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|  | ASIA-PACIFIC TELECOMMUNITY |  |  |
| **SOUTH ASIAN TELECOMMUNICATIONS REGULATORS’ COUNCIL** **(SATRC)** |
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|  **SATRC Report on** **EFFICIENT USE OF SPECTRUM USING LONG TERM EVOLUTION(LTE)**

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Developed by

**SATRC Working Group on Spectrum**

Adopted by

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**Preface**

This report has been prepared as an assigned work item of SATRC Working Group on Spectrum under SATRC Action Plan Phase III. The Work Group comprises of eleven experts from nine SATRC member regulators. The objective of this report is to provide guideline to utilize the available spectrum efficiently and optimally so that higher bandwidth applications can be served with the available spectrum using latest technologies like LTE. This report has analyzed various mobile systems available in SATRC countries. This has also included the challenges that will be faced by SATRC countries due to spectrum shortage. Recommendation has been made to overcome these challenges.

1. **Introduction**

‘Spectrum’ is collection of various types of electromagnetic radiations of different wavelengths. Spectrum is a finite and scarce but non-exhaustible natural resource which is a vital input for wireless services. With its broad range of applications in personal and business communications, it has ever increasing economic and social utility. The consumer and business benefits derived from it are very significant. Rapid development of wireless technology has ensured that there is an increasing range of valuable uses of the spectrum. With competing users, uses and growth of wireless services, the demand for spectrum has tremendously increased. The trend of modern communications is towards mobility, with increasingly higher data rates/ speeds, for which wireless is the only option. The requirements of captive applications are also growing. All these have resulted in greater demands/ pressure on the already scarce RF spectrum resource.

Because there is a finite amount of spectrum and a growing demand for it, effectively managing the available spectrum is a strategic issue for the Spectrum Regulators. Increasing demand for spectrum-based services and devices is straining long standing spectrum policies. There is a growing need to appropriately changed to exploit the full potential of spectrum use through market orientation and stimulating development of new technologies that are more efficient and economize the spectrum usage because future success and growth of telecommunications sector depends heavily on effective and efficient spectrum management. Unless spectrum can be made available to meet the ever growing demand, there will be a setback to innovations and competition and businesses as well as consumers will be worse off. Making spectrum available at a time when convergence is causing rapid and unpredictable change poses a severe challenge. Advances in technology create the potential for systems to use spectrum more efficiently and to be much more tolerant of interference than in the past.

As the wireless industry is witnessing explosive growth in the demand for both voice and data services, the number of mobile telephone subscribers, as well as usage rates, have also grown considerably. Consequently, the Service providers have been upgrading their networks with advanced technologies to meet this growing demand for high quality voice and data services. The equipment vendors are driving technical innovations with the latest wireless technologies showing significant gains in the efficiency of spectrum used, thus providing more capacity out of a given bandwidth.

With the availability of higher data speeds, the user requirements are also continually increasing with regard to different services and applications, expecting a dynamic, continuing stream of new capabilities that are ubiquitous and available across a range of devices using a single subscription and a single identity (number or address).

The bandwidth intensive services that users will want, and the rising number of users, are placing increasing demands on access networks. These demands may eventually not be met by the enhancement of radio access systems (in terms of peak bit rate to a user, aggregate throughput, and greater flexibility to support many different types of service simultaneously). Therefore there will be a requirement for new radio access technologies to satisfy the anticipated demands for higher bandwidth services. As third generation (3G) International Mobile Telecommunication 2000 (IMT-2000) systems are being deployed, further developments aiming at their enhancement are being conducted on a worldwide scale. Many operators in the developed countries are focusing on deploying IMT – advanced system networks to cater to the growing requirement of data, speed and content delivery.

International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities that go beyond those of IMT. Such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based. In order to fulfil the requirement of higher bandwidth systems like LTE Advanced and Wireless MAN-Advanced, are designed to enable high speed Internet anytime, anywhere. These systems will facilitate higher bandwidth, higher data rate, lower authentication load, and will support higher level of user-level customization. It is expected to provide virtual environment agnostic to network and devices being used.

An IMT- Advanced cellular system is expected to provide a comprehensive and secure all-IP based solution where facilities such as IP telephony, ultra-broadband Internet access, gaming services and streamed multimedia may be provided to users. According to the ITU requirements for IMT- Advanced, the targeted peak data rates are up to 100 Mbit/s for high mobility and up to 1 Gbit/s for low mobility, scenario. Scalable bandwidths up to at least 40 MHz should be provided.

IMT- Advanced systems support low to high mobility applications and a wide range of data rates in accordance with user and service demands in multiple user environments. IMT‑ Advanced also has capabilities for high quality multimedia applications within a wide range of services and platforms, providing a significant improvement in performance and quality of service having the following key features:

* a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
* compatibility of services within IMT and with fixed networks;
* capability of interworking with other radio access systems;
* high quality mobile services;
* user equipment suitable for worldwide use;
* user-friendly applications, services and equipment;
* worldwide roaming capability; and,
* enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research)[[1]](#footnote-1).

Technologies like mobile WiMax and the first release Long Term Evolution (LTE) has been in market since 2006 and 2009 respectively. The current versions of these technologies do not fulfill the IMT- Advanced requirement. IMT- Advanced compliant version of the above two standards are under development and called “LTE Advanced” and “WirelessMAN Advanced” respectively. Both LTE-Advanced technology and the IEEE WirelessMAN ‑Advanced technology make use of same key technologies viz. Orthogonal Frequency Division Multiplex (OFDMA), Multiple Input Multiple Output (MIMO) and System Architecture Evolution (SAE).

The framework for the development of IMT-Advanced systems can be considered from multiple perspectives, including the users, manufacturers, application developers, network operators, and service and content providers. From the user’s perspective, there will be a demand for a variety of services, content and applications whose capabilities will increase over time. Similarly, users will expect services to be ubiquitously available through a variety of delivery mechanisms and service providers, using a wide variety of devices that will be developed to meet their differing requirements. User demands will be addressed by a large community including content providers, service providers, network operators, manufacturers, application and hardware developers. The objectives of various stakeholders from IMT-advanced services are tabulated below:

**Table 2**:-**Objectives from multiple perspectives**

|  |  |
| --- | --- |
| Perspective | Objectives |
| END USER | Ubiquitous mobile accessEasy access to applications and servicesAppropriate quality at reasonable costEasily understandable user interface Long equipment and battery life Large choice of terminalsEnhanced service capabilitiesUser-friendly billing capabilities |
| CONTENT PROVIDER | Flexible billing capabilitiesAbility to adapt content to user requirements depending on terminal, location and user preferencesAccess to a very large marketplace through a high similarity of application programming interfaces |
| SERVICE PROVIDER | Fast, open service creation, validation and provisioningQuality of service (QoS) and security managementAutomatic service adaptation as a function of available data rate and type of terminalFlexible billing capabilities |
| NETWORK OPERATOR | Optimization of resources (spectrum and equipment)QoS and security managementAbility to provide differentiated servicesFlexible network configurationReduced cost of terminals and network equipment based on global economies of scaleSmooth transition from IMT-2000 to systems beyond IMT-2000Maximization of sharing capabilities between IMT-2000 and systems beyond IMT-2000 (sharing of mobile, UMTS subscriber identity module (USIM), network elements, radio sites)Single authentication (independent of the access network)Flexible billing capabilitiesAccess type selection optimizing service delivery |
| MANUFACTURER/ APPLICATION DEVELOPER | Reduced cost of terminals and network equipment based on global economies of scaleAccess to a global marketplaceOpen physical and logical interfaces between modular and integrated subsystemsProgrammable platforms that enable fast and low-cost development  |

1. **Overview of IMT-Advanced Systems**

ITU's Radio communication Sector (ITU-R) has completed the assessment of six candidate submissions for the global 4G mobile wireless broadband technology, otherwise known as IMT-Advanced in October 2010. Harmonization among these proposals has resulted in two technologies, "LTE-Advanced" and "Wireless MAN-Advanced" being accorded the official designation of IMT-Advanced, qualifying them as true 4G technologies[[2]](#footnote-2). ITU-R Working Party 5D, which is charged with defining the IMT-Advanced global 4G technologies, decided on these technologies for the first release of IMT-Advanced. These technologies will now move into the final stage of the IMT-Advanced process, which provides for the development in early 2012 of an ITU-R Recommendation specifying the in-depth technical standards for these radio technologies.

Over a period of time many new technologies have emerged when compared to the previous cellular systems. This has enabled new systems to utilize spectrum more efficiently and to provide the much higher data rates that are being required. Brief of some of advanced technologies are given in the paras below:-

***2.1 Multiple Input Multiple Output (MIMO)***

Multiple Input Multiple Output (MIMO) technology is a wireless technology that uses multiple transmitters and receivers. The use of multiple antennas allows independent channels to be created in space and is one of the most interesting and promising areas of recent innovation in wireless communications.

There are various approaches to use the multiple antenna elements at transmitter and receiver ends and are often collectively referred to as multiple input multiple output (MIMO) communication. These approaches are discussed here.

***2.2 Spatial Diversity***

Spatial Diversity gain results from the creation of multiple independent channels between the transmitter and the receiver and is a product of the statistical richness of those channels. One main advantage of spatial diversity relative to time and frequency diversity is that no additional bandwidth or power is needed in order to take the advantage of spatial diversity. Traditionally, the main objective of spatial diversity is to improve the communication reliability by decreasing the sensitivity to fading by picking up multiple copies of the same signal at different locations in space. A potential diversity gain is achieved and maximized if the antennas are sufficiently separated such that the fading characteristics are independent Diversity techniques are very effective at averaging out fades in the channel and thus increasing the system reliability. The benefits of diversity can also be harnessed to increase the coverage area and to reduce the required transmit power, although these gains directly compete with each other, as well as with the achievable reliability and data rate.

***2.3 Beamforming***

In contrast to the transmit diversity techniques, the available antenna elements can instead be used to adjust the strength of the transmitted and received signals, based on their direction. This focusing of energy is achieved by choosing appropriate weights for each antenna elements with a certain criterion. Beamforming techniques are an alternate to directly increase the desired signal energy while suppressing or nulling, interfering signal.

***2.4 Spatial Multiplexing***

From a data rate standpoint, the most exciting type of MIMO communication is spatial multiplexing. Increased capacity is achieved by introducing additional spatial channels that are exploited by using space-time coding. It allows multiple data streams to be simultaneously transmitted using sophisticated signal processing. Thus, the nominal spectral efficiency is thus increased by a factor equal to number of spatial channels. This is certainly exciting as it implies that adding antenna elements can greatly increase the viability of high data rates desired for wireless broadband Internet access.

These approaches can be used to

* Increase the system reliability (decrease the bit or packet error rate)
* Increase the achievable data rate and hence system capacity.
* Increase the coverage area.
* Decreases the required transmit power.

However, these four desirable attributes usually compete with one another; for example, increase in data rate often accompanies with an increase in either the error rate or transmit power. The way in which the antennas are used generally reflects the relative value attached by the designer to each of these attributes, as well as such considerations as cost and space. Despite the cost associated with additional antenna elements and their accompanying RF chains, the gain from antenna arrays is so enormous that it plays critical role in new wireless technologies.

When using MIMO, it is necessary to use multiple antennas to enable the different paths to be distinguished. There can be various MIMO configurations. For example, a 2x2 MIMO configuration is 2 antennas to transmit signals (from base station) and 2 antennas to receive signals (mobile terminal). Similarly 4X4 or even higher order configurations are possible in MIMO.

While it is relatively easy to add further antennas to a base station, the same is not true of mobile handsets, where the dimensions of the user equipment limit the number of antennas which should be place at least a half wavelength apart.

***2.5 Orthogonal Frequency Division Multiple Access (OFDMA)***

Orthogonal Frequency Division Multiplexing (OFDM) belongs to a family of transmission schemes called multi-carrier modulations, which is based on the idea of dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulating each stream on separate carrier – often called sub-carriers or tones.

Multi-carrier modulation scheme eliminate or minimize inter-symbol interference (ISI) by making the symbol time large enough so that the channel-induced delays are an insignificant (typically <10 percent) fraction of the symbol duration. Therefore, in high-data-rate systems in which the symbol duration is small, being inversely proportional to the data rate, splitting the data stream into many parallel streams increases the symbol duration of each stream such that the delay spread is only a small fraction of the symbol duration.

OFDM is a spectrally efficient version of multi-carrier modulation where the sub-carriers are selected such that they are all orthogonal to one another over the symbol duration, thereby avoiding the need to have non overlapping sub-carrier channels to eliminate inter-carrier interference.

In order to completely eliminate ISI, guard intervals are used between OFDM symbols. By making the guard intervals larger than the expected multi-path delay spread, ISI can be completely eliminated.

OFDM can be used as a multi-access scheme, where the available sub-carriers may be divided into several groups of sub-carriers called sub-channels. Different sub channels may be allocated to different users as a multiple access mechanism. This type of multi access scheme is called OFDMA. Theses sub-channels may be constituted using either contiguous sub-channels or sub-carriers pseudo randomly distributed across the frequency spectrum.

OFDMA is essentially a hybrid of FDMA and TDMA. Users are dynamically assigned sub-carriers (FDMA) in different time slots (TDMA). The advantages of OFDMA start with the advantages of single user OFDM in terms of robust multi-path suppression and frequency diversity. OFDMA is a flexible multiple access technique that can accommodate many users with widely varying applications, data rates and QoS requirements. It has the potential to reduce the transmit power and to relax the peak to average power ratio problem. Because the multiple accesses are performed in the digital domain before the IFFT operations, dynamic and efficient bandwidth allocation is possible. Lower data rates and data in burst are handled much more efficiently in OFDMA, since rather than having to blast at high power over the entire bandwidth; OFDMA allows the same data rate to be sent over a longer period of time using the same total power.

OFDMA achieves its high performance and flexible accommodation of many users through multiuser diversity and adaptive modulation.

***2.6 Multiuser Diversity***

This type of diversity is naturally inherent in systems where several users are communicating with a base station (BS) on a shared frequency band. The diversity is attributed to the fact that for a given moment in time, different users usually have different channel conditions. In this situation, the total system throughput can be maximized by only letting the user having the best channel quality transmit at any given time However, repeatedly scheduling the best user might not be a fair strategy to communicate on a shared frequency band, since the same favorable user might end up being selected every time. Hence, scheduling users in a multiuser system by exploiting multiuser diversity also involve fairness and latency issues.

***2.7 Adaptive Modulation and Coding***

In order to achieve high-speed transmission of data on a wireless channel, a reliable and spectrally efficient transmission scheme is needed. However, the hostility of the wireless channel makes this a challenging task, since signals tend to propagate along different paths due to reflection, scattering, and diffraction from obstructing objects. The received signal will then be a sum of randomly delayed signal components which will add either constructively or destructively, causing rapid fluctuations in the received signal level. This is called multipath fading, and through the years, it has been perceived as a phenomenon with detrimental effects on spectral efficiency. Based on this perception, wireless transmission schemes have traditionally been designed for the worst-case scenario by focusing on enabling the system to perform acceptably even in deep fading conditions. With such a design principle, spectral efficiency is sacrificed for link reliability.

A design principle focusing more on spectral efficiency is rate-adaptive transmission, where the basic concept is to exploit and track the time varying characteristics of the wireless channel to transmit with as high information rate as possible when the channel quality is good, and to lower the information rate (and trade it for link reliability) when the channel quality is reduced. With such a transmission scheme, a feedback channel is required, on which the receiver reports channel state information (CSI) to the transmitter. Based on the reported CSI, the transmitter can make a decision on which rate to employ for the next transmission period. In particular, the transmitter may choose to select symbols from the biggest constellation meeting a pre-defined bit-error-rate (BER) requirement, to ensure that the spectral efficiency is maximized for an acceptable (target) BER.

 A promising method is to vary the constellation size and the channel coding scheme (error control) according to the channel conditions, in which case a rate-adaptive transmission scheme is called as adaptive modulation.

***2.8 SAE (System Architecture Evolution)***

With the very high data rate and low latency requirements for IMT systems, it is necessary to evolve the system architecture to enable the improved performance to be achieved. One change is that a number of the functions previously handled by the core network have been transferred out to the periphery. Essentially this provides a much "flatter" form of network architecture. In this way latency time is reduced and data can be routed more directly to its destination.

***2.9 IEEE802.16m***

The **IEEE** 802.16e-2005 amendment to the IEEE Std 802.16-2004 Air Interface Standard which added Scalable-Orthogonal Frequency Division Multiple Access (S-OFDMA) and many other features for support of mobility has provided the basis for WiMAX System Release 1. Further specification enhancements for Release 1 were provided with IEEE Std 802.16e-2009. The first WiMAX System Release 1 deployments took place in 2006.

 In December 2006 the IEEE launched an effort to further evolve the IEEE 802.16 WirelessMAN OFDMA specification. This amendment is known as 802.16m, which is designed to support frequencies in all licensed IMT bands below 6 GHz and include TDD and FDD duplexing schemes as well as half-duplex FDD (H-FDD) terminal operation to ensure applicability to the wide range of worldwide spectrum assignments.

*Coverage and Spectral Efficiency*: The IEEE 802.16m amendment provides an improvement in the link budget over WiMAX System Release 1 of at least 3 dB with the same antenna configuration. This will provide a 20-30% increase in cell coverage area in a typical non line-of-sight environment. Several other enhancements included in IEEE 802.16m will improve spectral efficiency for data services. These enhancements include:

* Extended and improved MIMO modes with emphasis on multi-user MIMO (MU-MIMO) on both DL and UL to enable support for up to 8 data streams in the DL and up to 4 data streams in the UL.
* Improved open-loop power and closed-loop control
* Advanced interference mitigation techniques including fractional frequency reuse and inter-base station coordination
* More efficient use of pilot tones with new sub-channelization schemes and a cyclic prefix of 1/16 vs. 1/8 to reduce layer 1 overhead in both DL and UL
* Enhanced control channel design on both DL and UL with:
* Reduced overhead
* Improved coverage through power boosting and optimized channel coding
* HARQ protection for control messages

The net result of these enhancements will provide more than 2 times improvement in average channel spectral efficiency. The spectral efficiency enhancements described in the previous section lead directly to increased channel data capacity and increased peak data rates.

*Multi-Carrier Support:* The IEEE 802.16m amendment also supports channel aggregation of contiguous or non-contiguous channels to provide an effective bandwidth up to 100 MHz. The channels do not need to have the same bandwidth nor do they need to be in the same frequency band. This capability will enable operators with access to multiple channels or licenses to achieve significantly higher peak and average data rates than is achievable with individual channels. Aggregating several 20 MHz channels, for example, could support peak data rates exceeding 1 Gigabit/sec.

The key goal for 802.16m is to minimize latency for all aspects of the system including air link delay, state transition delay, access delay, and handover inter­ruption time to guarantee QoS for all services called for in IMT-Advanced. Specific latency objectives for IEEE 802.16m are:

* Link Layer/User Plane: < 10 ms DL or UL
* Hand-Off Interruption: < 30 ms
* Control Plane, Idle to Active: < 100 ms

IEEE 802.16m will be able to support multiple QoS parameter sets for a single service flow. This will provide the flexibility to meet the individual QoS parameters established for individ­ual multimedia classes established by IMT-Advanced. These classes are defined as follows:

* Low Multimedia: Data speed up to 144 kbps
* Medium Multimedia: Data speed up 2 Mbps
* High Multimedia: Data speed up to 30 mbps
* Super High Multimedia: Data speed up to 100 Mbps or possibly 1 Gbps.
1. **LTE (Long Term Evaluation)**

 **3.1 Specifications and Speed**

To date, there has been widespread adoption of GSM/CDMA as 2G technologies and WCDMA/UMTS/HSPA/CDMA 2000/EVDO for 3G service. LTE has been defined as the next step in the technological roadmap. It offers higher data rates, lower latency and greater spectral efficiency than previous technologies. LTE is compatible with HSPA, UMTS and GSM-based technologies and hence offers a simple evolutionary path for all existing GSM and HSPA operators. However, LTE’s complementary core network also offers the ability to support the handover of services between LTE and CDMA-2000 networks, making it a compelling option as a next step for CDMA-2000/EV-DO operators as well.

LTE has been developed to offer both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes, enabling TD-SCDMA networks to also make a smooth transition to TDD LTE. Indeed, a combined FDD and TDD LTE deployment is expected to gain a broad foothold in many markets.

A number of countries globally have launched LTE networks and most of them are on the FDD-LTE technology. However some European countries and China are showing a preference for TD-LTE for its spectrum efficiency. Leading manufacturers are developing TD-LTE terminals, while chipset and platform vendors are announcing availability of multi-mode LTE (FDD & TDD) offerings to ensure CSP service rollouts with one common technology platform. There exists a huge amount of unpaired spectrum available, and new TD bands will open as frequencies are freed-up. TD-LTE is very much a global technology now. The right countries and the ecosystem is clearly accelerating.

The objective for developing LTE is to provide an extremely high performance radio-access technology that offers full vehicular speed mobility and that can readily coexist with HSPA and earlier networks. Because of scalable bandwidth, it will be possible for the operators to migrate their networks and users from HSPA to LTE over time.LTE assumes a full Internet Protocol (IP) network architecture and is designed to support voice in the packet domain. It incorporates top-of-the-line radio techniques to achieve performance levels particularly in larger channel bandwidths. As 3G can coexists with 2G systems in integrated networks, it is possible that LTE systems coexist with 3G and 2G systems. Multimode devices will function across LTE/3G or even LTE/3G/2G, depending on market circumstances.

LTE is an overlay network on top of either 2G or 3G. LTE is standardized by both 3GPP and 3GPPA and can provide interoperability. LTE brings lower cost per bit, higher capacity, a high level of flexibility, and have significant global appeal compared to 2G and 3G wireless technologies. This technology is especially suited for a cost sensitive market like India and it will provide improved ROI and better quality or service. LTE capabilities include:

* Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth
* Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth
* Operation in both TDD and FDD modes
* Scalable bandwidth up to 20 MHz, covering 1.4, 3, 5, 10, 15, and 20 MHz.
* Increased spectral efficiency over Release 6 HSPA by a factor of two to four
* Reduced latency, up to 10 milliseconds (ms) round-trip times between user equipment and the base station, and to less than 100 ms transition times from inactive to active

Summary of the key parameters of the 3G LTE specification is given in the following table:

**Table 3: LTE specification**

|  |  |
| --- | --- |
| **Parameter**  | **Details**  |
| Peak downlink speed with 64QAM in Mbps  | 100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)  |
| Peak uplink speeds(Mbps)  | 50 (QPSK), 57 (16QAM), 86 (64QAM)  |
| Data type  | All packet switched data (voice and data). No circuit switched.  |
| Channel bandwidth (MHz)  | 1.4,   3,   5,   10,   15,   20  |
| Duplex schemes  | FDD and TDD  |
| Mobility  | 0 - 15 km/h (optimised),15 - 120 km/h (high performance)  |
| Latency  | Idle to active less than 100msSmall packets ~10 ms  |
| Spectral efficiency  | Downlink:   3 - 4 times Rel 6 HSDPAUplink:   2 -3 x Rel 6 HSUPA  |
| Access schemes  | OFDMA (Downlink)SC-FDMA (Uplink)  |
| Modulation types supported  | QPSK,   16QAM,   64QAM (Uplink and downlink)  |

These specifications give an overall view of the performance that LTE will offer. It meets the requirements of industry for high data download speeds as well as reduced latency - a factor important for many applications from VoIP to gaming and interactive use of data. It also provides significant improvements in the use of the available spectrum.

**3.2 LTE - Advanced**

Key features of LTE-Advanced are

* Compatibility of services
* Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility). Peak  data  rate of 1Gbps  will  be  achieved  by 4X4 MIMO  and transmission   bandwidth  wider  than  approximately  70  MHz
* Spectrum efficiency: 3 times greater than LTE.
* Peak spectrum efficiency: downlink – 30 bps/Hz; uplink – 6.75 bps/Hz.
* Spectrum use: the ability to support scalable bandwidth use and spectrum aggregation where non-contiguous spectrum needs to be used.
* Latency: from Idle to Connected in less than 50 ms and 10 msec (dormant state to active state)
* Cell edge user throughput to be twice that of LTE.
* Average user throughput to be 3 times that of LTE.
* Mobility: Same as that in LTE
* Compatibility: LTE Advanced shall be capable of inter-working with LTE and 3GPP legacy systems.

The development of LTE Advanced / IMT Advanced has evolved from various 3GPP releases from Rel99/4 onwards as summarized below:

**Table 4: Development of LTE**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **WCDMA (UMTS)** | **HDPA** | **HSPA+** | **LTE** | **LTE Advanced** |
| **Max downlink speed( bps)** | **384 k** | **14 M** | **28 M** | **300M** | **1G** |
| **Max uplink speed (bps)** | **128 k** | **5.7 M** | **11 M** | **75 M** | **500 M** |
| **Latency round trip time(approx)** | **150 ms** | **100 ms** | **50ms (max)** | **~10 ms** | **less than 5 ms** |
| **3GPP releases** | **Rel 99/4** | **Rel 5 / 6** | **Rel 7** | **Rel 8** | **Rel 10** |
| **Approx years of initial roll out** | **2003 / 4** | **2005 / 6 HSDPA2007 / 8 HSUPA** | **2008/ 9** | **2009/ 10** |  |
| **Access methodology** | **CDMA** | **CDMA** | **CDMA** | **OFDMA /SC-FDMA** | **OFDMA / SC-FDMA** |

**Comparison between various IMT-Advanced Technologies**

Comparison[[3]](#footnote-3) of the Legacy Mobile WiMAX features with IEEE 802.16m

**Table 5:- Comparison between Mobile Wimax and IEEE 802.16**

|  |  |  |
| --- | --- | --- |
| **Feature** | **Legacy Mobile WiMAX based on Release 1.0** | **IEEE 802.16m** |
| Duplexing Scheme |  TDD | TDD and FDD |
| Operating Bandwidth | 5,7,8.75 and 10 MHz | 5,7,8.75,10 and 20 (up to 100 MHz with carrier aggregation |
| Downlink Multi-User MIMO |  Not Supported | Multi-user Zero-forcing pre-coding based on transformed codebook or sounding. |
| Uplink Multi-User MIMO | Single-transmit-antenna Collaborative MIMO | Collaborative MIMO for up to four transmit antennas. |

1. Comparison IEEE 802.16m with LTE- Advanced specifications viz-a-viz requirement of IMT-Advanced is given here[[4]](#footnote-4).

**Table 6: Comparison between LTE-Advanced Specifications**

|  |  |  |  |
| --- | --- | --- | --- |
| **Requirement** | **IMT-Advanced** | **IEEE 802.16m** | **3GPP LTE-Advanced** |
| Peak spectrum efficiency (bit/sec/Hz) System level | DL: 15 (4x4)UL:6.75(2x4) | DL:8/15 (2x2/4x4)UL:2.8/6.75 (1x2/2x4) | DL: 30 (8x8)UL:6.75(4x4) |
| Cell spectral efficiency (bit/sec/Hz/sector) System level | DL: 2.2 (4x2)UL: 1.4 (2x4) (Base Coverage Urban) | DL: 2.6 (2x2)UL: 1.3 (1x2) (Mixed Mobility) | DL: 2.6 (4x2)UL: 2.0 (2x4)  |
| Cell-edge user spectral efficiency (bit/sec/Hz) System level | DL: 0.06 (4x2)UL: 0.03 (2x4) (Base Coverage Urba | DL:0.09 (2x2)UL: 0.05 (1x2) (Mixed Mobility) | DL:0.09 (4x2)UL: 0.07 (2x4) (Base Coverage Urban) |
| AntennaConfiguration | Not specified | DL:2x2 (baseline), 2x4, 4x2, 4x4, 8x8UL:1x2 (baseline), 1x4,2x4,4x4  | DL:2x2 (baseline), 2x4, 4x2, 4x4, 8x8UL:1x2 (baseline), 1x4, 2x4, 4x4 |
| Operating Bandwidth | Up to 40MHz (with band aggregation) | 5-20MHz (up to 100 MHz through band aggregation) | 1.4-20 MHz (up to 100 MHz through band aggregation) |
| Duplex Scheme | Not specified | TDD, FDD(support for HDD terminals) | TDD, FDD(support for HDD terminals) |
| Latency | C-Plane: 100 msec (idle to active)U-Plane: 10msec | C-Plane: 100 msec (idle to active)U-Plane: 10msec | C-Plane: 50 msec (idle/camped state to connected),10 msec (dormant state to active state)U-Plane: 10msec |

*LTE UE category*

The LTE UE (User Equipment) categories or UE classes are needed to ensure that the base station, or eNodeB, eNB can communicate correctly with the user equipment. By relaying the LTE UE category information to the base station, it is able to determine the performance of the UE and communicate with it accordingly.

 As the LTE category defines the overall performance and the capabilities of the UE, it is possible for the eNB to communicate using capabilities that it knows the UE possesses. Accordingly the eNB will not communicate beyond the performance of the UE.

*LTE UE category definitions*

There are five different LTE UE categories that are defined. As can be seen in the table below, the different LTE UE categories have a wide range in the supported parameters and performance e.g. LTE category 1 does not support MIMO, but LTE UE category five supports 4x4 MIMO.

It is also worth noting that UE class 1 does not offer the performance offered by that of the highest performance HSPA category. Additionally all LTE UE categories are capable of receiving transmissions from up to four antenna ports.

A summary of the different LTE UE category parameters provided by the 3GPP Rel 8 standard, for 20MHz bandwidth, is given in the tables below.

**Table 7:-LTE UE category data rates**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Category** | **1** | **2** | **3** | **4** | **5** |
| Downlink | 10 | 50 | 100 | 150 | 300 |
| Uplink | 5 | 25 | 50 | 50 | 75 |

**Table 8:-LTE UE category modulation formats supported**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Category** | **1** | **2** | **3** | **4** | **5** |
| Downlink | QPSK, 16QAM, 64QAM |
| Uplink | QPSK, 16QAM | QPSK,16QAM,64QAM |

**Table 9:- LTE UE category MIMO antenna configurations**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Category**  | **1**  | **2**  | **3**  | **4**  | **5**  |
| 2 Rx diversity  | Assumed in performance requirements across all LTE UE categories |
| 2 x 2 MIMO  | Not supported | Mandatory |
| 4 x 4 MIMO  | Not supported | Mandatory |

On the issue of congenial eco-system in terms of user equipment (UE) for LTE, there are nearly 5 categories of UE defined by 3GPP with significant variations in speeds. There are issues related to different architectures of LTE used by the vendors.

*IMT -Advanced security issue*

Security is an issue that is of paramount importance. It is necessary to ensure that IMT- Advanced security measures provides the level of security required without impacting the user.

IMT- Advanced brings with it packet-based access up to the user terminal. A packet infrastructure with a large number of IP addressed devices implies ease of proliferation of malware attacks, and complex requirements for their detection, prevention and cure. A new threat assessment framework and a security policy in line with this framework are necessary to secure these networks and their users.

These networks present significantly higher capacity challenges to legal-intercept systems deployed today. A large, dynamic public IP pool places enormous demands on infrastructure used by law enforcement agencies for call traces, and the capacity of current deployments seems inadequate.

With the level of sophistication of security attacks growing, it is necessary to ensure that IMT- Advanced security allows users to operate freely and without fear of attack from hackers. Additionally the network must also be organized in such a way that it is secure against a variety of attacks.

When developing the IMT- Advanced security elements there were several main requirements that were borne in mind:

* It has to provide at least the same level of security that was provided by 3G services.
* The security measures should not affect user convenience.
* The security measures taken should provide defence from attacks from the Internet.
* The security functions should not affect the transition from existing 3G services to IMT- Advanced.
* The USIM used for 3G services should still be used.
* To ensure these requirements for security are met, it is necessary to add further measures into all areas of the system from the UE through to the core network. The security infrastructure should be scalable and accounts for new usage patterns like social networking and peer-to-peer applications.
1. **Spectrum use in SATRC countries (band wise)**

There are various technologies being used in the SATRC countries. They are tabulated as below:-

**Bangladesh**:-

| Band (range) | Technology | Service | Block BW(MHz) | No. of Blocks |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 450 MHz (450-454.8/460-464.8     and  455.225-457.50/465.225-467.50) | CDMA  | WLL  | 1.25  |  3  | Yes |  | Blocks are not contiguous |
| 700 MHz (704-716/734-746) | - | Fixed Broadband (only data services) | 6  | 2  | Yes |  | Planning for new services  |
| 800 MHz (825-845/ 870-890 MHz) | CDMA | Mobile services WLL | 101.26  | 17 | Yes |  |  |
| 900 MHz (890-915/ 935-960 MHz | GSM | Mobile services | 7.455.2 | 211 | Yes |  |  |
| 1800 MHz(1710-1775/ 1805-1850 MHz) | GSM | Mobile services | 7.27.55.41015 | 11111 | Yes |  |  |
| 1900 MHz (1880-1910/ 1960-1990) | CDMA | WLL | 1.3 | 6 | Yes |  | --Blocks are free |
| 2.1 GHz (1920-1960/ 2110-2150 MHz) | WCDMA | Mobile services | 5 | 8 |  | Will be allocated to 3 BWA Operators by auction. |  |
| 2.3 GHz (2300-2400 MHz) | IEEE 802.16e  | Mobile BWA  | 10 | 10 |  | Allocated to 2 BWA operators by auction |  |
| 2.5 GHz (2500-2690 MHz) |  | Mobile BWA | 10 |  19 |  | Allocated to 2 BWA operators by auction |  |
| 3.3 GHz (3.3-3.4 GHz) |  |  |  |  |  |  | Not yet allocated |
| 3.5 GHz (3400-3500/3500-3600 MHz) | Any technology | Fixed BWA |  | --------------------------- | Yes |  |  |

**Nepal**

| Band (range) | Technology | Service | Block BW(MHz) |  No. of operator |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 450 MHz  |  |  |  |  |  |  | Being used by non-telecom operators,  |
| 700 MHz | - | - |  | - |  |  | Existing assignment to be confirmed |
| 800 MHz (824-840/ 869-885 )887.6-890 | CDMAMF-TDMA | Mobile Telephone/ Basic Telephone –WLL | 2x82x82x52x2.4 | 111 | Yes |  |  |
| 900 MHz (890-915/ 935-960 ) | GSM | Mobile Telephone | 2x2.42x62x4.4 | 111 | Yes |  | Some spectrum is assigned in temporary basis to the existing mobile operators |
| 1800 MHz(1710-1775/ 1805-1850)  | GSM | Mobile Telephone/Basic Telephone with Limited Mobility | 2x92x92x9 | 111 | Yes |  | Some spectrum is assigned on temporary basis to the existing mobile operators |
| 1900 MHz (1880-1930)(1850-1880/ 1930-1960) | WLL DECT, corDECTWLL CDMA | WLLBasic Telephone/LM | 2x10 | 1 | Yes -Yes |  | Previously WLL corDECT was used in western region by the incumbent operator  |
| 2.1 GHz (1960-1980/ 2150-2170 MHz) | IMT-2000-3G (WCDMA) | Mobile  | 2x102x10 | 11 | Yes |  | Spectrum assignment to the existing mobile operators |
| 2.3 GHz (2300-2400 MHz) |  |  |  |  |  |  | Not decided yet. Under considerati for auction |
| 2.5 GHz (2500-2690 MHz) |  |  |  |  |  |  | Radio Microwave Point to Point Links are being in operation. Under consideration for auction  |
| 3.3 GHz (3300-3400 MHz) |  |  |  |  |  |  | Not decided yet. Under consideration for auction |
| 3.5 GHz (3400-3800 MHz) | VSAT | VSAT users/Network Providers |  | - | Yes |  |  |

**Iran**

| Band (range) |  Technology |  Service | Block BW(MHz) |   No. of operator |   Allocation method |  Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 450 MHz |   |   |   |   |   |   | Being used by non-telecom operators,    |
| 900MHz | GSM | 2G,2.5G, 2.75G, 3G | 2\*82\*82\*4.62\*42\*4.8 | 5 | Yes |   |   |
| 1800MHz | GSM | 2G,2.5G, 2.75G | 2\*152\*152\*12 | 3 | Yes |   |   |
| 2100 MHz | UMTS | 3G | 2\*15 | 1 | Yes |   |   |

**Maldives**

| Band (range) | Technology | Service | Block BW(MHz) |  No. of operator |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 900 MHz  | GSM | 2G |  | 2 | Yes |  |   |
| 2100MHz | GSM | 3G |  | 1 | Yes |  |  |

**Bhutan**

| Band (range) | Technology | Service | Block BW(MHz) |  No. of operator |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 900 MHz  | GSM | 2G |  |  |  |  |   |
| 1800 MHz | GSM | 2G |  |  |  |  |  |

**Srilanka**

| Band (range) | Technology | Service | Block BW(MHz) |  No. of operator |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 900 MHz  | GSM | 2G |  |  |  |  |   |
| 1800 MHz | GSM | 2G |  |  |  |  |  |
| 2100MHz | WCDMA | 3G |  |  |  |  |  |

**Afghanistan**

| Band (range) | Technology | Service | Block BW(MHz) |  No. of operator |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 900 MHz  | GSM | 2G |  | 4 | Yes |  |   |
| 1800MHz | GSM | 2G |  |  |  |  |  |
|  | CDMA | 2G |  | 2 |  |  |  |

**India**

| Band (range) | Technology | Service |  Block BW / No. of Blocks |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 450 MHz (452.5-457.475 /462.5-467.475) | CDMA  | WLL |  Not Allotted |  |  | Will be made available as and when available |
| 700 MHz  |  |  |  |  |  | Will be made available as and when available  |
| 800 MHz (824-844/ 869-889 MHz) | CDMA | Mobile services  | 1.25 MHz (2 to 4 blocks) | So far based on Subscriber base criteria |  |   |
| 900 MHz (890-915/ 935-960 MHz | GSM | Mobile services | 4.4 – 15.0 MHz (After 6.2 MHz it is in increments of 1 MHz) | So far based on Subscriber base criteria |   |  |
| 1800 MHz(1710-1785/1805-1880 MHz) | GSM | Mobile services | 4.4 – 15.0 MHz (After 6.2 MHz it is incremental in 1 MHz) | So far based on Subscriber base criteria |   |  |
| 1900 MHz (1900-1910 / 1980-1990) |  |  |  |  |  | Will be made available as and when available |
| 2.1 GHz (1920-1980/ 2110-2170 MHz) | WCDMA | 3G Mobile services | 5 MHz,4-5blocks in various service areas  |  | Auction |  |
| 2.3 GHz (2300-2400 MHz) | WiMAX or others | BWA  | 20 MHz / 2 blocks |  | Auction |  |
| 2.5 GHz (2500-2690 MHz) | WiMAX or others  | BWA  | 20 MHz / 2 blocks |  | Auction |  |
| 3.3 GHz (3300-3400 MHz) | WiMAX or others | BWA | Upto 14MHz total 7 blocks |  |  | Will be made available as and when available |
| 3.5 GHz (3400-3600 MHz) |  |  |  |  |  | available with the broadcasters |

**Pakistan**

| Band (range) | Technology | Service/Jurisdiction |  Block BW / No. of Blocks |  Allocation method | Remarks |
| --- | --- | --- | --- | --- | --- |
| Command & Control | Market orientation |
| 450 MHz (450.55------) | CDMA/Neutral | WLL /Regional |  1.25 MHz / 2 1.25 MHz/1  | Yes | Auction | Blocks are not contiguous.PTCL was allocated one block before auction for rural coverage. However, subsequently price of the auction was paid for the block. |
| 479 MHz | Neutral | WLL/ Regional | 5 MHz/1 |  | Auctioned |  |
| 700 MHz (706-712/---) |  |  |  |  |  | Refarming is needed |
| 800 MHz (825-845/ 870-890 MHz) | CDMA/Neutral | Mobile/ National | 10 MHz /1 |  | Auction |  |
| 900 MHz (880-915/ 925-960 MHz | GSM/ Neutral | Mobile/ National | 7.8 MHz/34.8 MHz/2 |  | Auction |  |
| 1800 MHz(1710-1775/ 1805-1850 MHz) | GSM/ Neutral | Mobile/ National | 8.8 MHz/26 MHz/3 |  | Auction |  |
| 1900 MHz (1880-1910-1960-1990) | CDMA/Neutral | WLL/ Regional | 5 MHz / 3 |  | Auction |  |
| 2.1 GHz (1920-1950/2110-2140 MHz) | 3G/ Neutral | Mobile/ National | 10 MHz / 3 |  |  | The blocks will be auctioned in near future. Hopefully by end of 2008. |
| 2.3 GHz (2300-2400 MHz) |  |  |  |  |  | Refarming is needed. |
| 2.5 GHz (2500-2690 MHz) | Neutral | BWA/ Regional | 84 MHz / 134MHz/ 1 | Yes | Auction planned | In three cities.Regional basis in most of Telecom Regions  |
| 3.5 GHz (3400-3600 MHz) | Neutral | WLL/ Regional | 21 MHz/ 7 |  | Auctioned | Regional basis |

1. **Challenges Posed by Technologies like LTE in Spectrum Management**

The challenges are posed by technologies like LTE or IMT services in the management of spectrum. Some of the challenges are given below:-

* **Identification of common spectrum bands:-**

 It is important to identify the spectrum bands which are also common to other countries particularly SATRC countries. This will serve two purposes, first the roaming between SATRC countries become simple, secondly, cost of UE become low. Another challenge is to identify the availability of large chunk of spectrum in the identified bands, so that high speed connectivity can be achieved.

* **Spectrum management planning, allocation, allotment and regulations of frequency bands:**

 Withthe increasing demand of spectrum the challenge is in terms of allocation of frequency bands to the various radio services, for specific uses. When there are competing interests for spectrum use, it is necessary to determine the use or uses that would best serve the public and government interest, including how to share spectrum. Another challenge is to tackle the transmissions interference unless the user frequencies are sufficiently separated in terms of frequency, geography or time. This includes co-ordination with neighbouring countries, to mitigate the extent of harmful interference. There is a need to strike a balance between reducing the extent of harmful interference, through careful planning, and enabling new and potentially valuable new services to enter the market.

* **Frequency assignment and licensing (including non-licence allocations);**

 Traditional methods of assignment/licensing of the spectrum based on beauty contest(comparative hearings), lotteries, administrative methods etc. poses many challenges in terms of time, technological progress and the delivery of services, thus causing inefficient utilization of this precious resource. In the changing circumstances where the tremendous demand of radio spectrum has led to the many challenges, it is necessary to assign spectrum to those who value it the most and are able to utilize rationally and efficiently.

* **Responsive to change:**

 With a sharp acceleration in demand in recent years, change in the market place is outpacing the ability of the national and international regulatory regime to respond. It requires to devise procedures to ration current and future demand for radio spectrum between competing commercial and public service users. To do so it would require a detailed knowledge of supply and demand trends, technology developments, and the relative value to society of alternative services. This includes accumulation and assimilation of sufficient information to make a correct assignment of spectrum to optimise use over time.

* **Need for spectrum audit**

 With the increasing demand of spectrum its supply needs to be assured. For this there is need to conduct periodic audit about the spectrum held by the Government agencies and other agencies to see whether they are using all the available spectral efficient techniques. The audit needs to be conducted with an objective to vacate some spectrum from these agencies and if possible to relocate their operations in some other commercially less useful band. Another way of auditing of spectrum is with the existing mobile service providers with the objective to see whether they are using the available spectrum with them efficiently, if not the pricing of spectrum can be modified to ensure that this scarce natural resource is utilized rationally, optimally and efficiently. However to conduct spectrum audit will also pose challenges before the regulators and the Government in terms of technical, economic, legal and operational issues.

# Recommendations to Overcome the Challenges:

With the pace of technology march, SATRC countries need to prepare themselves to tackle the challenges posed by the new technologies. Timely preparation will help in orderly growth of the telecom radio sector.

Some of the recommendations to overcome challenges are:

**Refarm the spectrum**: As new applications are bandwidth hungry, there is a need to make available spectrum by way to making new bands available or by reframing the existing bands. If there is large shortage spectrum existing users may be asked to shift to other bands or they may be asked to start new technologies in the same band i.e. 2G spectrum bands may be refarmed for its usage for IMT or IMT advanced application and the operators may be asked to switch over to the new bands or it can be done after expiry of their validity of license. Another way could be to permit them to use the existing band for IMT advanced services however they may be required to pay to the Govt or regulator the balance the price they already have paid and the price which can be discovered using auction methodology or market driven mechanism.

**Audit the spectrum** held by various agencies: Another way to make spectrum available for new technology applications will be to audit the spectrum held by the Govt agencies and by the telecom/broadcasting operators to see if they are employing spectrum efficient techniques. If they are not doing so they may be asked to deploy these techniques so that they can serve more subscribers in the same amount of spectrum or may serve same number of subscribers in the smaller chunk of spectrum and leaving some of the spectrum for the new technology applications.

**Change the traditional way of spectrum planning and engineering**: The new ways will have to evolved for the planning and engineering of the spectrum management. While doing so not only the interests of the operators to keep the sight of but also revenue to the Govt should not be sighted-off. The spectrum should be assigned to those operators who value it the most.

**Spectrum sharing and trading**: Traditionally spectrum sharing and trading is not permitted in the SATRC region. In the new environment, this aspects has to be relooked into. Spectrum sharing, trading and spectrum pooling are some of the ways to efficiently utilize the available spectrum. In the developed countries spectrum trading and sharing is permitted in some of the spectrum bands. Looking at the growth of smart handsets and looking at the new concepts like smart grid, smart cities and smart homes it is expected that bandwidth requirement will increase in leap and bound, in such a scenario it seems necessary to permit spectrum sharing and trading.

**Exploring the new bands**: As discussed earlier new bands may be explored either for the telecom applications or for the application which are running in the bands meant for the telecom applications, so that other applications can be shifted to these bands and bands for the telecom applications may be made available for the telecom applications.

SATRC countries need to face the challenges posed by the new technologies and adopt their policies and planning for the new changes in the environment.

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