4G NETWORKS AND THE EVOLUTION OF THE CELLULAR PHONE

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ABSTRACT
The need and want for mobile technology and devices grows every year. According to the International Telecommunications Union (2011) "Mobile-broadband subscriptions have grown 45% annually over the last four years". As of 2011 there were "5.9 billion mobile-cellular subscriptions" (International Telecommunications Union, 2011), which is impressive when you consider there is an estimated 7 billion people alive today. It's easy to see the draw to mobile technology and devices. Cellular technologies and devices are extremely more convenient than the fixed technologies of the past. Modern 4G networks offer users a vast amount of freedom and mobility to conduct business and keep in touch with loved ones. These networks support everything from surfing the net to video streaming, as well as voice & video communications and texting all on the same device and while on the go.

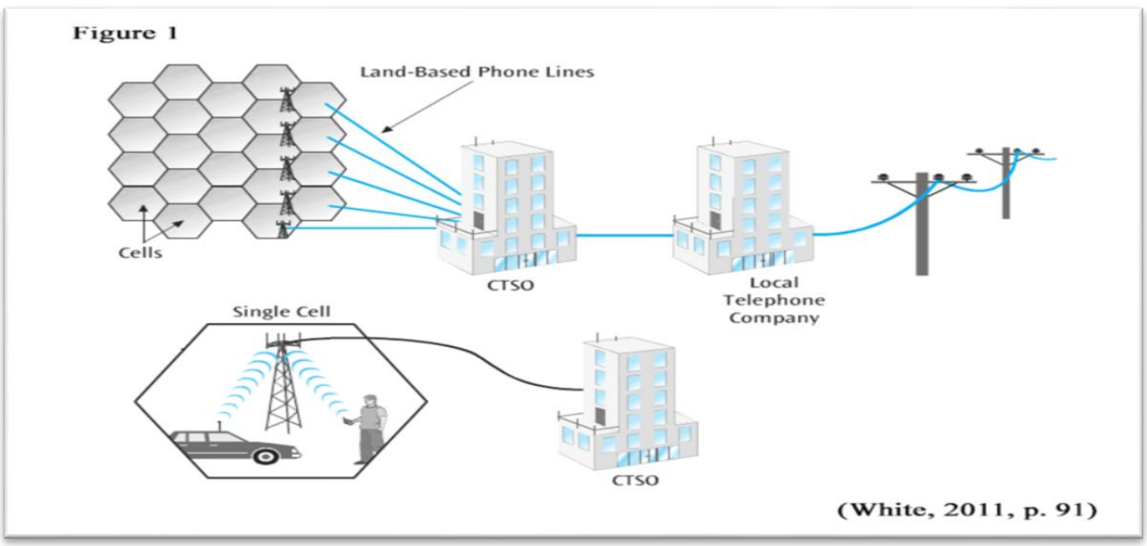
INTRODUCTION
Because there is an ever growing demand by consumers for faster and more reliable cellular technologies capable of handling more and advanced data and communications, the cellular networks that process these transmissions are always evolving. Despite advances in technologies, networks continue to push the limits of the frequency spectrum, which continues to be an imminent issue for cellular providers as well as users who experience drop calls and slow or loss of data transmissions. In fact, "recent estimates from the FCC indicate that the nation is running out of spectrum and will experience a spectrum deficit starting in 2013" (Kleeman, 2011)

In the past, cellular generations 1,2 &3, have employed techniques and equipment that for a time have assisted in the mitigating the impending "spectrum crunch" (WiMAX Forum, 2006). Likewise we continue to see new technologies, such as 4G, develop that show promise in continuing to ease the demand on the spectrum and pave the way for future generations.

To fully understand modern 4G networks one must first understand the cellular networks from which they evolved and past technologies employed.

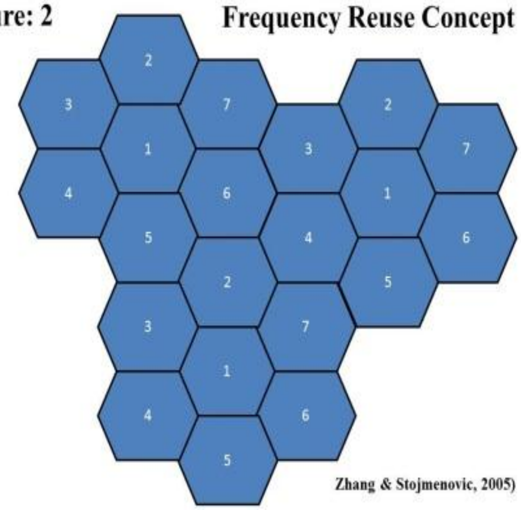
CELLULAR NETWORK BASICS
All cellular networks are built upon a basic network architecture. A network architecture is defined as "a template that outlines the layers of hardware and software operations for a computer network and its applications" (White, 2011, p. pg 468). At its very basics the architecture of a cellular network consists of; cells, base stations, cellular telephone switching office, a local telephone company, and the fixed lines / wired backhaul that connects them.

Cellular networks utilize cell towers or base stations (BS) to wirelessly transmit radio frequencies or signals to and from personal cellular devices, or what are technically referred to as mobile stations (MS). Each BS has a range that varies in “size from one-half mile in radius to 50 miles in radius” (White, 2011, p. 91). The range, or coverage area, of the base station is referred to as a cell. Mobile stations operate within the range of a cell when transmitting signals. After a BS receives a signal from a mobile cellular device it transmits the signal via telephone lines or a wired backhaul, consisting primarily of T-1 lines, to a cellular telephone switching office (CTSO). The CTSO then passes the signal to a local telephone company which then routes the signal down the line to its intended destination. Traditional cellular transmissions are very similar to that of circuit switching used in traditional land lines, in which a wired circuit creates a continuous dedicated channel between two telephones throughout the duration of a phone call. Modern cellular transmissions, however, such as 3G and 4G differ from this in that they use packet switching instead circuit switching. Many different networks and computer programs can be used in cellular transmissions making them extremely complex. Illustrated in Figure 1 is a standard cellular network, in which each cell is represented by hexagon.



Within each cell there are many different users attempting to connect to a base station with their portable cellular devices. Each of these devices must share airspace with the other in an organized manner to prevent interference and possible congestion. To control inference there are several techniques used called multiple access methods. “The popular multiple access methods include; frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA)” (Zhang & Stojmenovic, 2005).

Figure: 2 Frequency Reuse Concept



In the United States the FCC regulates frequencies and has designated a finite amount of spectrum for cellular use. Cellular transmissions operate in the 800 MHz range with 3G and 4G technologies also operating in the 1.4, 1.7-1.9, 2.1 and 2.4-2.7GHz ranges. Due to the popularity of personal cellular devices these frequencies have the potential to become overused, and lack of bandwidth to support all wireless users may ensue. One of the first methods to free up bandwidth and allow for more users on cellular networks was the frequency reuse concept. The frequency reuse concept relies upon frequency division multiple access. In the frequency reuse concept cells are typically clustered into 7 adjacent cells. Employing frequency division multiple access techniques the frequency spectrum is then divided into “several frequency bands, also known as channels” (Zhang & Stojmenovic, 2005). Each cell is then assigned its own set of frequencies or channels, unique from those of the cells surrounding it. Cells that are far enough away from each other, or outside of tolerable limits, can be assigned like channels. A user can then access the BS with their cellular device through a channel assigned solely to them. This technique keeps transmissions from one cell interfering with transmission from nearby cells. The frequency re-use concept is illustrated in figure 2.

Time Division multiple access usually works in conjunction with FDMA and further assists in alleviating overuse and bandwidth. TDMA allocates time slots within a frequency channel to users. Personal cellular devices sharing a single frequency then “take their turn transmitting or receiving in their allocated slots in a round robin fashion. Although the channel is shared, no interference can arise between users because only one user can use the channel at one time” (Zhang & Stojmenovic, 2005).

The third popular multiple access method is CDMA, which “is based on a spread spectrum technology. Spread spectrum essentially takes the data to be transmitted and rather than transmitting it in a fixed bandwidth spreads it over a wider bandwidth” (White, 2011, p. 410). Unlike TDMA which allocates a specific time slots to each user, code division assigns a code to each group of users attempting to communicate. Users do not experience interference because each group of users shares a unique code allowing them to communicate. Users also receive a higher level of security from CDMA because the signal has been “spread over a wider bandwidth, rather than transmitted in a fixed bandwidth” (White, 2011, p. 410). This technique makes it harder for eavesdroppers to channel in and listen to conversations.

EVOLUTION OF CELLULAR TECHNOLOGY

Cellular networks in the United States have undergone 3 major evolutions before the current 4th generation (4G) technologies were unveiled. The first generation (1G) also referred to as the advanced mobile phone service (AMPS) employed frequency division multiple access points. Amps operated between 825-845MHz and 870-890MHz. AMPS allowed for approximately 1332 channels, 21 of which were used for quality and control procedures. Half of the remaining channels were used for communications between personal cellular devices to BS's and the other half for BS's to personal devices. Like all cell phone generations AMPS employed a wired backhaul typically consisting primarily of T-1 lines. AMPS however had several drawbacks, among them, because it was an analog signal is was highly susceptible to noise. AMPS also had no security protection against threats like eavesdroppers. Due to many of the drawbacks and the development of more cost and efficient technologies AMPS it is no longer available in the United States.

Second Generation (2G) allowed for digital signals, and as such, is also referred to as digital cellular networks. 2G networks sought to expand the networks so they could handle more users. Digital signals allowed for advanced techniques like TDMA, CDMA and global system for mobile communications (GSM) technologies. Also with the advancement of digital signals, 2G networks were able to handle text messaging, as well as the ability to download media content such as ringtones. At their best 2G devices and networks were capable of handle data speeds of only up to "75 kbps" (White, 2011, p. 94).

With the introduction of the ability to transfer media and data in second generation technology consumers began to use and demand more bandwidth, and better systems & devices that could support more labor intensive projects. To support these needs cellular providers developed another generation of technology referred to as third generation (3G). 3G technology, which is still widely in use today, is capable of handling "data rates of 300 kbps to 500 kbps" (White, 2011, p. 94). The biggest difference between 2G and 3G services is the introduction and use of packet switching and the adoption of the high speed packet access (HSPA) technology. Data packets and HSPA allow for faster internet connection speeds or what is commonly referred to as mobile broadband speeds. Packet switching, simply put, is a method "to transfer all data between sender and receiver in fixed-sized packets" (White, 2011, p. 468). In addition to packet switching 3G technology still employed circuit switching for voice communications.

Despite the faster speeds brought about by 3G technology, a demand and need from consumers still existed for even faster, more reliable and capable networks, leading to the current 4G technologies and networks.

4G

The current and most advanced technology used today in cellular transmission is the fourth generation (4G) technologies. As set forth by the International Telecommunications Union, 4G is required to have speeds of up to 1Gb per second. The main difference between 3G and 4G cellular networks is the complete use of packet switching and the IP network. In order to go to a fully 4G network the old circuit switching phone model had to be eliminated, requiring all voice transmissions to be fully digitized so they could be routed via data packets. Currently there are two 4G networks available on the market today WiMAX and Long Term Evolution (LTE).

Before we can discuss the two technologies on the market packet switching must be explained a little more in detail. As previously stated the simplest definitions of packet switching is the "transfer all data between sender and receiver in fixed-sized packets" (White, 2011, p. 468). A packet, however, is a fixed sized unit of data. A message that is to be transmitted over a network is broken down into various amounts of packets. These packets are then routed throughout the network. "All packets that belong to a logical connection can follow the same path through the network" (White, 2011, p. 285) forming what is referred to as a virtual connection. In a virtual circuit, packets follow a predetermined route through the most optimal path to their intended destination. Once packets reach their destination they are reassembled for transmission. Because packets are routed through the internet they follow internet protocols (IP) which means they are subjective to things like queues, buffering and network congestion.

CONGESTION

Despite being far superior to other generations of cellular technology 4G has a major drawback that is worth noting. Since 4G relies upon packet switching and it follows the internet protocols it is subjective to buffering and queues and other delays that can lead to congestion. An overabundance of people trying to access the network on a limited amount of bandwidth and frequency spectrum can also cause congestion. Congestion on modern 4G networks occur when data packets from multiple mobile devices or smartphones trying to access a BS are transmitted at the same time and collide within the frequency spectrum. Congestion can cause the network to slow down and become unreliable, potentially causing voice, data and various other transmissions to be sent or received incorrectly or simply not transmitted or received at all.

In a network "congestion may be a result of a short-term problem, such as a temporary link or node failure, or it may be a result of a longer-term problem, such as inadequate planning for future traffic needs or poorly created routing tables and routing algorithms" (White, 2011, p. 297).

There are two main ways to control packet transfer congestion; either before the congestion has occurred or after. Ways to control it after congestion has occurred include flow controls, implicit forward and backward congestion controls and explicit congestion controls. Simply put flow controls are a way of controlling data rates so a node or connection point within a network does not transmit faster than a slower node. Implicit congestion require the network to measure its own throughput or successful packet deliveries and explicit congestion control focuses on measuring the delay between packets. Buffer preallocation seeks to stop congestion before it occurs. In order to accomplish this "the sending node inquires in advance whether the receiving node has enough buffer space to receive data packets" (White, 2011, p. 299).

LTE / WiMAX

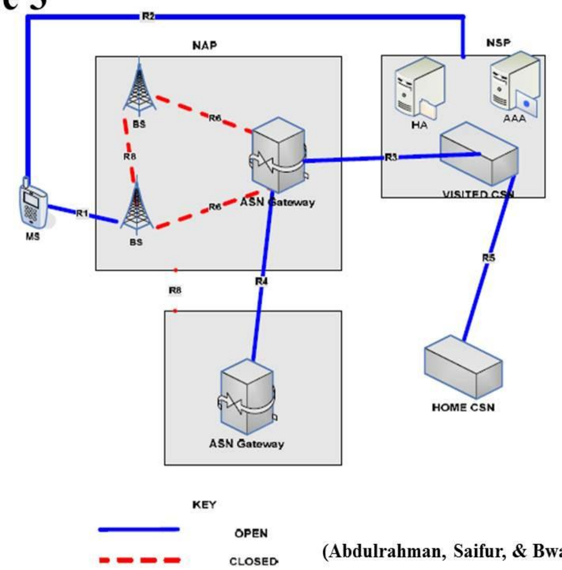
The two commercially available mobile network technologies that are seek to replace traditional cellular mobile networks phones and networks are Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX).

Long Term Evolution was first released in the United States by cellular providers Verizon and AT&T. Over the years both these organizations had used a considerable amount of resources and assets building and establishing their network infrastructure. To recoup some of their investments LTE initially has been an upgrade to existing technologies like GSM, FDMA, CDMA and HSPA. Because LTE is an upgrade to existing technologies users who subscribe to LTE services, and have a 4G compatible device, are able to access 2G and 3G networks when 4G services are unavailable.

Technically speaking LTE, like WiMAX, doesn't meet the guidelines originally established by the International Telecommunication Union standards to be considered 4G technology, which are supposed to be capable of "download speeds of 100 Mbps to 1 Gbps" (Isaac, 2011). Currently the most robust 4G LTE devices and technologies are able capable of reaching speeds of up to roughly 12 Mbps. In order to reach even these speeds most cellular providers have or have had to upgrade their current wired backhauls to a more robust fiber, copper or even microwave (for short distances) links.

LTE's most fierce competitor in the 4G arena currently is WiMAX. "WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture" (WiMAX Forum, 2006). Much like LTE, WiMAX employs a full packet switching technology and abides by basic FDMA techniques. However unlike LTE, WiMAX was originally intended to replace previous cellular networks and technologies like GSM and CDMA. Because WiMAX was intended to replace legacy cellular technology it adheres to an IP's platform and follows 802.16 wireless standards. Due to its many similarities it is often compared to Wi-Fi however it is a much more advanced and long range system.

Figure 3



(Abdulrahman, Saifur, & Bwanga, 2008)

Despite operating completely on a IP platform WiMAX transmission operate similar to signals transmitted in cellular transmission, however have a slightly different architecture. "Mobile WiMAX network architecture mainly has three components. These include; the Access Services Network (ASN), the Core Services Network (CSN) and the Application Services Network (AS)" (Abdulrahman, Saifur, & Bwanga, 2008). A typical signal or data packet sent by an MS will be received by a BS thru an ASN. An ASN is essentially the network access provider who owns the network & operations "and provides the interface between the user and the core service network" (Abdulrahman, Saifur, & Bwanga, 2008). An ASN directs the packets to the ASN Gateway which "performs functions of connection and mobility management" (Abdulrahman, Saifur, & Bwanga, 2008). From there the CSN grabs hold of it. "The CSN is the transport, authentication and switching part of the network and represents the core network in the WiMAX, containing the IP servers, and gateways to other networks" (Abdulrahman, Saifur, & Bwanga, 2008). This process is depicted in figure 3.

"WiMAX has a communication range of up to 50km, and can provide shared data rates of up to 70 Mb" (Abdulrahman, Saifur, & Bwanga, 2008). Because of its range and data capabilities WiMAX is considered to be a wide area or metropolitan area network. Mobile WiMAX was intended to operate within the "2.3 GHz, 2.5 GHz, 3.3 GHz, and 3.4-3.8 GHz frequency bands with a range of 2 to 6 MHZ" (Abdulrahman, Saifur, & Bwanga, 2008).

In the digital age security is huge concern. WiMAX offers security protections that are far superior to previous generations of technology. "WiMAX supports triple data encryption standard (DES)" (Abdulrahman, Saifur, & Bwanga, 2008). In triple-DES "the data is encrypted using DES three times—the first time by a first key, the second time by a second key, and the third time by the first key again, and is virtually unbreakable" (White, 2011, p. 404). WiMAX also has "built-in VLAN support, which provides protection for data that is being transmitted by different users on the same base station. Both variants use Privacy Key Management (PKM) for authentication between base station and subscriber station" (Abdulrahman, Saifur, & Bwanga, 2008).

In the United States Sprint and Clear wire are the biggest owners and providers of WiMAX services. In addition, "Sprint and Clear wire currently own the biggest share of the 2.5-GHz spectrum" (Isaac, 2011) which is considered to be "the most readily usable licensed spectrum in the United States" (WiMAX.com, 2012).

PROS

One of the biggest pros of 4G Services, as previously discussed, is the higher data transfer rates and expanded coverage zones. Currently WiMAX has data rates reaching speeds of 12 Mbps and LTE 100Mbps. These speeds allow users to stream and download videos, music, maps and other data at speeds almost as fast, and in some instances faster, as conventional cable or DSL users on a fixed wired system.

Advanced security in 4G technologies is another huge plus. Many users have inadvertently fallen prey to hackers and eavesdroppers over the years. Advanced security procedures like Triple-DES, which is noted to be "virtually unbreakable" assures many users who are afraid of potential threats.

Another pro of 4G is the technology relatively cheap. WiMAX does requires a new network however "requires little or no external plant construction compared with the deployment of wired solutions and base stations should cost under $20,000" (Abdulrahman, Saifur, & Bwanga, 2008). As for LTE despite having to upfront costs for a more robust wired backhaul most of the technology infrastructure is already in place.

CONS

Despite both WiMAX and LTE being global technologies and standards 4G networks are still limited in the US. Verizon and AT&T are the two largest providers of LTE, with AT&T claiming to have 4G coverage in "41 markets" (AT&T, 2012) and Verizon in "304 cities" (Verizon Wireless, 2012). Sprint/Clear wire, the largest providers of WiMAX are available in "77 metropolitan markets across the US" (Clear, 2012). Sprint however plans to add to its 4G technology and offer "4G LTE by mid-2012" (Sprint, 2012). In spite of limited coverage areas users who subscribe to and have 4G LTE devices and coverage plans are also able to utilize 3G technologies due to LTE being backwards compatible.

Another potential Con for 4G technology is it is still relatively a new technology and many of the bugs and glitches have not been worked out yet. Verizon Wireless 4G LTE customers recently experienced these bugs and glitches first hand when "For a period of more than 30 hours from April 26 through 28 (2011), customers experienced nationwide downtime on the company's 4G LTE network" (Isaac, 2011).

VIABLE ALTERNATIVES

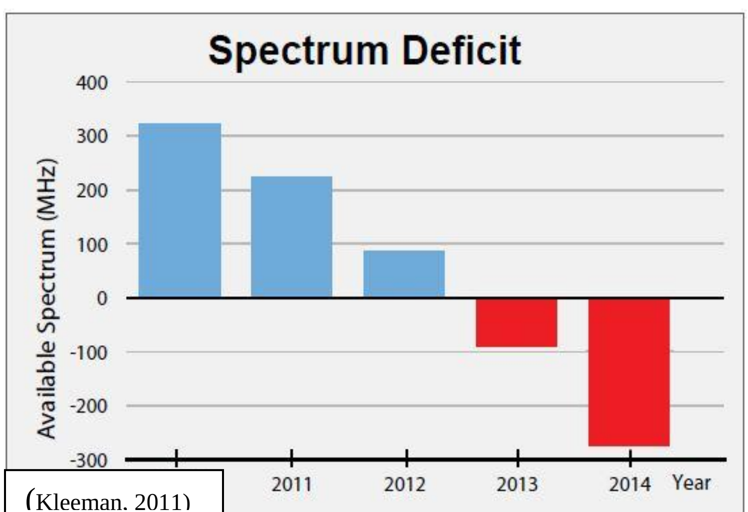
Wi-Fi offers the most feasible alternative to 4G and other cellular technologies. Wi-Fi follows the 802.11 standards which have been modified over the years and currently consist of 802.11 a, b, g and n standards. Wi-Fi allows users to wirelessly connect supported devices to a local area networks (LAN) to communicate and access the internet. Current Wi-Fi technologies are “capable of supporting data rates of 100-Mbps at several hundred feet” (White, 2011, p. 98), and utilize the 2.5 and 5 GHz frequencies.

A huge advantage to Wi-Fi is there are many “wireless hotspots” setup that allow users to connect to the internet for free. Most modern laptops, smartphones, gaming systems, printers and like devices have an internal wireless modem capable of connecting to Wi-FI and hotspots to access networks. Another advantage is most Wi-Fi networks offer unlimited amounts of data transfer with subscription. Wi-Fi isn’t without its disadvantages. It is highly susceptible to noise and other interference, it also “has trouble going through walls, floors, and furniture” (White, 2011, p. 223), and may have poor security. Another disadvantage associated to Wi-Fi is it isn’t capable of handling to many users before it begins to become congested.

Bluetooth is another wireless technology that may offer an alternative to 4G and cellular devices. Bluetooth “uses the 2.45-GHz frequency band, communicate among multiple devices, and transfer data at reasonably high speeds” (White, 2011, p. 97). Bluetooth, does have several problems that keep it from becoming a mainstream contender to include; short transmissions distances, and “problems with getting multiple (more than two) devices to synchronize data with each other” (White, 2011, p. 98).

CONCLUSION

For years cellular providers have tried to avoid spectrum crunch, within their networks, by releasing new generations of cellular technologies and techniques like frequency reuse. Each generation has offered faster services, more reliable networks and connections, and better security than the last. Despite all this the finite amount of frequency available still continues to present a problem.



(Kleeman. 2011)
The FCC projects a spectrum deficit by the year 2013

Demand on networks continues to grow. According to the International Telecommunications Union (2011) "of 1.8 billion households worldwide, one third have internet access, compared to only one fifth five years ago" More and more of these consumers are choosing to access the internet from smartphones or mobile-broadband capable devices. As previously stated "mobile-broadband subscriptions have grown 45% annually over the last four years" (International Telecommunications Union, 2011) reaching "almost 1.2 billion in subscriptions in 2011" (International Telecommunications Union, 2011). More than ever consumers are using their wireless devices to stream and download various types of media and data. All this use puts a strain on the spectrum. Because of this increased demand and use spectrum deficit in wireless transmissions is a reality. "The FCC projects a spectrum deficit by the year 2013" (Kleeman, 2011).

The introduction of packet switching and mobile broadband to wireless communications has been a blessing and detriment. On one hand it has allowed users to access the internet and download or stream mass amounts of data on MS's faster than ever before, allowing us to have access to information, at our finger tips, virtually anywhere and at any time we want. One the other hand it has increased the amount of traffic on networks exponentially.

4G services & technologies are still rather new and untested. They still need to undergo a lot of upgrades, to include wired backhaul and the deployment of BS's or antennas, before being fully functional. There is still debate, and it isn't fully clear on, whether they will be able to handle the growing amount of traffic that is required of them, with or without needed upgrades. It is also unclear on which emerging 4G technology, WiMAX or LTE, will prevail in the 4G arena, if they will be able to continue to coexist, or if a next generation of technology will be ushered around the corner sooner than expected. Fortunately, for the time being, 4G networks and mobile broadband services have sort of an ally in Wi-Fi, that similarly offers wireless connections and in most cases offered in conjunction with most 4G capable devices.

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