ABSTRACT

4G – “connect anytime, anywhere, anyhow” promising ubiquitous network access at high speed to the end users, has been a topic of great interest especially for the wireless telecom industry. 4G seems to be the solution for the growing user requirements of wireless broadband access and the limitations of the existing wireless communication system. The purpose of this paper is to provide an overview of the different aspects of 4G which includes its features, its proposed architecture and key technological enablers. It also elaborates on the roadblocks in its implementations. A special consideration has been given to the security concerns of 4G by discussing a security threat analysis model proposed by International Telecommunication Union (ITU). By applying this model, a detailed analysis of threats to 4G and the corresponding measures to counter them can be performed.

1. INTRODUCTION

Wireless telecommunication history can be classified into different generations of network. Each generation has been a giant stride which revolutionized the field of mobile communication. As discussed in paper [1], era of telecommunication started with 1G in 1980 where all the systems where based on analog radio signal technology. Voice was considered to be the main traffic. Various 1G standards defined were Advance Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). In 1990, 1G was replaced by 2G which provided rich set of services such as high voice quality and global mobility based on the digital radio signal technology. Here also voice was considered to be the main traffic. 2G includes standards such as Global System For Mobile Communications (GSM), General Packet Radio System (GPRS). Both 1G and 2G are based on circuit-switched technology for data communication at low speed. 2G was a huge success.

2G was followed by 2.5G which is an intermittent between 2G and 3G. It is based on both circuit switched and packet switched technologies providing high data rate with low power consumption. It uses the infrastructure of Global System for Mobile communications (GSM) and Code division multiple access (CDMA) to provide its services.

In the present generation, 2.5G is replaced by 3G which includes standards from 2.5G and also some other technologies such as WiMAX (Worldwide Interoperability for Microwave Access). It is totally based on the packet switching technology providing broad range of high quality services to the end user to meet the demand of high data rate and increasing rate of network users. But 3G was unable to repeat the success story of 2G as it provided only few new features over 2G.

Before 3G was deployed all over the world, the idea of technology beyond 3G started evolving. This idea was beyond the imagination of ordinary mobile user promising “connect anytime, anyhow, anywhere” [4]. This ubiquitous network access will be achieved by seamlessly integrating the available and new networks using a core IP based network layer. This vision is called as the 4th generation of communication (4G).

The paper introduces the idea behind 4G providing a brief overview about its features, architecture and challenges faced in its implementation. Security being a primary concern in any implementation; it motivates the discussion about threat analysis model. Section 2 cites an example of how an ideal wireless communication network should provide service to the end user. Motivation behind 4G and its features are covered in Section 3. Proposed architecture for 4G and key technologies enabling 4G are discussed in Section 4 and 5 respectively. Section 6 covers the challenges in the migration to 4G while section 7 elucidates the threat analysis model which can be used as a base for the future research work in 4G security. Current developments and future work to be done in 4G are covered in Section 8. Section 9 briefs up the conclusion of the paper and Section 10 enlist all the references of the research papers.

2. AN IDEAL WIRELESS COMMUNICATION SCENARIO

Paper [2] provides a good example summarizing the user’s expectations from the next generation of wireless network as illustrated below:

Before going on a vacation, people generally buy travel guide or browse internet to gather information spending time and money. But what the users wants to experience is something like this: The user plans for a
vacation with his family. He downloads a mobile tourist guide application provided by a mobile service provider (SP) on his personal terminal. Using this application, user downloads a travel guide package in his language of choice. The personal terminal also has a route planner (GPRS enabled) which can interact with the guide application helping the user in smooth navigation of his holiday destination. SP also sends information about various famous tourist spots like museum and can also book tickets for the museum on user’s request by interacting with the museum operator’s network. Once the user reaches the museum, he uses the local network of museum (Wi-Fi) to listen to the streaming guided tour of the museum explaining the different artifacts.

Thus, the user would have an experience of lifetime. Now the question is whether such an ubiquitous communication network service can be provided to the user at high quality and low cost.

3. WHY THE LEAP TOWARDS 4G

The vision which considers 4G as an extension to 3G cellular services is called as the linear 4G vision [2]. But the extent of 4G capabilities goes beyond the cellular services. Envisioning 4G as high speed delivery of services via the most efficient network available from the pool of wireless networks is called as the concurrent 4G vision [2]. One of the major reasons of 3G being unable to repeat the success story of 2G was the provision of only few additional services over 2G. It was not encouraging enough for the customer’s to change their equipments. Paper [2] suggests a user-centric approach for the design of 4G to avoid mismatch between the user’s expectations and the services provided by 4G. Using the discussion in paper [2-5], features of 4G which cater to the end-user’s expectations and the problems of the current generation networks can be listed as follows:

**User friendliness**

4G aims at providing myriad of services to the end users at high speed. The applications developed to avail these services should be highly user friendly minimizing the interaction between the application and the user. For example, integration of speech recognition technology in the user interfaces would ease the use of the applications for every layman.

**User personalization**

High data transfer rates and ubiquitous coverage of 4G networks would provide users access to large repository of data and services. Users should have flexibility to filter these data and services as per his preferences by configuring the operational mode of their devices, so that he can preselect the service features he wants to use. For an example, user in a mall interested in buying clothes should receive alerts about various discount offers on clothes rather than about the other accessories.

**Terminal and Network heterogeneity**

Terminal heterogeneity refers to the different types of terminals in terms of the size, weight, display features, power consumption, etc. Network heterogeneity means the different types of access networks like WiMAX, Wi-Fi (Wireless Fidelity), UMTS (Universal Mobile Telecommunications System) and so forth which differ in their coverage area, data rate, latency and data loss rate. Each of these terminals and services cater to different user requirements. In 4G, all these terminals and networks will provide common services independent of their capabilities. This is also called as service personalization.

**High Performance**

Low transfer rates of 3G restrict the user’s ability to take advantage of the rich multimedia contents across the wireless networks. 4G is expected to provide wireless download speeds of about 1Gbps in local area network (LAN) and 100 Mbps in wide area network (WAN), about 260 times greater than the 3G wireless networks.

**Interoperability**

Multiple standards of 3G restrict the user’s mobility and interoperation across different networks. 4G targets at providing a unified global standard which will facilitate global mobility and service portability. In other words, end user can subscribe to different services from different service providers using the same mobile device.

**Intelligent Networking**

4G is based primarily on cell or base station WAN design. 4G aims at building hybrid networks utilizing both the Wireless LAN concept and WAN design. Thus, the world would have base stations everywhere providing ubiquitous network coverage to users at high speed. For example, a user walking on road is browsing internet using GPRS (General Packet Radio Service-WAN design). The moment he enters a mall with Wi-Fi (LAN design), seamless hand-over from GPRS to Wi-Fi would take place without the user’s knowledge.

**Network Convergence:**

Network convergence is the efficient coexistence of multimedia, voice and data communication within a single network. [5]

Currently the telecommunication environment is divided into wireless and fixed line communication. To avail these different kinds of services, the end user require different devices such as cellular phones, fixed line phones, laptops and PDA’s. Once the fixed mobile convergence is in place in 4G, the distinction between these services will disappear. The current 3G technology is not able to capture the market share as done by the fixed line services partly because of its low bit rates of 384kbps and because of the high costs associated with these services. But with the emergence of 4G aiming at global integrated IP based network, the wireless sector will be able to match the fixed line sectors in terms of both costs and speed. 4G will lead to convergence in terms of both devices and services. Thus, handset capabilities, MP3, camera, mobile broadband services would be made available in a single device. Service convergence will result from availability of telecommunication and internet on a single platform. This would force the fixed line sector to jump in the competitive wireless market. In response, the wireless operators will also jump into the fixed line sector. Thus slowly the boundaries between these markets will disappear. Thus, the end user will benefit from one business providing variety of services. He will experience high quality service at affordable prices. Thus fixed mobile convergence will act
as a catalyst for stimulating markets to come up with new innovative and cost effective ideas.

**Scalability**

Scalability in mobile networks is the ability to handle the increasing numbers of users and services. 4G will use IPv6 addressing scheme which will support large number of wireless devices eliminating the need for Network address translation (NAT). NAT is technique of sharing limited number of addresses among large number of devices. The huge expanse of current internet world signifies the scalability support of IP. Thus, the use of IP as core network layer will make 4G easily scalable.

**Lower power consumption**

Battery technology has not been able to keep pace with the growing telecom industry. 2G devices required one battery while 3G required two batteries. Battery drain is a persistent problem of wireless devices. 4G aims at breaking this directly proportional rule. Shorter communication links is one of the few solutions proposed to cater to this requirement.

**Low costs**

4G is designed to be spectrally efficient with no requirement to buy costly extra spectrum. It is not development of a completely new system rather built on the top of the existing networks. 4G will also support backward compatibility with 2G and 3G devices. All these factors will make 4G much cheaper than the current generation networks.

### 4. 4G NETWORK ARCHITECTURE

*Figure 1* shows the widely accepted 4G network structure with IP as the core network used for communication; integrating the 2G, 3G and 4G technologies using a convergence layer [4].

**Application**

This layer is composed of various third party applications which provide value added services to its subscribers.

**Network**

This layer consists of various sub layers described as follows:

- **Services**
  This layer manages the interaction between various value-added services and networks.

- **Mobility Management**
  This layer provides quality and uniform services to the mobile/stationary terminal across various heterogeneous networks. It provides features of low handover latency and packet loss during the provision of real-time and non-real time services to the end user moving across different networks. To achieve this, it performs tasks such as binding update (updating the care-off address of the mobile user), location management, common control signaling (signaling required to perform wireless network discovery), address assignment, handover control mechanism and so forth.

- **Resource Management**
  This layer incorporates the functionalities of allocation, de-allocation and reallocation of the network resources which are acquired during the communication sessions within the same or different network domains. This activity is performed during or
before the communication activity. This layer also performs the task of congestion control, packet scheduling and packet classification.

- Quality of service (QoS) management
  This layer provides best optimal utilization of the available resources. In scenarios where the network resources are limited it provides an option to the applications to choose between high overall throughput and low end-to-end delay. It provides the best trade-off mechanisms depending on the application’s preference. It encompasses several activities such as link utilization control, bandwidth control and so forth.

**Physical**
This layer consists of the core IPv6 network of 4G and other heterogeneous access networks such as GSM (Global System for Mobile communications), CDMA (Code Division Multiple Access) and WLAN in their physical view. This layer is composed of two sub-layers namely:

- Convergence layer
  This layer provides common control signaling mechanism across the core and other heterogeneous networks at the physical level. It also allows different radio access networks to transparently use the independent network services such as mobility management, resource management and QoS management.

- Different RAN
  This layer consists of several radio access networks communicating with each other at the physical level.

**Operation, Administration, Maintenance and Provisioning**
This layer spans across all the layers of the network architecture and provides the functionalities of network controlling, network monitoring and fault detection. It also maintains the repudiation between various services and resources of several heterogeneous and core networks.

**Security**
This layer also branches across all the layers of the 4G network architecture which perform the function of authentication, authorization, encryption, establishment and implementation of service policy agreement between the various vendors.

5. **KEY 4G TECHNOLOGIES**

This section provides a brief description of the key technologies which would enable 4G implementation based on the discussion in [7-11]. They are discussed as follows:

5.1 **OFDMA**

OFDMA can be used for the downlink transmission (signal transmission from the base station to mobile terminal) of the symbols for achieving high spectral efficiency. It provides high performance on full bandwidth usage.

It is a channel allocation scheme based on the orthogonal frequency division multiplexing technique that splits the data to be transmitted along the orthogonal narrowband carriers well spaced by frequency. The technique used for splitting the data is Inverse Fast Fourier Transform (IFFT) which incorporates the advantage of transmitting the data at a higher rate. The introduction of a cyclic prefix (CP) in terms of guard interval consists of repetition of the last part of the symbol at the beginning of each symbol transmitted. This avoids interference between the various symbols and the carriers if the CP interval is longer than the delay caused by the interferences of the channel. This improves the robustness of the technology used for the multipath transmission. The use of narrowband subcarrier is to get a channel which is constant for each sub-band (input symbol broken down number of smaller bands). This avoids synchronization problems at the receiver side during the symbol transmission through the channel. In order to get high spectral efficient system, overlapping between the mutually orthogonal subcarrier is allowed.

OFDMA is compatible with other technologies such as Multiple Input Multiple Output and smart antennas. OFDM not only improves the performance of the physical layer but also adds to the improvement of the Data Link Layer. It facilitates the optimization between various layers of network for usage of radio link from multiple radios.

OFDMA is currently applied on various wireless and wireline standards such as Wi-Fi, Wireless LAN, Ultra Wideband (UWB), Wireless PAN, WiMAX, WiBro, HiperMAN, Wireless MAN, 3GPP UMTS & 3GPP@ LTE (Long-Term Evolution).

5.2 **SCFDMA**

It can be used for the uplink transmission of the symbols. It is a channel allocation scheme used for data transmission based on single carrier frequency division multiplexing technique that allows the transmission of the symbols across a single carrier. The techniques used for splitting the data is IFFT described in the above section and Discrete Fourier transform (DFT) which performs the task of splitting the data across multiple sub-carriers and transmitting virtually as a single carrier. DFT is performed prior to IFFT. SCFDMA provides low peak-to-average-power ratio (PAPR) as compared to OFDMA. In this scheme, as the data is transmitted along the multiple subcarriers and if one subcarrier is in problem it is easy to recover the data from the other subcarriers based on frequency selection for the channel. But the recovery of data at the receiver side requires the selection of the data from the multiple subcarriers and requires more efforts for removing the error in the data.

5.3 **Multiple-Input and Multiple-Output (MIMO)**

This is an antenna technology which uses multiple channels in radios to provide the functions of both the transmitter and receiver of data signals sent over the network as shown in the figure 3 [12]. It provides high spectral efficiency and link reliability facilitating significant increase in the data throughput and radio link usage without additional bandwidth and transmission power. This high efficiency is due to the availability of an
independent path in a rich scattering environment for each transmitter and receiver antennas in the radio.

![Figure 3: MIMO](image)

The MIMO channels can be used with OFDMA for transmission and reception of modulated signal over network to single or multiple users. This is currently used in WLAN – Wi-Fi 802.11n, Mesh Networks (e.g., WMAN – WiMAX 802.16e, RFID, and Digital Home.

5.4 Multi-user – MIMO (MU-MIMO)

This is the variant antenna technology that enhances the communication capabilities of the individual radio terminal used by radios in the network by introducing multiple independent radio terminals. This allows transmission and reception to and from multiple users using the same band.

5.5 Software Defined Radio (SDR)

SDR is a radio communication system implemented as software on the personal computer or embedded devices. It scans the available networks and then reconfigures itself for the selected network by downloading the software specific to that network. It is used for implementation of the multimodal, multi-band, multi-standard user terminals and base stations which allows accessibility across various wireless and wireline heterogeneous networks. There are several advantages of SDR such as flexibility in network expansion i.e. operator can expands its network infrastructure by adding few modems to base station transceiver system. It reduces the cost for development of multimodal, multiband and multi-standard user equipments. This will benefit both the end users and the service providers. The current SDR technology is not capable of supporting the multiple networks. It should be enhanced to support multiple networks.

6. CHALLENGES IN 4G

Paper [13] groups challenges faced in the migration to 4G into three different aspects and discusses them in detail as follows:

**Mobile station:**

- Multimode user terminal

  **Multimode user terminal** is a device working in different modes supporting a wide variety of 4G services and wireless networks by reconfiguring themselves to adapt to different wireless networks. They encounter several design issues such as limitations in the device size, cost, power consumption and backward compatibility to systems. One possible solution to this is the use of SDR which adapts itself to the wireless interface of the network. *Figure 4 shows multimode user terminal simultaneously interacting with the different access networks.*

  - **Wireless network discovery**

    Availing 4G services require the multimode user terminal to discover and select the preferred wireless network. Service discovery in 4G will be much more challenging than 3G because of the heterogeneity of the networks and their access protocols. SDR approach has been proposed to counter this challenge. As shown in the *figure 4*, SDR will scan for the available networks and download the software required to interface with the selected network. Software can be downloaded from a PC server, smart card or from over the air (OTA). Slow download speeds is one of the major problems faced by the SDR approach.

  - **Wireless network selection**

    4G will provide the users a choice to select a wireless network providing optimized performance and high QoS for a particular place, time and desired service (communication, multimedia). But what parameters define high QoS and optimized performance at particular instant needs to be clearly defined to make the network selection procedure efficient and transparent to the end user. Possible considerations may be available network resources, network supported service types and cost and user preference.

  ![Figure 4: Multimode user Terminal System](image)

**System**

- **Terminal mobility**

  Terminal mobility is an essential characteristic to fulfill the “Anytime Anywhere” promise of 4G. It allows the mobile users to roam across the geographic boundaries of wireless networks [13]. Two main issues in terminal mobility are location and hand off management. Location management involves tracking the location of the mobile users and maintaining information such as the authentication data, QoS capabilities, and the original and the current cell location. Handoff management is maintaining the ongoing communication when the terminal roams. Handoff can be horizontal or vertical depending on whether the user moves from one cell to another within the same wireless systems or across different wireless systems (WLAN to GSM). Handoff process faces several challenges like maintaining the QoS and system performance across different systems, deciding
the correct handoff time, designing the correct handoff mechanism, packet losses, handover latency and the increased system load.

- **Network infrastructure and QoS support**
  Unlike previous generation networks (2G and 3G), 4G is an integration of IP and non-IP based system. Prior to 4G, QoS designs were made with a particular wireless system in mind. But in 4G networks QoS designs should consider the integration of different wireless networks to guarantee QoS for the end-to-end services.

- **Security**
  Most of the security schemes and the encryption/decryption protocols of the current generation networks were designed only for specific services. They seem to be very inflexible to be used across the heterogeneous architecture of 4G which needs dynamically reconfigurable, adaptive and light-weight security mechanism.

- **Fault tolerance**
  Wireless networks characterize a tree-like topology. Any failure in one of the levels can affect all the network elements at the levels below. This problem can be further aggravated because of the multiple tree topologies. Adequate research work is required to devise a strategy for fault tolerance in wireless networks.

**Services**

- **Multiple operators and billing system**
  In the current era of 2G and 3G networks, each operator has its own billing scheme based on the call duration, services used, etc. But in 4G each user can avail to different services made available by different operators. This would complicate the billing system for both the service providers and the end users. This asks for a unified billing system for all the services of the 4G network. To cater to these issues several frameworks are being studied based on the requirements of scalability, flexibility, accuracy and usability.

- **Personal mobility**
  Unlike terminal mobility, personal mobility considers the movement of the user. It emphasizes on provision of personal communication- ensuring message delivery to the user irrespective of his location and the terminal he is using and personalized operating environment- adapting the message display as per the characteristics of user terminal.

### 7. 4G SECURITY THREAT ANALYSIS

Amidst the concerns of technology, devices, architecture for 4G; security has not received much attention although being an important parameter for its marketing among the end users. Paper [14] discusses the security aspect of 4G in detail. A region may be connected by multiple Radio Access Network (RAN). One of the governing factors for selecting an appropriate RAN will be the security features provided by the network.

#### 7.1 Key Objectives for secured N/W architecture

- **Availability**: network services are available without any disruptions or interruptions
- **Interoperability**: the security solutions are generic and not specific to any particular services or networks
- **Usability**: security services provided should be easy to use
- **QoS guarantee**: Security services like cryptographic algorithms should meet the QoS constraints of voice and multimedia traffic
- **Cost-effectiveness**: The cost of security should be lower than the cost of the risks

Each stakeholder in the 4G network has its own set of security requirements. 4G security systems need to be flexible enough to adapt to these requirements. They should also comprehend other vulnerabilities which might disrupt the functioning of the systems.

#### 7.2 Possible threats faced by 4G

- As all the network operators and service provide would share a common core network infrastructure, compromise of a single operator will lead to the collapse of the entire network infrastructure.
- Third-parties can masquerade as legitimate users resulting in theft of service and billing frauds.
- Since 4G is a secure IP based solution it will be vulnerable to all the security threats as the current Internet world.
- On the lines of email-spam, the Spam over Internet telephony (SPIT), the new spam over VoIP may become serious threats.
- Spoofing attacks can lead to misdirected communication and internet banking related frauds.
- Eavesdropping and interception of private communications.
- Phishing attacks, stealing bank account details and other secured information.

#### 7.3 Security threat analysis model

X.805 is a standard based on the Bell Labs security model developed by ITU. This standard provides a systematic and organized way of performing network security evaluation and planning. This model has been proposed by ITU to perform a network security analysis of the emerging new generation networks.

The network security architecture consists of three layers, three planes and eight dimensions which help identify possible threats or attacks on the system.
7.3.1 Security layers

Security layer defines the network equipments or the facilities which need to be protected from security threats. The three layers are mainly:

- **Infrastructure layer**: Consists of the building blocks of the network like routers, switches, Ethernet links, etc.
- **Service layer**: Services provided to the end users like VoIP (Voice over Internet Protocol), Wi-Fi, etc constitutes this layer.
- **Application layer**: Network-based applications accessed by the end-users such as web browsing, email, etc constitute this layer.

7.3.2 Security Planes

The security plane specifies the different types of network activities that need to be protected. The three security planes classified are [15]:

- **User plane**: is concerned with information routing and performs several functions such as error correction and flow control. User services such as voice, fax, video, web access, etc can be categorized under the user plane.
- **Control plane**: deals with the short term network operations such as control of communication sessions like call setup, call release, etc. It contains several functions like security( performing authentication) , QoS, mobility, charging, etc
- **Management plane**: is concerned with the long-term network operations and includes functions like fault, configuration, accounting (pricing and billing), performance and security (maintaining the authentication system) management.

7.3.3 Security dimensions

Security dimensions specify the different threats and the measures to counter them. The eight security dimensions are:

- **Access control**: Keeps a track on the protection level against the unauthorized use of network resources. For example, password, ACL, firewall.
- **Authentication**: checks whether the user of the network resources has been authenticated. For example, digital signature and certificates.
- **Non-repudiation**: Prevents denial of occurrence of an activity on the network. For example, system logs, digital signatures.
- **Data confidentiality**: ensures that data is made available only to the authorized user using encryption mechanism.
- **Communication security**: Ensures the data flow only between authorized end points.
- **Data integrity**: Counters unauthorized attempts made to modify the data using anti-virus software or encryption mechanisms.
- **Availability**: Ensures that the network resources and services are always available to the authorized users using network redundancy techniques.
- **Privacy**: Prevents revelation of any important information derived from network monitoring activities performed by other malicious users using encryption techniques.

7.3.4 Threat Analysis Model

As shown in the Figure 5 [14], we define nine modules corresponding to the three security layers and three security planes. The eight security dimensions are applied to each of the module. Each module has different security objectives and corresponding security measures to cater to those objectives. Thus, these architecture help us to comprehend which network resources and activities are vulnerable to which threats and what measures can be taken to counter those threats. It can be applied to any network technology like wireless, wired, converged networks, etc.

![Figure 5: Threat analysis Model](image)

8. WHEN WILL 4G HAPPEN?

Air of uncertainty is looming large over the development and deployment of 4G networks. Telecom experts predict 2010-2011 time frame. Vodafone and Verizon Wireless have developed a common platform for supporting mobiles in 4G networks using LTE technology and they are currently in the field trial phase [16]. NTT-DoCoMo has managed to achieve a speed of about 100MBPS for the moving terminal and 1 GBPS for the stationary terminal. They are scheduling to deploy the first commercial network by 2010 [17]. Spring Nextel is planning to deploy 4G network mobile services using WiMAX technology in US [17]. Ericsson will deploy first commercial 4G network based on LTE to provide mobile broadband services for the TeliaSonera customers in Stockholm [18].

9. CONCLUSION

The advent of 4G is sure to revolutionize the field of telecommunication domain bringing the wireless experience to a completely new level. It would provide wealth of features and services making the world a smaller place to live. Thus, 4G seems to have the capability to realize the scenario discussed in Section 2. But 4G should
also take lesson from the 3G’s failure to capture the imagination of the end-users. Technology should not be developed for technology’s sake rather it should target the end user. Thus, user-centric approach towards 4G’s development is the key to its success. Common consensus on the standards and the technologies for 4G needs to be reached to fasten 4G’s deployment which would be a gradual process. Lot of research work is required to investigate the open issues like design for SDR, QoS parameters and so forth. The threat analysis model provided by ITU is very apt for the complete analysis and planning for security of 4G. It can be used as a reference framework for future research. But still comprehensive research work is required in the field of network security to tackle potential security threats because a ubiquitous “secured” heterogeneous network will appeal more to the today’s consumers.

10. REFERENCES


