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Fourth Generation Wireless Systems: Requirements and Challenges for the Next Frontier

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FOURTH GENERATION WIRELESS SYSTEMS: REQUIREMENTS AND CHALLENGES FOR THE NEXT FRONTIER

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ABSTRACT

Fourth generation wireless systems (4G) are likely to reach the consumer market in another 4-5 years. 4G comes with the promise of increased bandwidth, higher speeds, greater interoperability across communication protocols, and user friendly, innovative, and secure applications. In this article, I list the requirements of the 4G systems by considering the needs of the users in the future. These requirements can be met if technical and business challenges can be overcome. Technical challenges include mobility management, quality of service, interoperability, high data rate, security, survivability, spectrum, intelligent mobile devices, middleware, and network access. I discuss the most plausible solutions to these technical challenges in this paper. Business-related challenges include billing, payment methods, pricing, size of investments, content provision and mediation, and the trade-off between richness and reach. If these technical and business challenges can be met, then 4G will become the next frontier in data and voice communication infrastructure.

Keywords: convergence, challenges, fourth generation wireless systems, interoperability, mobile business, mobility, quality of service.

I. INTRODUCTION

The world is experiencing a surge in the usage of mobile devices and mobile services. The worldwide wireless voice adoption rate in 18 countries in 2004 exceeded 68%, with countries like Hong Kong and Italy experiencing adoption rates exceeding 100% [Brosnan, 2005]. Although wireless systems are still primarily used for voice communication, the demand for wireless data services is growing quickly. The number of mobile Internet users is expected to exceed 74 million by 2007 [Brosnan, 2005]. The number of mobile phone users exceeded the number of fixed line phone users for the first time in 2002 [ITU, 2003]. Analysts believe that the number of mobile Internet subscribers will exceed the number of fixed Internet subscribers around 2007 and will reach 1700 million subscribers worldwide by 2010 [Ha et al., 2003]. At about the same time, 75% of the network operators' revenue will come from data traffic [Katz and Fitzek, 2005b]. As the population of the world becomes more technologically knowledgeable, the average annual household expenditure for telecommunications services will continue to rise and will reach 2% of the annual household income by 2015 [Brosnan, 2005].

Clearly, fixed line services and subscriptions are on the decline and wireless subscriptions are on the rise with some families 'cutting the cord' by canceling their fixed line services and becoming fully wireless. Stat/MDR, a consultancy firm in the USA, estimated that about 29.8% of all wireless subscribers in the USA will become 'mobile only' by 2008 [Wheelock, 2004]. Several developments contributed to this increasing popularity of wireless systems.

1. The declining cost of mobile voice and data services. Most mobile service providers adopted a flat-rate pricing for usage of a fixed but large number of minutes per month, which proved quite popular with consumers.

2. The growing interest in new types of applications that depend specifically on wireless systems. Examples of such applications include mobile financial services (mobile banking mobile payments, mobile ticketing), mobile gaming and entertainment services (mobile television, mobile music, multiplayer mobile gaming, multimedia online role playing games, mobile sports, video on demand, mobile gambling) [Varshney and Vetter, 2002], mobile healthcare (mobile telemedicine, mobile healthcare data center) [Varshney, 2005a], vehicular mobile commerce (diagnostics and safety messaging, highway and traffic management, entertainment on-the-go, vehicular advertising, emergency management) [Varshney, 2005b], mobile auctions [Varshney, 2002], mobile home management [Katz and Fitzek, 2005b], mobile travel guide, mobile inventory management [Mathew et al., 2004], mobile logistics [Dekleva, 2004], mobile office [Fjermestad et al., 2006], among others.

Juniper Research forecasts:

- the revenues generated from mobile gaming, currently US $3.1 billion, will reach US $18.5 billion by 2009

- the revenues generated from mobile music services will reach US $9.3 billion in 2009 from US $3.6 billion in 2004, and

- the revenues for mobile sports services will increase to US $5 billion in 2009 from a mere US $600 million in 2004 [Juniper Research, 2005].

These new applications which are often grouped under the umbrella of mobile commerce or m-commerce will continue to evolve over the next few years and gain more popularity among users. At the same time, the wireless telecommunications infrastructure grew significantly in the last decade. From a pure voice-based service, wireless systems evolved to a voice and data based service. The wireless systems progressed rapidly from the first (1G) and second generations (2G) of systems to the third generation systems (3G). Although the 3G system is still being deployed in several countries, leading telecommunications companies are devoting effort and resources to developing the fourth generation wireless technology (4G) that can become operational by 2010. In the forefront of these companies is Japan's DoCoMo which plans to devote a research budget of US $91 million to developing this state-of-the-art technology [Rocks, 2004]. It is generally accepted that 4G wireless systems will overcome the limitations of the existing wireless systems, support new applications that are increasing in popularity, provide enhanced content management and delivery using higher bandwidth, support interoperability of heterogeneous networks, provide efficient resource allocation for maintenance of quality of service (QoS), and use an all-IP architecture that will allow easy mobility management of users. Despite these promises, 4G wireless systems must still overcome several challenges before 4G promises can be delivered to the full satisfaction of future customers.

II. DEFINITION OF 4G

What 4G will be is not clearly defined. However, the earliest vision about 4G (often termed as the 'linear vision' of 4G) is that it will be a super-enhanced version of 3G. That is, an entirely packet switched network with all digital network elements, and a high available bandwidth of 1 Gbps standstill and of 100 Mbps in motion. This view is much more prevalent in Asia than in other places of the world. Another definition of 4G (often termed as the ‘concurrent vision’ of 4G) is that it will be a convergent platform that will consist of heterogeneous networks and heterogeneous systems. This view is more prevalent in Europe [Katz and Fitzek, 2005b]. For example, Walter Konh Suser of Siemens stated that “the transition to 4G will not be a change in interface technology as with UMTS but it promises to integrate different modes of wireless communications – from indoor networks such as wireless LANs and Bluetooth, to cellular signals, to radio and TV broadcasting, to satellite communications” [Duda and Sreenan, 2003]. Researchers believe that 4G will be much more than an advanced version of 3G. 4G is definitely not another technology driven approach, not another new access scheme, nor another extension of the capabilities of current mobile systems [Katz and Fitzek, 2005a]. The researchers’ vision of 4G consists of five key elements:

1. fully converged services that allow seamless, secure, and personalized delivery of services to users,
2. ubiquitous mobile access that transcends different types of networks working on different technological standards,
3. diverse user devices that are adaptable and intelligent,
4. autonomous networks that provide self-management according to the needs of the users, and
5. dependency on mobile middleware agents that simplify activities and provide transparency to users [Evans and Baughan, 2000].

The network supporting 4G will have a heterogeneous, distributed, and all-IP architecture so that users will be able to access it anytime and anywhere. ‘Integration’ will be the key word for 4G. It will be backward compatible with 2G, 2.5G, and 3G systems, and will be fully IP-based. The all-IP feature will allow integration with many systems from satellite broadband to 3G systems. Although it is hard to provide a clear definition of 4G, NTT DoCoMo is defining 4G by introducing the concept of ‘MAGIC’, an acronym for <u>M</u>obile multimedia communications; <u>A</u>nywhere, anytime with anyone; <u>G</u>lobal mobility support; <u>I</u>ntegrated wireless solution; and <u>C</u>ustomized personal service [Sun et al., 2001].

III. MIGRATION TO 4G

The first generation (1G) wireless telephony was designed in 1970s. Its implementation was based on analog techniques and cellular structure of mobile communications. The main limitations of the 1G system was that, because of analog voice signaling, the quality of communication was low and the use of the spectrum was inefficient.

The second-generation (2G) mobile technology was primarily used for voice transmission and was based on digital signal processing techniques. The competitive rush to design and implement digital systems gave rise to a number of incompatible standards for 2G such as GSM (Global System Mobile), CDMA (Code Division Multiple Access), TDMA (Time Division Multiple Access) and PDC (Personal Digital Cellular) [Ibrahim, 2002]. The 2G system was a significant improvement of the 1G system it terms of quality. It allowed increased bandwidth and better security.

2.5G, an interim step that was introduced to entice users to move on to 3G services, was an extension to 2G with data service and packet switching methods. GPRS (General Packet Radio Services) and EDGE (Enhanced Data GSM Environment) were used in 2.5G to allow Internet access from mobile devices.

To reconcile the incompatible standards and to introduce higher data transfer rates, the 3G system was developed. 3G allowed better handling of multimedia including voice, data, and video and it also provided flexibility in terms of routing. Two technical standards are currently in use for the 3G systems. They are the WCDMA and the CDMA 2000. The third standard that is being developed indigenously by China is known as TDSCDMA. Although 2.5G and 3G technologies promised data transfer rate up to 384 Kbps and 2 Mbps respectively, the average throughput per user is not expected to be more than 171 Kbps in busy hours [Zahariadis, 2003]. This speed is just adequate to meet voice, basic data communications, and wireless Internet access. It is true that 3G can support multimedia Web-based services at a much higher speed and quality than 2G/2.5G. However, the current deployment of 3G includes the following limitations [Zhen et al., 2002]:

- Difficulties to extend to higher data rates with CDMA due to excessive interference between services
- Difficulties to satisfy different QoS and performance requirements for diverse variety of multimedia services due to constraints imposed on the core network by the air interface standard
- Saturated bandwidth allocation for 3G
- Difficulties to support global roaming across heterogeneous networks like cellular, fixed wireless, satellite etc.
- Difficulties to support high speed mobile access and provide various services from narrowband voice to wideband multimedia Internet browsing

Table 1 compares the generations of wireless systems.

Table 1. A Comparison of 1G, 2G, 2.5G, 3G, and 4G Wireless Systems

Technology	**1G**	**2G**	**2.5G**	**3G**	**4G**
Design start time	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	~ 2010
Technology	Analog signal processing	Digital signal processing	Packet switching	Intelligent signal processing	All-IP based
Standards	AMPS, TACS, NMT	TDMA, CDMA, GSM, PDC	GPRS, EDGE, 1xRTT	WCDMA, CDMA2000	OFDM
Bandwidth	2.4 – 30 kbps	9.6 - 14.4 kbps	171 – 384 kbps	2 Mbps	~100 Mbps
Core network	PSTN			PSTN, some IP network	Internet
Services	Voice	Voice, SMS	Voice, data	Voice, data, multimedia	Voice, data, content-rich multimedia

Adapted from Ibrahim [2002]

1xRTT – 2.5G CDMA data service up to 384 kbps	**GSM** – Global System For Mobile
AMPS – Advanced Mobile Phone Service	**NMT** – Nordic Mobile Telephone
CDMA – Code Division Multiple Access	**PDC** – Personal Digital Cellular
EDGE – Enhanced Data For Global Evolution	**PSTN** – Public Switched Telephone Network
FDMA – Frequency Division Multiple Access	**TACS** – Total Access Communications System
GPRS – General Packet Radio System	**TDMA** – Time Division Multiple Access
WCDMA – Wideband CDMA	**OFDM** – Orthogonal Frequency Division Multiplexing

IV. REQUIREMENTS FOR 4G

In the last three and a half decades wireless systems moved from being used only for military and scientific communication to affecting the everyday life of a large portion of the globe. As the technology evolved over time, the needs of the users and the services also changed. Initially, the wireless systems were designed only to carry voice communication. As the Internet became more and more popular, users felt the need to access the Internet through their mobile devices. This attitudinal change gave rise to the requirement of data communication through wireless systems. The transformation from 1G to 2G was fueled by the requirement to improve quality of voice communication. The transformation from 2G to 3G was fueled by the need to allow voice and data communication through the mobile devices. An important question to answer is therefore what will be the requirements that will speed up the transformation from 3G to 4G.

BANDWIDTH

We can easily see from the statistics reported in Section I that the bandwidth needs of the users are changing. Downloading and sharing of photos, ringtones, movie clips, patient diagnostic images are all bandwidth intensive activities. New applications include mobile television with full-motion video and real-time videoconferencing. Although SMS is still popular with users, it is likely that, with the right pricing, MMS will become as popular or more. If customers avail themselves of some of the mobile commerce activities described earlier, they will demand greater bandwidth. The current data connections through traditional cellular networks provide bandwidths below 100 Kbps and less when the user is inside a building [Yang et al., 2004]. Indeed the bandwidth must increase.

SEAMLESS ACCESS, INTEROPERABILITY, AND CONVERGENCE

One of the problems that all users of mobile devices currently face is the lack of universal and seamless access due to unavailability of a global standard. It will be of great benefit to consumers in the future if any type of mobile device is able to work in any type of network, be it Wi-Fi, cellular, or satellite networks. Interoperability implies that there will be no need to use a laptop for data analysis, mobile phone for conversation, PDA for checking the user’s calendar, and TV for viewing sports events. Life will be simpler if all devices converge to a universal mobile device that allows plug-and-play in any type of network environment and supports all activities that users want. Furthermore, such access will work unhindered when the user travels between regions and even in transit.

QUALITY OF SERVICE

Current wireless systems do not provide an assurance of quality. Latency and jitter are two problems that affect all wireless systems. These problems will become more pronounced in the future as delay sensitive applications become more common. For example, remote telemedicine in emergency situations imposes stringent restrictions on delay, jitter, and packet loss. The common approach of overprovisioning capacity may not work because many multimedia rich, bandwidth intensive applications are running at the same time and vying for capacity. A fair resource allocation scheme that is adaptable to network conditions, allows prioritization of traffic, is easy to implement, and provides cost savings is needed in future wireless systems.

EFFICIENT USE OF FREQUENCY SPECTRUM

Frequency reuse is a characteristic of wireless systems and techniques like FDMA, TDMA, and CDMA allow multiplexing of channel frequency between users to allocate a constrained resource intelligently among contending users. But the number of users of mobile services is increasing at a tremendous rate as well. This is evident in the increasing adoption of mobile services in the two most populous countries in the world, China and India. Although new frequency bands were released for wireless systems, it may not be sufficient to support such large number of subscribers. More advanced techniques for frequency sharing and channel reuse will be required in the future.

MOBILE DEVICES

Mobile devices advanced in the last decade both in appearance and functionality. Black and white LCDs gave way to multi-pixel color screens. The weights of devices decreased, chip and battery design improved, and Internet access became commonplace. So far, however, mobile devices play a passive role in generating options in call and content management. In most cases, the functionalities provided by the mobile devices are not automatic but user driven. For future applications, the devices will need to incorporate more software support to make them adaptable, location aware, context sensitive, and more attuned to serving the needs of the user without requiring user intervention.

PERSONALIZATION

At present, mobile services contain few personalized features in them like screensavers and ringtones. Future mobile services will demand 'deeper' understanding of the users' needs and the time of a specific need. Recommendation systems will be an integral part of mobile services in future. Every mobile device will act as an agent to represent the user in activities and transactions ranging from automatic bill payments to making reservations at a local restaurant [Zhang, 2003]. If the user is looking to buy a used car the mobile location based service should search used car Web sites belonging to the locality and alert the user when (s)he is in the immediate vicinity of a dealer offering cars that the user prefers.

CONTENT AND BILLING

Multimedia rich content that includes streaming or recorded video or interactive gaming is available in today's wireless systems. However, it usually comes from the same content provider and does not change according to the location and needs of the user. Future wireless systems will allow users more choice of content from a number of content providers. Obviously billing will become more complicated because many network service providers and content providers will be involved. However, the same simplicity of billing that is a hallmark of today's wireless systems will have to be maintained in spite of the complexities involved in content management.

SECURITY AND PRIVACY

Viruses and spam are a common feature affecting mobile services. For example, at least 30 variants of mobile virus for the Symbian operating system are known [Martin, 2005]. As more m-commerce activities take place, the threats of malware and phishing will only increase. Although many users believe that m-banking is advantageous, they are reluctant to take advantage of it due to security concerns. Future wireless systems need to be more secure in terms of better authorization, authentication, integrity, and non-repudiation, and need to improve the user perception about the security of the provided services. Since future mobile services will be more personalized the user related data will be of great importance and the wireless systems will have to ensure the privacy of the data related to user preferences and user transactions.

In addition to these requirements consumers will expect that the 4G wireless systems will be backward compatible with the earlier wireless systems. Given the slow adoption rate of 3G it is likely that consumers will adopt 4G slowly as well. So there will be a time period with significant overlap between 3G and 4G. At the same time, it only makes sense if the 4G systems will make use of the existing infrastructure for the earlier wireless systems. A large amount of investment went into building that infrastructure. An attempt to reinvent must be avoided. All the eight requirements that I listed above in this section act as drivers for the next generation wireless systems. When I compare my list of drivers for 4G with that available in the literature I find four main drivers for 4G: (1) personalization, (2) seamless access, (3) QoS, and (4) intelligent billing [Ballon, 2004]. An alternative view of the drivers for 4G include high bandwidth, lower cost, spectrum availability, new applications, and integration of wireless technologies [Forge, 2004]. Some researchers include multitude of diverse devices, predominance of machine-to-machine communications, location dependent applications, QoS, dynamic networking and air interfaces, improved coverage, and improved and dynamic spectrum usage as the key drivers for 4G [Evans and Baughan, 2000]. Whatever the list of drivers for 4G may be, a number of technical and business hurdles must be overcome to achieve the requirements specified in this section.

V. TECHNICAL CHALLENGES FOR 4G SYSTEMS

Several technical issues need to be resolved before practical implementation of 4G is possible. Research is ongoing to find feasible solutions to overcome the technical hurdles. This section describes the various technology related challenges that will be faced by 4G systems and possible solutions that current technology offers to meet these challenges.

MOBILITY MANAGEMENT

In 4G systems, mobility may occur in two ways: (1) by the user moving from place to place (personal mobility) and (2) by the user accessing the network using different devices at different places (terminal mobility). For example, a user may access a video message using a desktop computer at work, a PDA on the road, and a laptop at home. In terminal mobility the user moves through the network while accessing the application using the same mobile device. Management of personal mobility can be achieved in 4G systems by using the Session Initiation Protocol (SIP) [Raivio, 2001]. It can help to locate one or more IP addresses where the user can receive multimedia streams so the user can change the access device without notifying the callers. The protocol of choice for terminal mobility is mobile IPv6. In mobile IPv6, each mobile device will have a permanent 'home' IP address and a 'care-of' IP address. In the roaming mode, the call will be forwarded to the 'care-of' address and the caller will be notified of this forwarding. Because mobile IPv6 is not designed for real time communication, service disruptions are possible during handoffs. The most important aspect of terminal mobility is to provide the capability for seamless vertical handoffs (when users move between different wireless systems) as well as horizontal handoffs (when users move between cells) in 4G systems. For handoff situations, the challenge is to authenticate and manage user profiles and to allow transparent movement to users.

The solution to this problem is to develop preemptive context aware handoff. For example, if the user is moving from one location to another on a train, it can be predetermined which access points of which networks should take up the call during the course of the journey. This situation may be preprogrammed in the operating systems of the handheld device [Prehofer et al., 1999]. In 4G systems, vertical handoff becomes a necessity due to the converged nature of the networks. Vertical handoff is complicated because several factors must be considered before vertical handoff can take place. The information about available bandwidth and traffic condition, cost of operation, and reliability of operation of the different available networks have to be considered and a complex multi-network optimization problem has to be solved before the decision to handoff to a different network can take place. [McNair and Zhu, 2004]. Figure 1 shows how a vertical and horizontal handoff may take place in a 4G network.

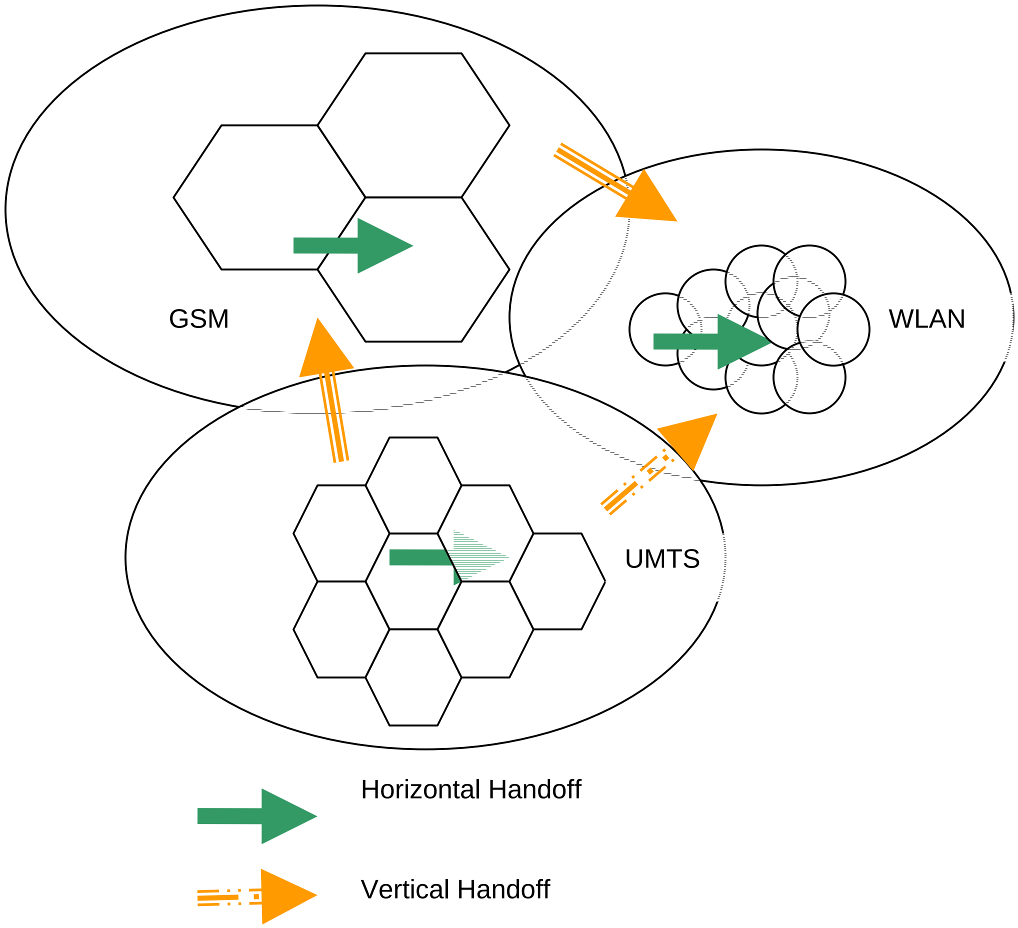

Figure 1. 4G network Showing Horizontal and Vertical Handoff

Stratospheric communication [Chao et al., 2002] can also be used for mobility management in 4G systems. In this technology, a balloon filled with helium or an unmanned aircraft provides a mobile platform in the sky, about 20 km from the surface of the earth. There will be several such platforms in the sky that will be linked by wireless to form the backbone. The platforms will be able to position themselves on spots where emergencies or disasters happen. Stratospheric communication offers several advantages including

- low signal attenuation
- large coverage that remains unaffected due to terrain (compared to terrestrial networks)
- higher flexibility for emergency management.
- small transmission delay
- lower cost of installation and operation (compared to satellite networks)

QUALITY OF SERVICE (QOS)

The current wireless systems can be broadly classified into two categories: non-IP-based and IP-based. With the development of 4G systems, all these networks will converge to a single transparent network. This convergence creates a QoS challenge because different wireless systems will have different properties such as bit rates, channel characteristics, bandwidth allocation, fault-tolerance levels, and handoff support [Varshney and Jain, 2001]**.** Existing networks can guarantee QoS by the use of bearer services proposed by the 3G Partnership Project [Hui and Yeung, 2003]. However, bearer services are inadequate for guaranteeing end-to-end QoS in 4G networks as multiple wireless networks will be involved. To guarantee end-to-end QoS in 4G networks, developers will have to improve the current QoS schemes at the packet, transaction, circuit, user, and network levels [Varshney and Jain, 2001].

Another concept which should become popular with 4G systems is the idea of 'always best connected' [Droma et al., 2003]. In this scenario, it is imagined that the user mobile device will have the embedded intelligence to automatically switch between different types of services (e.g., wireless to satellite or vice versa) according to need in a transparent manner. The device will be programmed to find the service which provides lowest delay or lowest price-to-performance ratio according to the need specified by the user. This arrangement should improve utilization of network resources and provide higher QoS on a real-time basis in 4G systems.

Since 4G systems will use the higher frequency band for transmitting signal, they would be subjected to severe frequency selective fading. Robust modulation and demodulation schemes like OFDM will tackle this problem [Zahariadis, 2003]. In OFDM, orthogonal waves are multiplexed in one time symbol waveform. Since several narrowband channels are used in parallel in OFDM, they will prevent large scale performance degradation in a severe frequency selective channel. With OFDM it will be feasible to design 4G systems with high data rates in public hotspots with high density of population.

An important component of QoS assurance is resource allocation. Since 4G systems will need to accommodate different types of users and applications with different QoS needs, the appropriate allocation of network resources will be quite challenging. A possible solution is the presence of a network resource manager who will monitor the utilization of the network on an end-to-end or link-by-link basis and adaptively allocate and shuffle bandwidth on an as-needed basis [El-Sayed and Jaffe, 2002]. Another important task will be to reserve bandwidth for high priority users. The network resource manager will be complemented by the call admissions control manager who will possess global information about all available and in-use resources and will have the ability to grant or refuse connections based on the condition of the network and the value of the previously agreed upon call drop probability [Niyato and Hossain, 2005].

SECURITY

The existing security schemes for 2G and 3G networks are inflexible and are not suitable for use in 4G networks consisting of different technologies and devices. This inflexibility largely results from the fixed sizes of keys and fixed encryption and decryption algorithms that work for specific networks. With 4G networks, a flexible security system needs to be designed. One of the major challenges is that different networks in a 4G system may use different security protocols, which may or may not be compatible. Handling the security of a transaction seamlessly during handoffs will be complicated. It is probable that a third party security provider will be used to oversee that security protocol transfers take place smoothly during handoffs. For example, tiny SESAME is a lightweight, reconfigurable security mechanism that can provide security services for multimedia applications in 4G networks [Hui and Yeung, 2003].

INTEROPERABILITY

Since operators will deploy networks with multiple standards and protocols, 4G systems will allow interconnection with different networks and provide seamless and robust universal mobility. An all-IP based architecture will be used for 4G systems [Marques et al., 2003]. The traditional ATM backbone networks will be replaced by an all-IP backbone that will handle IP traffic and VoIP calls. A prototype all-IP architecture is shown in Figure 2. The all-IP 4G system will be compatible with all common network technologies. It will include the Broadband Radio Access for IP-Based Networks (BRAIN) project from Japan [Kim, 2003]. The common all-IP based core network will be commonly accessed by five different layers [Ha et al., 2003]. These layers include:

- a digital broadcast layer which will carry television signals,
- a cellular layer which will carry voice traffic,
- a hot spot layer which will carry data traffic,
- a nomadic layer which will be used for private wireless data access, and
- a personal network layer which will carry short range communication between household devices.

HIGH DATA RATE

To maintain high data rates, smart antenna systems have been proposed for 4G wireless systems [Bria et al., 2001]. Smart antenna systems combine multiple antenna elements with intelligent and powerful signal processing such as spatial processing, auto-tracking of desired signals, and digital beam forming. Since 4G systems demand more bandwidth, two additional unlicensed frequency bands were identified on top of those frequency bands used currently by 2G and 3G mobile systems. One of them is in the range of 5GHz and the other is in the range of 60GHz [Varshney and Jain, 2001]. Because of the operation of 4G in the higher frequency bands, propagation loss increases. This loss will be compensated for by the power gain of the smart antenna. To achieve good channel conditions, Adaptive Modulation and Coding (AMC) will be used to respond to feedbacks received about channel conditions and allow different data rates to be assigned to different users based on their channel conditions. 4G systems will provide repeated frequency change during a single call (i.e., frequency hopping). This technique will increase the available bandwidth because frequencies will be reused more often within an area [Bria et al., 2001].

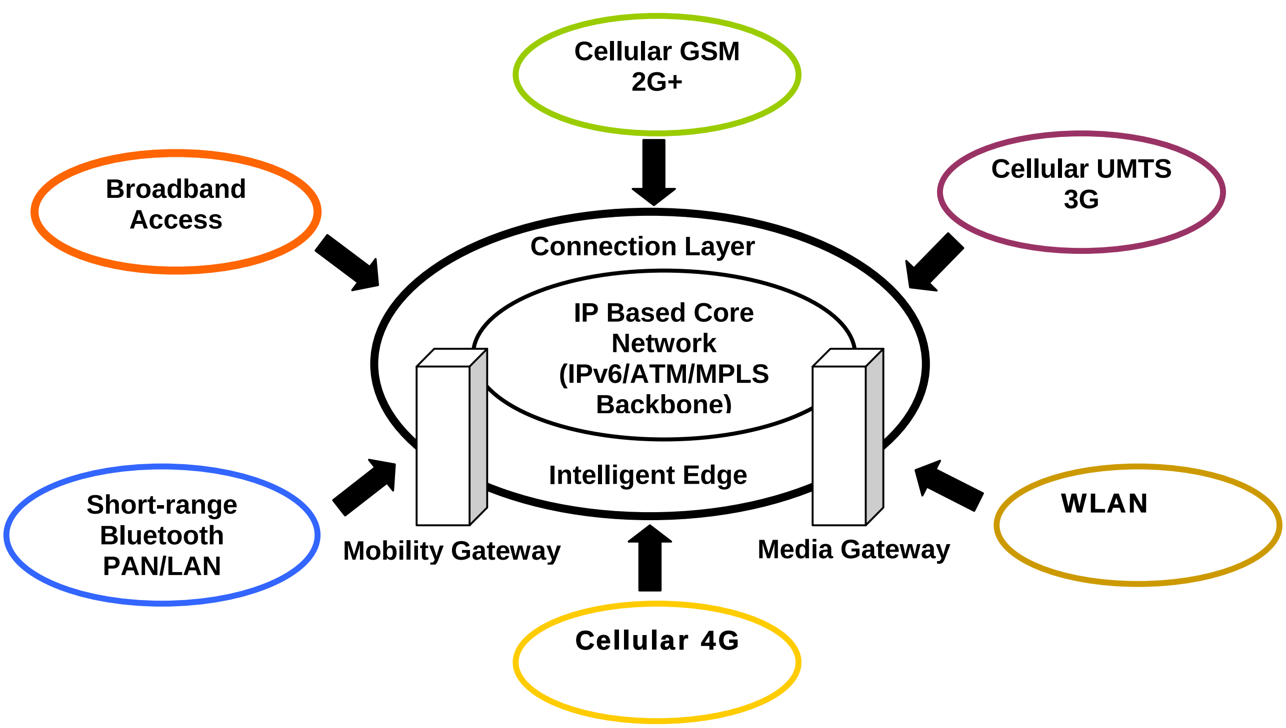

Figure 2. All-IP Architecture for 4G Networks

SURVIVABILITY

4G systems will contain more fault tolerance capabilities to avoid unnecessary network failure, poor coverage, and dropped calls. In a typical cellular network when any level fails, all levels below it are affected. This failure condition happens because the network is designed as a tree topology. The 4G network design will be survivable enough so that it can make use of strategies to reduce the impact of failures. One suggestion is that hierarchical cellular network system or overlapping heterogeneous wireless networks will provide better survivability to 4G systems [Hui and Yeung, 2003; Tipper et al., 2002]. During restoration of a failure, it will be important not only to re-instate the connection but also to make sure that the promise of QoS made at the beginning of the transmission is maintained. It is likely that the boundary between two constituent networks in 4G will have a software manager that will continuously monitor both networks. Before a call is handed off to a new network, the software manager will signal the reliability and/or the availability of the destination network. In case of failure, the software manager will be able to direct the call to a different network or to refuse the call altogether.

SPECTRUM

The allocation of the frequency spectrum for 4G services is a major challenge. The frequency bands in the range of 806-960 MHz and 1710-1885 MHz are used by the GSM and PCS systems worldwide. The initial frequency bands allocated for 3G services included the 1900-2025 MHz and 2110-2200 MHz bands. In the future, as 3G becomes more popular and the number of subscribers increases, the bands 806-960 MHz, 1710-1885, and 2550-2690 MHz will be used [Zahariadis, 2003]. The 4G networks of the future will support a high number of users and a high data throughout rate. Researchers speculate that 4G services will operate at higher and less congested frequency bands like the 5 GHz and 60 GHz. Some problems are, however, associated with these two frequency bands. Many WLAN systems operate at the 5 GHz band and interference is a problem at 60 GHz. The choice of frequency spectrum for 4G is not clear and the frequency spectrum allocation will take place in 2007 [Katz and Fitzek, 2005a]. Since it is still a long time to the allocation of the frequency it is a challenge to design a wireless system without knowing the characteristics of the channel. In the future we will need a closer integration between the spectrum allocation bodies operating worldwide so that interests of all parties can be satisfied and the frequency bands allocated are known immediately to designers.

INTELLIGENT MOBILE DEVICES

It is believed that the mobile device to be used in 4G systems will be much more sophisticated than the ones used at present. The intelligent mobile device will be used at both the sender and the receiver ends. The most important component of the device will be the smart multiple antennas that will use three techniques: diversity, beam forming, and spatial multiplexing [Katz and Fitzek, 2005b].

- Diversity means the antenna elements will be widely separated from one another so that supported channels fade independently. Such diversity will be a necessity for smart antennas in order to handle complex handoffs.

- Beam forming means the antenna will be able to combine signals when they receive or transmit so that they are directed in a preferred direction. Beam forming will help in establishing better connections and will allow the device to ensure the existing QoS of a connection.

- Spatial multiplexing allows better utilization of bandwidth by allowing parallel transmission of data from the different antennas at the same time. This arrangement is often refereed to as multiple-input-multiple-output (MIMO) [Rouffet et al., 2005]. MIMO will be necessary to support the high data rate for 4G applications.

These requirements will increase the power consumption of the device and may also lead to an increase in its size. More research in fuel-cell technology that can offer much higher energy densities than available today is needed to develop energy efficient batteries that can power these devices.

MIDDLEWARE

Researchers defined middleware as “an enabling layer of software that is used by application developers to connect their applications with different mobile networks and operating systems without introducing mobile awareness in the applications” [Varshney and Vetter, 2000]. The middleware in future 4G systems will be advanced and will allow reconfigurability of the network according to the needs of the user or the connection. It will serve multiple purposes such as accepting new connections, providing appropriate QoS to existing connections, creating new topologies, and discovering appropriate services and providers of those services [Prasad and Gavrilovska, 2001]. The middleware will also deal with managing user subscriptions, user preferences, and user profiles. An important task of the middleware will be to provide intelligent billing support. For that it will need to liaise with various service providers or their agents, collect information about services and network resources used, QoS parameters supported, and combine all that information in a single itemized bill to the user. The middleware will also play the role of an accounting clearinghouse and will decide which network service provider or content provider should get what percentage of the revenue generated from a connection [Gazis et al., 2002]. Finally, the middleware will play an important role in security management by controlling location privacy of users, end-to-end security of a connection, and protection of metadata related to users and service providers [Ganchev et al., 2004].

NETWORK ACCESS

In 4G systems the mobile device will need to access multiple networks such as fixed wireless network, WLAN, satellite network, and cellular network. To access multiple networks it may be necessary to have an overlay network with multiple universal access points. The access points will perform a number of functions that will include translation of protocols and frequencies, negotiation of QoS for connections, and seamless handoffs, between networks [Varshney and Jain, 2001]. An alternative proposal for network access is the idea of software defined radio [Hui and Yeung, 2003]. In this arrangement, the multimode intelligent mobile radio devices will scan available networks as they appear and disappear and download needed software or drivers and reconfigure themselves for accessing networks when they anticipate handoffs. An important issue in this case is the download time of the software which must be small because the time between discovery of a handoff situation and actual handoff will be small as well. A third approach that can be used for network access involves the use of a common wireless access protocol such as wireless ATM [Varshney and Vetter, 2000]. Whether the network access is controlled by overlay network or the mobile terminal or the common access protocol, the choice of the access network will be determined by several factors such as accessibility, service capabilities, QoS, and cost. In exceptional situations, the network access may not be automatic but will need manual intervention of the user if, for example, the network usage cost exceeds the allowable credit granted to the user [Eijk et al., 2003].

SUMMARY OF TECHNICAL CHALLENGES

Table 2 summarizes the technical challenges faced by 4G systems and proposed solutions to overcome these challenges.

Table 2. List of technical challenges and proposed solutions for 4G systems

Issues	Challenges	Proposed solutions
Mobility management	• Terminal mobility • Personal mobility • Seamless horizontal and vertical handoffs while maintaining authentication and user profiles	• Use of Session Initiation Protocol • Use of mobile IPv6 • Preemptive context aware handoff • Use multi-network optimization program during handoff • Stratospheric communication using unmanned aircraft or gas filled balloon
Quality of service	• End-to-end QoS as message traverses through a number of networks • Frequency selective fading • Appropriate allocation of resources like bandwidth and decisions about new connections	• 'Always best connected' for every network that the message passes through • Use of OFDM • Network control manager for adaptively allocating and shuffling bandwidth and call admissions control manager for allowing new connections
Security	• Flexible security system that works with all participant networks	• Third party security provider
Interoperability	• Allow any participant network to communicate with each other in a seamless manner	• All-IP core network architecture that consists of several participant layers
High data rate	• Propagation loss due to high data rate	• Use of smart antennas in mobile devices with high power gain
Survivability	• Failed connections	• Software manager at boundary points between networks to restore connection with appropriate QoS
Spectrum	• Choice of frequency band not clear • Difficult to design a wireless system without knowing the channel	• 5 GHz and 60 GHz bands are probable choices • Wait till 2007 when spectrum will be allocated
Intelligent mobile devices	• Handling handoffs is not simple • Guarantee of QoS of existing connections • Support data intensive multimedia applications with high data needs • Drainage of battery power	• Diversity in smart antenna system • Use beam forming to concentrate signals to specific directions • Spatial multiplexing will allow efficient utilization of bandwidth • Develop fuel-cell technology to provide higher energy density
Middleware	• User centric computing • Intelligent billing and accounting • Security management of user connections and data	• Reconfigurability and management of user profiles and preferences • Liaise with multiple vendors, set standards, and act as clearinghouse • Provide location privacy, metadata privacy, and end-to-end security
Network access	• Find most appropriate network for handoff or new connection while considering accessibility, service capability, QoS, and cost	• Overlay network with universal access points or multimode mobile terminals with software defined radio or common access protocol

VI. BUSINESS CHALLENGES FOR 4G SYSTEMS

Solving technological issues may not be enough for successful implementation of 4G systems. For 2G and 3G systems it was a common observation that better technology does not always payoff in the long run if the telecommunications service provider does not understand the business issues associated with the technology. For 4G systems, the following business related challenges are likely to play a significant role.

BILLING

With the launch of 4G systems, existing wireless technologies such as GSM, Bluetooth, and wireless LANs will be seamlessly integrated. This integration will be convenient for users as they will be able to use any system, any time, and anywhere. However, the existing accounting, billing, and charging systems need to be restructured to provide a central brokering service for all the services involved in 4G systems. Customers will subscribe to various service providers at the same time. But it will be quite troublesome for them to deal with the many service providers if there is no central agent helping them to handle all financial transactions. As a result, collecting, managing, and storing customers' accounting information from multiple operators will be a challenge in the development of 4G systems and will necessitate the development of a billing brokerage system [Hui and Yeung, 2003].

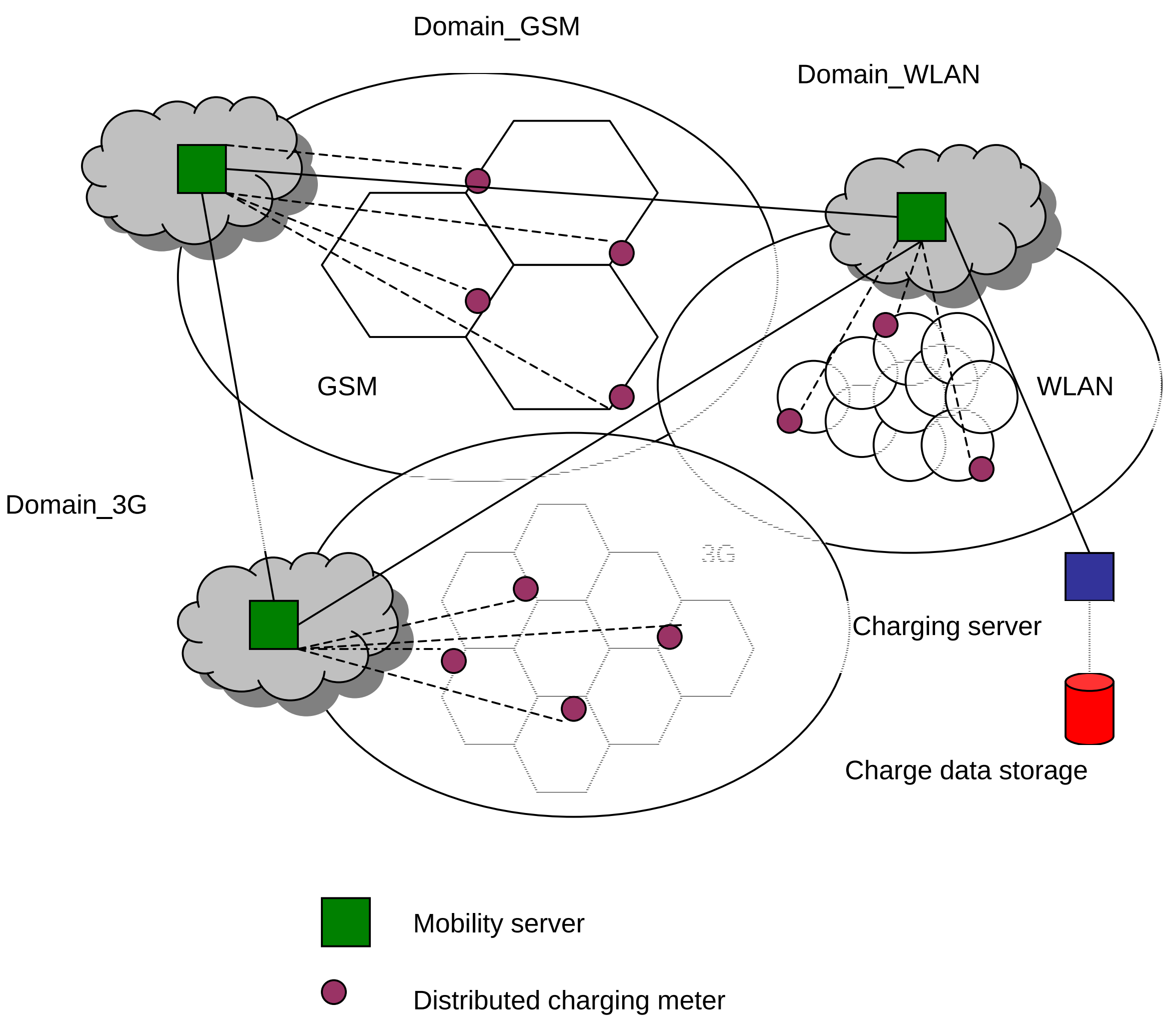

Figure 3. A Distributed Metering and Charging Arrangement in 4G Network

Another challenge will be to measure resource usage by the user. Since the user will be able to switch between technologies and move between networks it will not be an easy task to measure usage in each network and for each technology. Besides, this information will need to be collated for billing purposes. For this reason, a hierarchical distributed metering system will be needed in 4G systems [Jahnert, 2003]. While a distributed metering system will be able to capture the usage data, it will be a challenge to obtain useful and necessary pieces of information from the vast amount of usage data that will be gathered and shared between the billing meters. Any billing system to be used must also be flexible enough to incorporate changes in service agreements, service providers, technologies, and competitors' pricing policies.

PAYMENT METHODS

Currently, most of the bill payment methods adopted by individual 3G service providers include different payment options. These options include auto-payment via bank account or credit card, post, ATM, and over-the-shop-counter in person. It is most likely that monthly billing systems will be used for 4G systems as well since this cycle has been used widely in the industry ever since 2G systems. With increased acceptance of Internet shopping, it is likely that payment made by electronic cash, where anonymity can be promised to a certain extent, will become popular. A micropayment method will be a good choice for those users who can afford to lose one single small payment if they are not satisfied with the service quality. Service providers will also need to provide for prepaid services though the minimum value for such prepaid cards will be much higher than those available for 2G systems.

PRICING

It is not beyond anyone's imagination that price competition among 4G operators will be strong in the future. To attract customers, it would not be a good idea to put too much detailed pricing information in the first correspondence sent to potential customers. It will be in the interests of the operator to include some general price information in the broadcast advertisement messages and allow people to obtain further information via the Web. The charging model that the operators will use in calculating subscribers' bills will be a critical issue in 4G systems [Gazis et al., 2002]. It is advisable to develop a highly flexible, event-based and truly convergent charging model for services. Possible parameters on which 4G pricing model can be based include:

- Price per time unit
- Price per kilobyte/packet transferred
- Price per amount of bandwidth reserved
- Price per upload/download of content

It is also possible that service providers may use a combination of these metrics for pricing services. For example, the service providers may use duration-based pricing for real-time connections, and volume-based pricing for non real-time or background services. If the service providers allow the users to choose the QoS dynamically, then the pricing policy will vary from time to time. Instead of a static pricing policy, a dynamic pricing policy that takes into account the various technologies that are used in completing a call would be devised. An added complexity will be to consider the different service agreements entered into between users and service providers and to keep these details in perspective when pricing services for the user.

The operators will need to provide bundling of services (that may change from time to time according to user preference). According to user participation in separate bundled services over a given time period, they may be charged differently for the same service obtained from the same service provider. For this reason, a master software agent will be developed that will communicate with several agents responsible for each service bundle and will decide the right price the user must be charged.

SIZE OF INVESTMENTS

4G wireless networks will cater to the increased demand for accessing and transmitting high quality images and videos any time and anywhere. To tackle simultaneous transmission of multimedia data, higher available frequencies will be needed. With a shift to using higher frequencies, the propagation characteristics imply that the size of the mobile cells will become smaller. Hence, a larger number of base stations will be built outdoors as well as inside buildings.

As a result, huge investments will be needed to construct these additional base stations. In addition to that, 4G systems will also need smart antennas that will make up for the propagation loss due to operation in the high frequency band. These antennas will be expensive to install and maintain [Nakajima and Yamao, 2001]. In addition, by transmitting high quality video through the network, 4G systems will impose heavy traffic on the wired backbone network. Traffic load will eventually lead to upgrade of the wired backbone network and will require additional investment. It will be quite challenging for mobile service providers to recover these high investment costs and to break even by generating enough revenue in the long run [Zhen et al., 2002]. In a report using a European service provider as an example [Bjorkdahl, 2004], the authors calculated that to recoup the investment on 4G, each mobile subscriber must contribute between £1.1[1] per month (in the best case) and £6.0 per month (in the worst case). This estimate is believed to be much less than that for 3G because 3G services were marked by exorbitant license fees. This calculation assumes no license fees for 4G. It also assumes that coverage for 4G services will be much less than that of 3G. Although, the average revenue generated from a mobile customer is not extremely ambitious, this estimate assumes that 3G services will gradually acquire and retain users in the next few years and that 4G services will gradually (rather than abruptly) replace 3G services by 2010.

CONTENT PROVISION AND MEDIATION

Since a vast number of value chain participants will be involved in 4G networks, a wide diversity of products and services will be made available to the public. Communication environments will be complex and heterogeneous in nature. All these factors enhance the need for intelligent mediation to efficiently engage and coordinate the service provision for the customers [Gazis, 2002]. Another major task of intelligent mediation will be to provide one-stop billing services to customers. The billing services will also be responsible for collecting related charging information from firms engaged in providing service processes, organizing them, and issuing a single itemized bill to customers. No one anticipated that Short Messaging Services (SMS) will gain so much popularity in 2G networks. Similarly, it is not clear which content or service will boost the popularity of 4G systems. However, it can be guessed that any of the mobile applications listed earlier like multi-party interactive video gaming, interactive television, disaster management applications, and video map-locator services will become popular applications in 4G systems.

RICHNESS VERSUS REACH

It is not known if the huge variety of services promised by 4G systems will act towards its benefit. The term richness indicates high level of sophistication and comprehensiveness of services and data whereas reach indicates how fast and how easily the services can be delivered to customers. Tradeoffs need to be made between richness and reach according to the current usage pattern of customers and their future demand for services. A prominent example that illustrates that richness may not be as important as reach is the pioneering 3G services iMode developed by NTT DoCoMo, the Japanese cellular phone operator [Barnes and Huff, 2003]. It is believed that the applications running in 4G systems must be simple enough to be used by millions of mobile terminals. The applications should be such that they follow the ‘write once, run anywhere’ paradigm [Munoz and Rubio, 2004]. The application logic must be clearly separated from the application execution environment and it must be device-independent. This means mobile gaming software that is installed in a 4G mobile device must work irrespective of whether it is in a WLAN environment or 3G environment. At the same time the applications developed for 4G mobile devices must be forward compatible with applications that will be developed in future and backward compatible with existing applications.

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[1] The British pound was trading at $1.78 in mid-April 2006.

SUMMARY OF BUSINESS CHALLENGES

Table 3 summarizes the business challenges faced by 4G wireless systems and the proposed solutions to overcome these challenges.

Table 3. Business Challenges and Proposed Solutions for 4G Systems

Issues	Challenges	Proposed Solutions
Billing	• Measurement of usage of services in different networks • One-stop bill for services used in different networks	• Hierarchical distributed metering system • Billing brokerage system
Payment methods	• Multiple modes of payment	• Use of micropayment
Pricing	• Development of a fair pricing scheme for various services • Pricing based on different technologies used and user service agreements • Pricing bundled services	• A mixture of pricing strategies to be used • Dynamic and flexible pricing system will be developed • Use of a master pricing agent
Size of investments	• Smaller cell size will make construction of large number of base stations necessary • Smart antennas will be expensive • Develop wired networks to support high bandwidth applications	• Need to acquire and retain increasing number of customers to recoup investment • Need to find out low cost manufacturing options for handsets • Revenue gained from 3G services can be channeled for increasing capacity of wired networks
Content provision and mediation	• Management of diversified content across different networks	• An intelligent mediator system for content management
Richness versus reach	• Provide interesting content that can run efficiently irrespective of users operating environment	• Content to be kept simple using the 'write once, run anywhere' computing paradigm

VII. CONCLUSION

4G is the wireless frontier of the future. It promises to overcome the limitations of 3G systems and become the first true seamless and heterogeneous wireless system. Before the dream of 4G becomes a reality several technical and business challenges, as listed in this paper, need to be resolved. In mid-2006 a number of telecommunications service providers are involved in research related to 4G wireless systems, including AT&T, Hewlett Packard, NTT DoCoMo, and Sun Microsystems among others. Though some skeptics doubt the need for 4G, telecommunications service providers believe that increased competition and new applications will pave the way for this next frontier in wireless systems.

> *"As we provide higher transmission speeds the service will follow"* Seizo Onoe of NTT DoCoMo [Rocks, 2004].

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LIST OF REFERENCES

EDITOR'S NOTE: The following reference list contains the address of World Wide Web pages. Readers who have the ability to access the Web directly from their computer or are reading the paper on the Web, can gain direct access to these references. Readers are warned, however, that

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Ballon, P (2004) "Scenarios and Business Models for 4G in Europe", *info*, 6(6), pp. 363-382.

Barnes, S.J. and S.L. Huff (2003) "Rising Sun: iMode and the Wireless Internet", *Communications of the ACM*, 46(11), pp. 79-84.

Bjorkdahl, J. et al. (2004) "Financial Assessment of Fourth Generation Mobile Technologies", in *Proceedings of the EURO CPR Conference,* Barcelona, Spain, 28-30 March.

Bria, A. et al. (2001) "4th Generation Wireless Infrastructures: Scenarios and Research Challenges", *IEEE Personal Communications*, 8(6), December, pp. 25-31.

Brosnan, G.A. (2005) "Trends in the Mobile Data Services Market", *The Telecommunications Review*, pp. 1-14.

Chao, Z., X. Xiaohui, and L. Xiaokong (2002) "Stratospheric Telecommunication in 4G", in *Proceedings of the IEEE International Conference on Communications, Circuits and Systems and West Sino Expositions,* 1, PRC, 29 June-1 July, pp. 172 – 176.

Dekleva, S. (2004) "M-business: Economy Driver or a Mess", *Communications of AIS,* 13, pp. 111-135.

Droma, M.O. et al. (2003) "Always Best Connected Enabled 4G Wireless World", in *Proceedings of the IST Mobile and Wireless Communications Summit*, Aveiro, Portugal, 15-18 June.

Duda, A. and J. Sreenan (2003) "Challenges for Quality of Service in Next Generation Mobile Networks", in *Proceedings of the Information Technology & Telecommunications Conference,* (IT&T2003), Letterkenny, Ireland, October.

El-Sayed, M. and J. Jaffe (2002) "A View of Telecommunications Network Evolution", *IEEE Communications Magazine*, December, pp. 74-81.

van Eijk, R. et al. (2003) "Access Network Selection in a 4G Environment and the Roles of Terminal and Service Platform", *Wireless World Research Forum Meeting 10*, New York, NY, USA, 27-28 October, pp. 1-4.

Evans, B.G. and K. Baughan (2000) "Visions of 4G", *Electronics and Communications Engineering Journal*, December, pp. 293-303.

Fjermestad, J. et al. (2006) "Moving Towards Mobile Third Generation Telecommunications Standards: The Good and Bad of the 'Anytime/Anywhere' Solutions", *Communications of AIS,* 17, pp. 71-89.

Forge, S. (2004) "Is Fourth Generation Mobile Nirvana or … Nothing?", *info*, 6(1), pp. 12-23.

Ganchev, I. et al. (2004) "Requirements for an Integrated System and Service 4G Architecture", in *Proceedings of the 59th IEEE Vehicular Technology Conference,* VTC 2004, 5, Milan, Italy, 17-19 May, pp. 3029-3034.

Gazis, V. et al. (2002) "Evolving Perspectives of 4th Generation Mobile Communication Systems", in *Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* 1, Lisbon, Portugal, 15-18 September, pp. 201-207.

Ha, J., S.H. Kim, and D. Kim (2003) "A Phased Approach to 4G Mobile Network System", in *Proceedings of the 10th International Conference on Telecommunications*, ICT 2003, 2, Papeete, French Polynesia, 23 February -1 March, pp. 1318-1322.

Hui, S.Y. and K.H. Yeung (2003) "Challenges in the Migration to 4G Mobile Systems", *IEEE Communications Magazine,* 41(12), December, pp. 54-59.

International Telecommunication Union (ITU) (2003) "Mobile Overtakes Fixed: Implications for Policy and Regulation", June, http://www.itu.int/osg/spu/ni/mobileovertakes/Resources/Mobileovertakes_Paper.pdf (current April 20, 2006)

Ibrahim, J. (2002) "4G Features", *Bechtel Telecommunications Technical Journal*, 1(1), December, pp. 11-14.

Jahnert, J. (2003) "Problem Statement: Metering and Accounting in the Full-IP 4G Environment", in Stiller B. et al. (eds.) *Lecture Notes in Computer Science*, Springer-Verlag, pp. 298-307.

Juniper Research (2005) "White Papers", http://www.juniperresearch.com/ set_whitepapers.htm (current April 14, 2006)

Katz, M. and Fitzek, F.H.P. (2005a) "Cooperative Techniques and Principles Enabling Future 4G Wireless Networks", in *Proceedings of the International Conference on Computer as a Tool*, EUROCON 2005, Belgrade, Serbia and Montenegro, 22-24 November, pp. 1-4.

Katz, M. and Fitzek, F.H.P. (2005b) "On the Definition of the Fourth Generation Wireless Communications Networks: The Challenges Ahead", in *Proceedings of the International Workshop on Convergent Technologies*, ICWT 2005, Oulu, Finland, 6-10 June, pp. 1-8.

Kim Y. et al. (2003) "Beyond 3G: Vision, Requirements, and Enabling Technologies", *IEEE Communications Magazine*, 41(3), March, pp. 120-124.

Marques, V. et al. (2003) "An IP-Based QoS Architecture for 4G Operator Scenarios", *IEEE Wireless Communications*, 10(3), June, pp. 54-62.

Martin, K. (2005) "Mobile Virus Epidemics: Don't Panic", The Register, 28 January, http://www.theregister.co.uk/2005/01/28/mobile_phone_viruses/ (current April 14, 2006).

Mathew, J., S. Sarkar, and U. Varshney (2004) "M-commerce Services: Promises and Challenges", *Communications of AIS,* 14, pp. 558-568.

McNair, J. and F. Zhu (2004) "Vertical Handoffs in Fourth Generation Multinetwork Environments", *IEEE Wireless Communications*, 11(3), June, pp. 8-15.

Munoz, M. and C.G. Rubio (2004) "A New Model for Service and Application Convergence in B3G/4G Networks", *IEEE Wireless Communications*, 11(5), October, pp. 6-12.

Nakajima, N. and Y. Yamao (2001) "Development for 4th Generation Mobile Communications", *Wireless Communications and Mobile Computing*, 1, pp. 3-12.

Niyato, D. and E. Hossain (2005) "Call Admission Control for QoS Provisioning in 4G Wireless Networks: Issues and Approaches", *IEEE Network,* 19(5), September/October, pp. 5-11.

Prasad, R. and L. Gavrilovska (2001) "Research Challenges for Wireless Personal Area Networks", in *Proceedings of the 3rd International Conference on Information, Communications and Signal Processing,* ICICS 2001, Singapore, 15-18 October.

Prehofer, C. et al. (1999) "An Architecture Supporting Adaptation and Evolution in Fourth Generation Mobile Communication Systems", *Journal of Communications and Networks*, XX(Y), pp. 1-15.

Raivio, Y. (2001) "4G – Hype or Reality", in *Proceedings of the IEE 2nd International Conference on 3G Mobile Communication Technologies,* 477, London, UK, 26-28 March, pp. 346-350.

Rocks, D. (2004) "Making 3G Look as Slow as Smoke Signals", *Business Week*, November 15, p. 40.

Rouffet, D. et al. (2005) "4G Mobile", *Alcatel Telecommunications Review*, pp. 1-7.

Santhi, K.R. et al. (2003) "Goals of the True Broadband's Wireless Next Wave (4G-5G)", in *Proceedings of the 58th IEEE Vehicular Technology Conference*, VTC 2003, 4, Orlando, FL, USA, 6-9 Oct, pp. 2317-2321.

Sun, J.Z., J. Sauvola, and D. Howie (2001) "Features in Future: 4G Visions from a Technical Perspective", in *Proceedings of the IEEE Global Telecommunications Conference, GLOBECOM 2001,* 6, San Antonio, TX, USA, 25-29 November, pp. 3533-3537.

Tipper, D. et al. (2002) "Providing Fault Tolerance in Wireless Access Networks", *IEEE Communications Magazine,* 40(1), January, pp. 58-64.

Varshney, U. (2002) "Multicast over Wireless Networks", *Communications of the ACM*, 45(12), December, pp. 31-37.

Varshney, U. (2005a) "Pervasive Healthcare: Applications, Challenges, and Wireless Solutions", *Communications of AIS*, 16, pp. 57-72.

Varshney, U. (2005b) "Vehicular Mobile Commerce: Applications, Challenges, and Research problems", *Communications of AIS*, 16, pp. 329-339.

Varshney, U. and R. Jain (2001) "Issues in Emerging 4G Wireless Networks", *IEEE Computer*, 34(6), June, pp. 94-96.

Varshney, U. and R. Vetter (2000) "Emerging Mobile and Wireless Networks", *Communications of the ACM*, 43(6), June, pp. 73-81.

Varshney, U. and R. Vetter (2002) "Framework, Applications, and Networking Support for M-commerce", *ACM/Kluwer Journal on Mobile Network and Applications* (MONET), 7(3), June, pp. 185-198.

Wheelock, C. (2004) Director, Wireless Research, *InStat/MDR,* February.

Yang, S.M., S. Chatterjee, and C.C. Chen (2004) "Wireless Communications: Myths and Reality", *Communications of AIS,* 13, pp. 682-696.

Zahariadis, T. (2003) "Trends in the Path to 4G", *Communications Engineer,* 1(1), February, pp. 12-15.

Zhang, D. (2003) "Delivery of Personalized and Adaptive Content to Mobile Devices: A Framework and Enabling Technology", *Communications of AIS,* 12, 183-202.

Zhen, L. et al. (2002) "Consideration and Research Issues for the Future Generation of Mobile Communication", in *Proceedings of the IEEE Canadian Conference on Electrical &*

Computer Engineering, CCECE 2002, May 12-15, Winnipeg, Manitoba, Canada, pp. 1276-1281.

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