavy data users using apps that are extremely data intensive can have a disproportionate impact on a large number of users. The eNodeB scheduler, as often as every millisecond, needs to consider a number of factors such as the number of active user devices, capabilities of these devices, capabilities of the eNodeB, prevailing channel conditions of different devices on the network, and target QoS of different services to determine the amount of radio resources for individual users. Even if best-effort service were the goal for all users, these users would typically experience different data rates as the eNodeB scheduler would try to improve overall network throughput and overall user throughput.

Dynamic Channel Conditions. For a given level of service quality, the required amount of radio resources is a function of the channel conditions, and the channel conditions not only vary over time, but also as a function of distance from the serving cell. The signal-to-interference plus noise ratio (SINR) directly influences the required radio resources. SINR is influenced by a variety of factors such as the propagation-based signal attenuation, the severity of fading (e.g., shadow fading and Rayleigh fading), and the amount of interference. Furthermore, the channel conditions hardly remain static. The channel conditions change due to factors such as user mobility. Network operators need maximum flexibility to manage radio resources to quickly adapt to changing channel conditions. Even to preserve a given data rate, the user may need 36 times more radio resources when the channel conditions degrade.[7] For

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[3] Cisco, Cisco Visual Networking Index, Global Mobile Data Traffic Forecast Update, 2013-2018 at 2 (Feb. 5, 2014) ("Cisco Feb. 2014 VNI Report"), available at http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf.

[4] *Id.*

[5] Cisco, VNI Mobile Forecast Highlights, 2013-2018 at "United States – Accelerating Network Speeds" ("Cisco VNI Highlights"), *at* http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/index.html#~Country (last visited June 10, 2014).

[6] *See* Cisco VNI Highlights at "United States – 2018 Forecast Highlights."

[7] To quantify downlink channel conditions, the LTE standard has defined Channel Quality Indicator (CQI) that is a measure of achievable spectrum efficiency. CQI=1 corresponds to poor channel conditions, while CQI=15 corresponds to excellent channel conditions. The efficiency of transmission decreases from 5.5547 bits to 0.1523

example, a far-away user may require more coding (effectively more redundancy, meaning a higher real radio data rate to support the same effective data rate) and more retries (faulty packets with too high an error rate to be properly decoded are resent). Thus not all users are the same, even though their perceived data rates (the data rate the end user observes) appear the same. There are no definable metrics that could 'fairly' assess the achieved data rate. It takes the network effectively more network air interface resources (radio capacity) to serve such far-away (poor radio channel) customers. There is no such analogous situation for wired or fiber optic networks, because the channel quality conditions do not vary by such a large ratio, nor are the channel conditions so variable over time or space.

Varying Resource Consumption. Users in different channel conditions and using different services consume different amounts of resources. Even for the fixed throughput, different users would consume different amounts of radio resources depending upon the device-specific channel conditions. For a given channel condition, different services such as email and a VoIP call would consume different amounts of resources. It is nearly impossible to determine the exact amount of radio resources for a given user due to the highly dynamic nature of mobile wireless networks.

Challenges of Network Capacity Additions. Mobile broadband providers invest heavily to increase network capacity and keep up with rising user traffic and user expectations. Capacity can be increased by adding more spectrum (more different bands or more channels within the existing band(s)), deploying capacity-enhancing features such as advanced antenna techniques, and adding more cells (either by deploying 'split' macro cells or small cells) via cell-splitting techniques to gain more capacity via more 'frequency reuse.' In general, many of these techniques are quite expensive and take a long time from the concept to full commercial realization. Also, many of these radio capacity enhancing techniques have practical limitations. Deploying multiple bands requires replacing the users' handsets, and the costs rise as the devices are more complex to serve multiple bands. Base station cell splitting techniques cannot be implemented indefinitely because co-channel interference levels rise as the cells get smaller. Advanced antenna techniques require larger antenna arrays.

Thus, as noted above, mobile wireless broadband providers cannot simply build their way out of capacity constraints but instead are dependent on government allocation of spectrum resources and must purchase rights to use these resources at auction. Purchasing spectrum resources and implementing other capacity-increasing techniques can be quite expensive. Adding macro cells poses an additional challenge of finding real estate. To exploit the full potential of the standard, the user equipment and the eNodeB need to have compatible capabilities. It may take years before the commercial incarnations of user equipment and the eNodeB are coordinated and can deliver the target theoretical peak performance aimed by the standard. The intricacies of capacity growth along with ever-rising user traffic imply that efficient utilization of the existing radio resources is absolutely critical to the user experience and the network efficiency.

Ever-Evolving Network. As mentioned in Section 2, the mobile broadband service provider's network keeps changing to adapt to the newer generations of cellular standards and multiple revisions within a given generation of the cellular standard. The network has to manage the user equipment (UE) across various generations and revisions. As the newer standard emerges, the older standard does not

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bits for a given modulation symbol, leading to 5.5547/0.1523=36.4 more resources under the poor channel conditions to preserve a given data rate in poor and excellent channel conditions.

disappear immediately. Even the first-generation analog standard in the U.S., AMPS, survived for more than two decades! There are wide variations in achievable network performance and user-experienced QoS change among generations and even revisions within a generation. For example, a user may experience data rates of tens of Mbps (megabits per second) in an LTE network, but this speed could go down to hundreds of kbps (kilobits per second) when the user enters a UMTS network. Such wide disparity of the achievable performance makes it difficult to quantify even the minimum level of QoS or any metric (used for assessing performance and network neutrality) that relies on the apparent user experience.

Integration of Devices and Network. The user equipment and the network need to be tightly integrated to ensure satisfactory user experience. The standards typically define multiple categories of user equipment with different capabilities. Common ground needs to be found between a given category of user equipment and the eNodeB. In LTE, the network learns about the capabilities of the user equipment during the initial attach procedure and properly configures the equipment to ensure seamless communications between the device and the network. The network often works with user equipment of differing capabilities. Hence, even when two devices have identical channel conditions and identical allocation of radio resources, they could experience widely different throughput depending upon their capabilities as well as the proprietary aspects of the devices, such as antenna design. Extensive integration testing is carried out to ensure proper operations of user equipment and the eNodeB and error-free interactions between the device and the network. Tight integration between the user equipment and the network (e.g., eNodeB, Evolved Packet Core, and IMS) plays an important role in ensuring good user experience. Again, no 'fair' metrics could be defined to account for such differences in performance.

Complexity of Network Management. The network management in modern mobile wireless networks is extremely complex. Numerous interactions among the user equipment, the eNodeB, the Mobile Management Entity, the Serving Gateway, the Packet Data Network Gateway, the IMS network, and the Policy and Charging Control network occur to provide seamless communications experience and end-to-end QoS to the user. As mentioned in Section 2, the eNodeB scheduler allocates radio resources for the downlink and the uplink data transfer to achieve target QoS levels for the established Evolved Packet System bearers. The eNodeB executes a handover algorithm to choose the best possible serving cell for a user. The eNodeB also manages uplink power control commands to the mobiles to minimize inter-cell interference. The user equipment would be allowed to transmit more power if its uplink channel conditions are poor and/or its uplink throughput requirements are high. The eNodeB and the Mobile Management Entity manage connected-to-idle transitions for the user equipment. The network management must consider different capabilities of different mobile device categories to optimize the experience for the user. Ensuring seamless mobility across different radio access technologies is a non-trivial task. The network needs to configure the user equipment with suitable measurements and needs to connect radio networks supporting different radio access technologies. Integration testing within the network is also required to verify error-free coordination across radio access technologies. Nevertheless, this cross-layer optimization of the overall network is important for overall system performance and continues to be a promising area for further improving overall network performance.

3.2 Differences Between Wireline Networks and Mobile Wireless Networks

Any proposals to extend network neutrality principles conceived in a wireline context to mobile operations must contend with the vastly different technical challenges of these two types of communication networks. This section provides an overview of the differences in technical challenges between wireline and wireless systems as they relate to network neutrality regulation.

Wireless channels are quite different from wireline channels. First, the bandwidth for a wireless service provider might be on the order of 10s of MHz (~10^7 Hz) (5-30 MHz), but a fiber optic system could be 10s of GHz (~10^{10} Hz). The difference represents at least a one thousand-fold difference and in many cases is much greater in total bandwidth. The number of users or data rates that can be accommodated is directly proportional to the total bandwidth (and, in wireless systems, is also affected by the relative dispersion of the users within particular cells). Although 3G and 4G technologies can enable multi-megabit per second wireless transfer rates (assuming adequate spectrum resources), wireless systems will never have the bandwidth of wireline systems. A wireline network can exploit advances in optical fiber technologies to achieve extremely high bandwidth exceeding thousands of Gbps (gigabits per second). In contrast, the limited amount of radio spectrum in mobile wireless networks puts a severe constraint on the achievable data rates on a wireless link. Additionally, the wireline network is very consistent with respect to capacity capabilities of the channel over time (no fading) and space (low loss per distance of fiber). The wireline network engineer knows precisely how much bandwidth is available in a single fiber optic strand and (other than losses over distance) will have a near-constant understanding of the performance of the transport layer. In contrast, wireless networks are faced with ever-changing radio environments. Temporal issues such as multipath, clutter, blockage, channel fading, and extraneous interference will result in changes in the performance of the network and the quality of service experienced by subscribers. Also, the quality of the radio channel necessarily degrades rapidly as a function of distance from the serving cell. Without extensive management (and the inherent compensation mechanisms used within the radio air interface: variable rate coding, variable modulation, retry, etc.) of the wireless network to account for these transport layer issues, customers would not receive the types of services and data rates that they expect.

Moreover, a "build more infrastructure" approach is much less of a solution to capacity issues in wireless systems than in wireline systems for a number of reasons. First, spectrum constraints place outside limits that simply do not exist in wireline. Overall aggregate wireline bandwidth can be expanded infinitely by adding more cables or fibers, or by technology upgrades. Wireless bandwidth is ultimately constrained by fundamental performance limits, available spectrum and interference. Second, mobility and propagation issues combine to create much greater variability in the channel as compared to wireline channels. Third, mobility and propagation issues combine to create much greater variability in wireless traffic—the spread between peak and average traffic levels is typically much wider for wireless than wireline—which makes it infeasible to design networks to meet anything approaching peak demands. Fourth, issues unique to wireless networks are associated with deploying more capacity. Wireless carriers continue to spend billions of dollars annually on infrastructure upgrades, but they will continue to face severe capacity constraints, particularly with demand growing far faster than anticipated and faster than new bands can be added.

In wireline systems, in contrast, capacity improvements without the large expense of laying new fiber have been made possible through better technology at the fiber ends. Such technology options simply are unavailable for wireless systems, and dynamic prioritization and other management techniques are and will remain essential. While wireless network providers have taken efforts to use their spectrum resources more efficiency, such as by using small cell technology, as explained above wireless operators simply cannot "build out" of capacity constraints to the same extent as their wireline counterparts. In the 30 year history of commercial mobile networks, wireless providers have moved from analog (1G) to digital (2G) to 3G and now 4G services. However, each radio interface change requires substantial time and investment to bring about the gains in efficiencies expected from the more robust standards. Each base station must be updated via software and/or hardware to accommodate the changes in the air interface. All of the existing mobile devices in the network must be replaced to provide the full benefits to spectrum efficiency that the new radio standards allow. In contrast, wireline networks are able to upgrade solely at the edge of their networks to help gain efficiencies and do not require the extensive costs associated with wireless network technology migration to provide capacity gains. Fiber also presents extensive capacity availability throughout the network that has not yet been tapped for use, but is readily available for carrying traffic with updates to the technology at the fiber ends. Not only is the bandwidth of the wireless channel severely constrained compared to wireline channels, the reliability of the wireless channel is well below that of a wireline channel. The reliability issue is due to a number of factors, such as blockage of the radio signal (called shadowing), echoes or multipath of the signal, thermal noise, and, more importantly, interference. These impairments to the channel create substantial additional complexity and variability. Planning and operating a wireless deployment to ensure Quality of Service (QoS) and coverage is extraordinarily difficult because these impairments are random and unpredictable.

Interference is often the most important of these impairments, and, by its very nature, is constantly changing between and within cells. Interference occurs when multiple signals share the same spectrum. These signals are typically associated with the same service provider but are sometimes due to another service provider using the same or adjacent spectrum bands. Interference limits capacity in a wireless system on a dynamic basis, varying by location and from one millisecond to the next, and this problem has no counterpart in wireline systems.

Deployment and maintenance of wireline systems is less dynamic than wireless systems. Although wireline electronics and services continue to evolve, the advent of fiber has brought relative stability and efficiency to the wireline network architecture. In contrast, only change is constant in wireless standards and networks. As a result, network management practices must constantly evolve to address new architectures, new technologies, new standards, and new wireless applications with new performance needs.

These various features of mobile wireless networks make them much different than wireline networks. Table 1, below, summarizes the differences between wireless and wireline networks.

Table 1. Summary of Differences Between Wireless and Wireline 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
Power	No need to manage power/battery life in wireline network for end user devices.	Limited power/battery on user device that must be accommodated through network management
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 Increased Traffic Demand (i.e., the Capacity Problem)	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	Comparatively 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 is required; Infrastructure changes to address localized capacity issues can have ripple effects through adjacent cells

Characteristic	Wireline	Wireless
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 toward IMS and PCC

4. Challenges of Implementing the FCC's Proposed 2014 Rules on Net Neutrality to Mobile Wireless Networks

The NPRM seeks feedback on the *transparency rule*, the *no-blocking rule*, and the *anti-discrimination/commercial reasonableness rule* in the context of mobile broadband service providers. The NPRM proposes to apply the transparency rule to both fixed and mobile broadband wireless access. Regarding the no-blocking rule, the NPRM proposes to treat mobile and fixed broadband services differently. Furthermore, just as the FCC chose not to apply the 2010 unreasonable discrimination rule to mobile broadband service, the 2014 NPRM tentatively concludes that the replacement rule – or "anti-discrimination/commercial reasonableness" rule – would not be applicable to mobile broadband. Section 4.1 discusses the challenges of applying the enhanced transparency rule to mobile wireless networks. Section 4.2 describes the problems encountered while applying the enhanced no-blocking rule to mobile wireless networks. Section 4.3 briefly explains why the NPRM's view of not applying the unreasonable discrimination rule and the "anti-discrimination/commercial reasonableness" rule to mobile wireless networks is the correct approach. Extensions of the transparency and no blocking rules beyond those adopted in 2010 would be unwieldy and over-inclusive. Application of an anti-discrimination/commercial reasonableness rule to mobile broadband providers would hamper their ability to innovate, optimize, differentiate, and deliver high quality products and services.

4.1 Transparency Rule and Mobile Wireless Networks

The 2014 NPRM seeks comment on expansions of the transparency rule that would require mobile service providers to disclose information in several categories, including *network management practices*, *performance*, *congestion specifics (e.g., speed and packet loss)*, *peak load management*, and *parameters of default or best-effort service*. However, as explained below, for mobile providers there are numerous technical and practical problems in meeting these proposed expanded disclosure requirements that make implementation of any enhanced transparency rule problematic, resulting in increased costs, less responsive service due to limitations on network management and would not provide consumers with relevant or useful information.

4.1.1 Network Management Practices

In a typical wireline network, the only variable is the amount of traffic on a given link – all other things such as capacity, etc. are typically static. This makes management of the traffic relatively straightforward using standard queuing techniques (e.g. Weighted Fair Queuing) to ensure all customers receive a fair share of the available bandwidth during congestion caused by a small number of users.